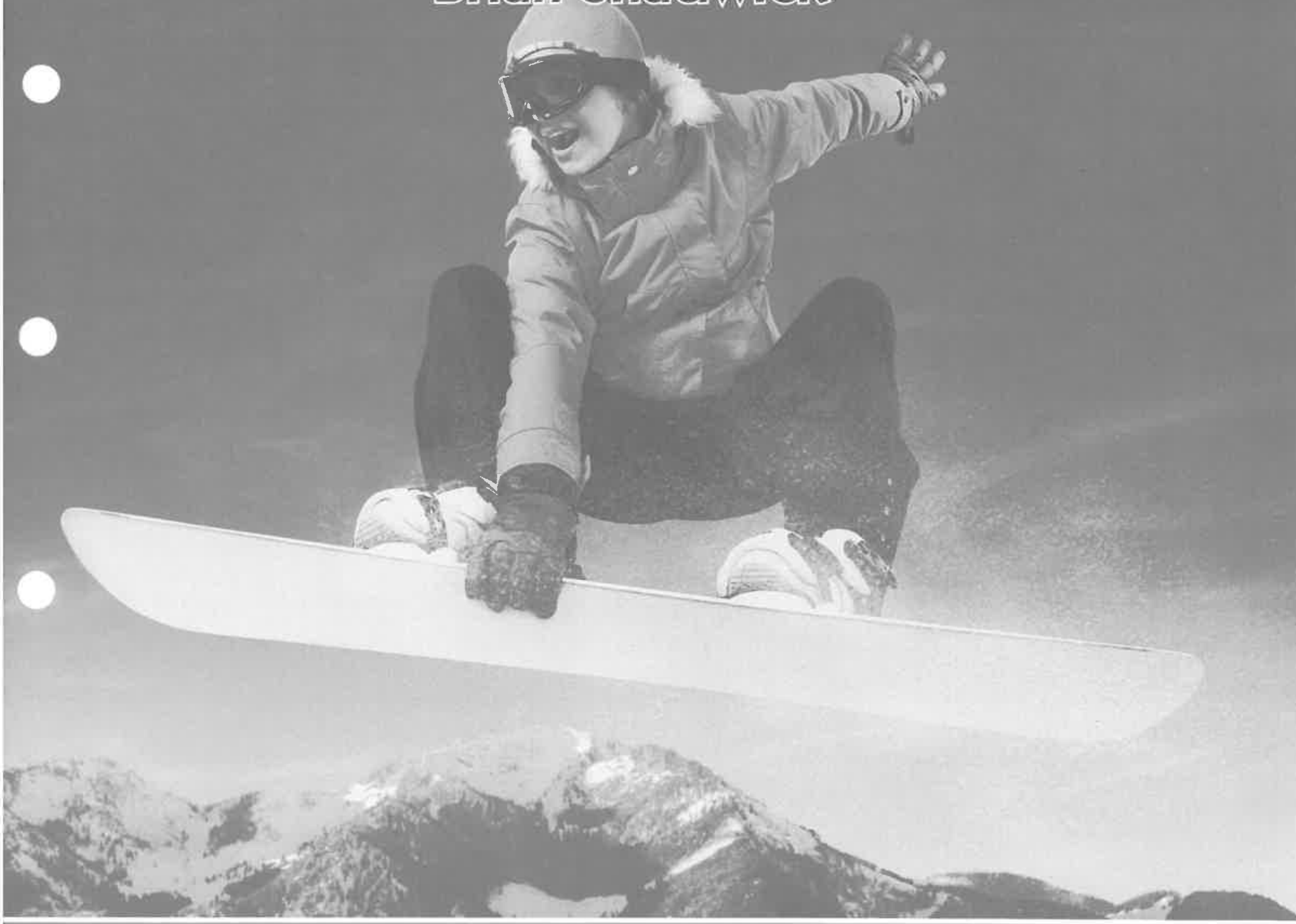
:DOT POINT

NSW PHYSICS MODULES 5 TO 8

Brian Shadwick



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Contents

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Introduction

What the book includes

This book provides questions and answers for each dot point in the NSW Physics Stage 6 Syllabus for each module in the Year 12 Physics course:

- Module 5 Advanced Mechanics
- Module 6 Electromagnetism
- Module 7 The Nature Of Light
- Module 8 From the Universe To the Atom

Format of the book

The book has been formatted in the following way:

1.1 Subtopic from syllabus.

1.1.1 Assessment statement from syllabus.

1.1.1.1 First question for this assessment statement.

1.1.1.2 Second question for this assessment statement.

The number of lines provided for each answer gives an indication of how many marks the question might be worth in an examination. As a rough rule, every two lines of answer might be worth 1 mark.

How to use the book

Completing all questions will provide you with a summary of all the work you need to know from the syllabus. You may have done work in addition to this with your teacher as extension work. Obviously this is not covered, but you may need to know this additional work for your school exams.

When working through the questions, write the answers you have to look up in a different colour to those you know without having to research the work. This will provide you with a quick reference for work needing further revision.

Module 5 Advanced Mechanics

Module 5 Advanced Mechanics

Dot Point		Page

Circular Motion

INQUIRY QUESTION

Why do objects move in circles?

Module 6 Electromagnetism

Module 6 Electromagnetism

Module 7 The Nature Of Light

Electromagnetic Spectrum

INQUIRY QUESTION

What is light?

Light: Wave Model

INQUIRY QUESTION

What evidence supports the classical wave model of light and what predictions can be made using this model?

Module 7 The Nature Of Light

Module 8 From the Universe To the Atom

Module 8 From the Universe To the Atom

DOT POINT

MODULE 5

Advanced Mechanics

In this module you will:

- Describe and analyse qualitatively and quantitatively circular motion and motion in a gravitational field, in particular, the projectile motion of particles.
- Explain and analyse motion in one dimension at constant velocity or constant acceleration.
- Extend your study of motion into examples involving two or three dimensions that cause the net force to vary in size or direction.
- Develop an understanding that all forms of complex motion can be explained by analysing the forces acting on a system, including the energy transformations taking place within and around the system.
- Apply new mathematical techniques to model and predict the motion of objects within systems. You will examine two-dimensional motion, including projectile motion and uniform circular motion, along with the orbital motion of planets and satellites, which are modelled as an approximation to uniform circular motion.
- Engage with all the Working Scientifically skills for practical investigations involving the focus content to examine trends in data and to solve problems related to advanced mechanics.

Notes

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Projectile Motion

5.1 Analyse the motion of projectiles by resolving the motion into horizontal and vertical components, making the following assumptions: a constant vertical acceleration due to gravity and zero air resistance.

INQUIRY QUESTION

How can models that are used to explain projectile motion be used to analyse and make predictions?

5.1.1 Resolution of vectors – Revision.

5.1.1.1 Find the horizontal and vertical components of each of the following vectors. All vectors are drawn to a scale where 1 cm = 10 m.

(a) ....

(b) ....

(c) ....

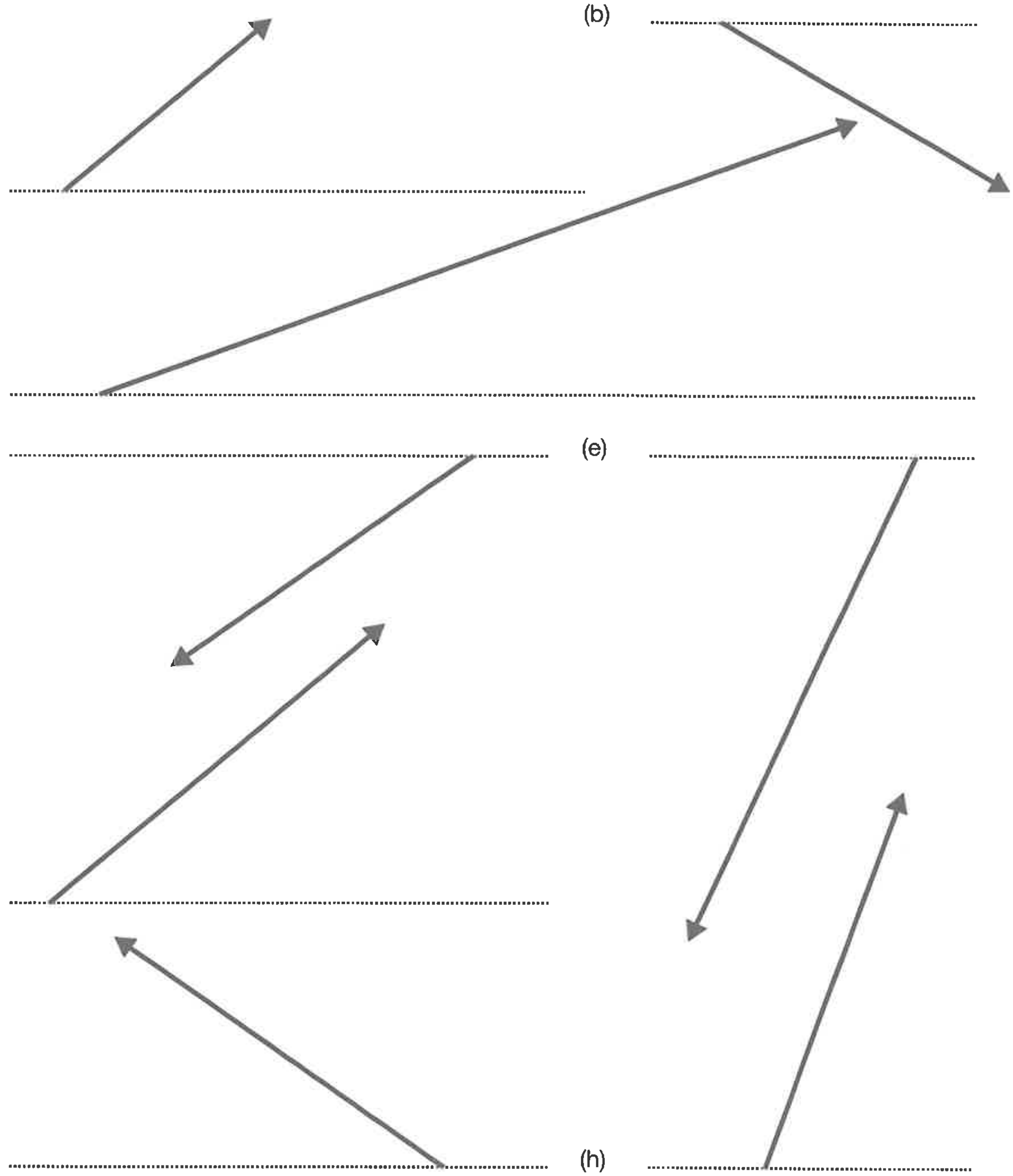
(d) ....

(e) ....

(f) ....

(g) ....

(h) ....



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5.1.2 Analysing projectile motion 1.

Use the following information to answer the next TEN questions.

Some students rolled a ball down a ramp from different heights and then let it roll across a frictionless benchtop for a distance of 1.0 m. They launched the ball from the end of the bench which was 1.2 m above the floor and the horizontal range of each ball was measured. The table shows their average results.

Projectile	Height up the ramp (m)	Time to roll 1.0 metre (s)	Time of flight (s)	Launch velocity (m s^{-1})	Range (m)
P	0.30	0..86	*W*		
Q	0.45	0.72		*X*	
R	0.60	0.61			*Y*
S	0.90	0.45	*Z*		

5.1.2.1 What is the independent variable?
(A) Horizontal range.
(B) Launch velocity.
(C) Time to roll over the bench.
(D) Time of flight.

5.1.2.2 Which statement about the time of flight for these projectiles is correct?
(A) Time for P will be the least.
(B) Time for Q will be the least.
(C) Time for S will be the least.
(D) They will all have the same time of flight.

5.1.2.3 What will be the launch speed for P?
(A) 0.72 m s^{-1}
(B) 0.86 m s^{-1}
(C) 1.16 m s^{-1}
(D) 1.40 m s^{-1}

5.1.2.4 What is the best value for *W*?
(A) 0.45 s
(B) 0.86 s
(C) 1.16 s
(D) 1.39 s

5.1.2.5 What is the best value for *X*?
(A) 0.60 m s^{-1}
(B) 0.74 m s^{-1}
(C) 1.39 m s^{-1}
(D) 2.70 m s^{-1}

5.1.2.6 What is the best value for *Y*?
(A) 0.74 m
(B) 0.88 m
(C) 1.64 m
(D) 2.36 m

5.1.2.7 What is the best value for *Z*?
(A) 0.45 s
(B) 0.50 s
(C) 0.86 s
(D) 2.22 s

5.1.2.8 What is the range of Z?
(A) 0.2 m
(B) 1.0 m
(C) 1.2 m
(D) 2.67 m

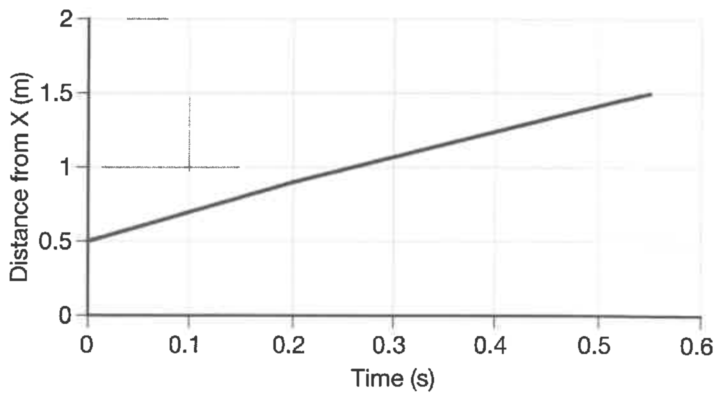
5.1.2.9 What is the best estimate for the speed of R at the bottom of the ramp?
(A) 0.98 m s^{-1}
(B) 1.02 m s^{-1}
(C) 1.64 m s^{-1}
(D) 1.96 m s^{-1}

5.1.2.10 The experiment is repeated with a ball with twice the mass. How is each range affected?
(A) Ranges will be quartered.
(B) Ranges will be halved.
(C) Ranges will be doubled.
(D) Ranges will be the same.

5.1.3 Analysing projectile motion 2.

Use the following information to answer the next FIVE questions.

A ball was rolled from X, 1.5 m across a horizontal table to the table's edge. The time and its distance from X as it rolled across the table were measured. The results are shown in the graph.



5.1.3.1 What was the ball's speed at the edge of the table?

(A) 0.54 m s^{-1}
(B) 1.50 m s^{-1}
(C) 1.82 m s^{-1}
(D) 2.78 m s^{-1}

5.1.3.2 If the ball landed 0.75 m out from the edge of the table, what was the time of flight?

(A) 2.47 s
(B) 1.0 s
(C) 0.8 s
(D) 0.4 s

5.1.3.3 If the ball landed 0.75 m out from the edge of the table, what was the height of the table?

(A) 0.4 m
(B) 0.5 m
(C) 0.6 m
(D) 0.8 m

5.1.3.4 The experiment was repeated on the Moon. How would the range of the projectile compare?

(A) It would be the same on Earth and the Moon.
(B) It would be larger on the Moon.
(C) It would be larger on Earth.
(D) It would still depend on the horizontal speed of the ball.

5.1.3.5 The experiment was repeated using a ball with half the mass of the original ball. Indicate, for each of the questions above, how the results would be different.

(a) For 5.1.3.1 ....

(b) For 5.2.3.2 ....

(c) For 5.1.3.3 ....

(d) For 5.1.3.4 ....

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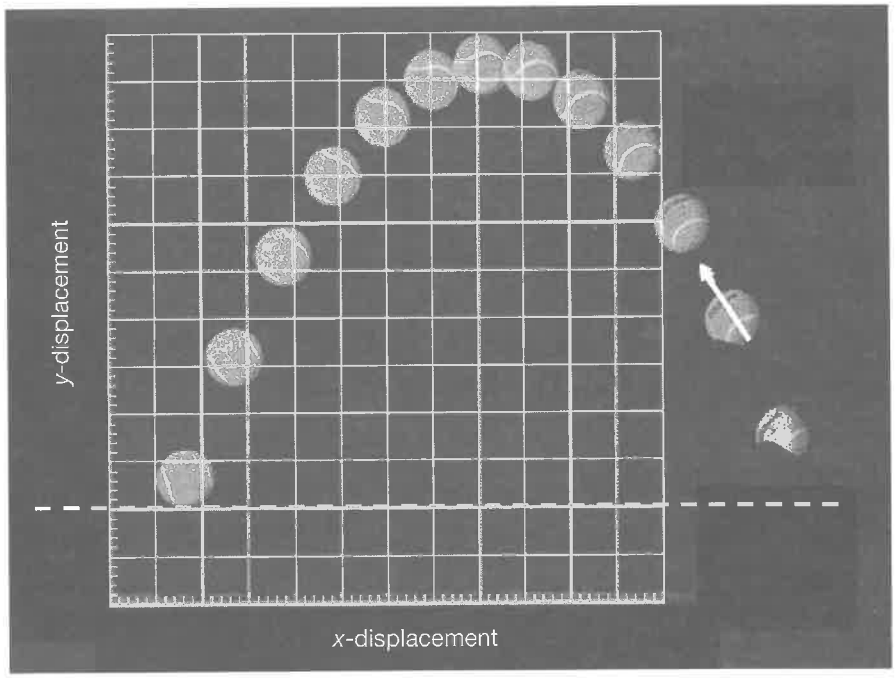
5.1.4 Analysing projectile motion 3.

Use the following information to answer the next SIX questions.

Students studying projectile motion fired a tennis ball into the air and photographed its flight using a stroboscopic camera which photographed the position of the ball every 0.1 s.

They did several runs of the experiment, launching the ball at different velocities to determine the maximum heights reached at each velocity.

In the photograph, the dotted horizontal line represents the surface of the benchtop. One set of their results are shown in the photograph.



5.1.4.1 What was the time of flight of the ball?

(A) 0.1 s
(B) 1.1 s
(C) 1.2 s
(D) 1.3 s

5.1.4.2 What was the frequency of the stroboscope used to record these results?

(A) 0.1 Hz
(B) 1.2 Hz
(C) 1.3 Hz
(D) 10 Hz

5.1.4.3 Which choice correctly identifies the dependent and independent variables in this experiment?

	Dependent variable	Independent variable
(A)	Time to rise	Launch velocity
(B)	Time to rise	Time to rise
(C)	Maximum height	Launch velocity
(D)	Maximum height	Time to rise

5.1.4.4 What is the maximum height of the ball (measured from its bottom) above the benchtop?

(A) 1.76 m
(B) 3.53 m
(C) 9 m
(D) 10 m

5.1.4.5 What is the best estimate of the scale of the grid in the photograph?

(A) 1 grid square = 0.2 m
(B) 1 grid square = 0.4 m
(C) 1 grid square = 1.11 m
(D) 1 grid square = 1.12 m

5.1.4.6 What was the magnitude of the velocity of the tennis ball at its maximum height above the benchtop?

(A) 0
(B) 1.0 m s^{-1}
(C) 2.1 m s^{-1}
(D) 4.2 m s^{-1}

5.2 Apply the modelling of projectile motion to quantitatively derive the relationships between the following variables: initial velocity, launch angle, maximum height, time of flight, final velocity, launch height and horizontal range.

5.2.1 Projectile motion 1.

5.2.1.1 Outline the characteristics of the motion of a projectile. ....

....

....

5.2.1.2 A projectile is launched at 40 m s^{-1} at 75° to the horizontal. Calculate the components of its launch velocity.

....

....

5.2.1.3 List the three characteristics of projectile motion as cited by Galileo. ....

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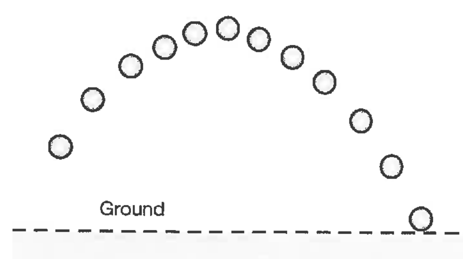
5.2.1.4 A tennis ball is hit into the air and follows the path shown in the diagram.



(a) Which statement regarding the flight of the ball is correct?

(A) The velocity of the ball at its highest point is zero.
(B) The velocity of the ball is always changing.
(C) The direction of the ball's acceleration changes when it reaches the highest point.
(D) The acceleration of the ball at its highest point is zero.

(b) The final displacement of this projectile could be described as being negative. Explain this.

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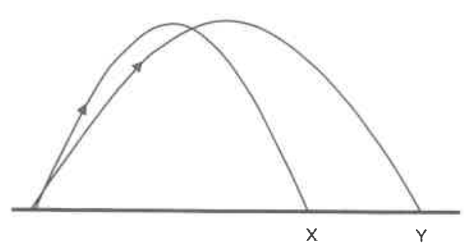
5.2.1.5 The diagram shows the paths of the flights of two projectiles, X and Y.

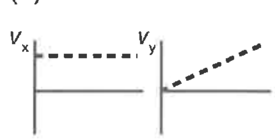


Which of the following is different for X and Y?

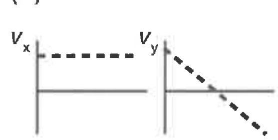
(A) Their accelerations.
(B) Their times of flight.
(C) Their maximum y-displacements.
(D) Their initial velocities.

5.2.1.6 A cannonball is fired into the air towards a distant castle. Which graphs below correctly describe the horizontal and vertical components of the cannonball's velocity?

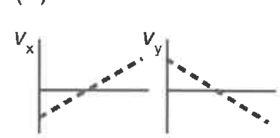
(A)



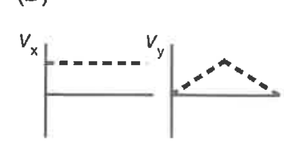
(B)



(C)

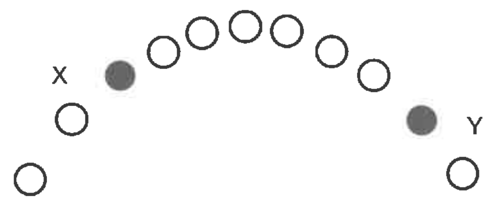


(D)



5.2.1.7 The diagram shows the path of a projectile. Which choice correctly shows the directions of the velocity and acceleration of the projectile at points X and Y?

	Velocity at X	**Acceleration at X**	**Velocity at Y**	**Acceleration at Y**
(A)	→	↓	→	↓
(B)	↗	↑	↘	↓
(C)	↗	↓	↘	↓
(D)	↑	→	↓	→



5.2.1.8

(a) A projectile is launched into the air at 60° to the horizontal. Which statement about the projectile is true when it is at its maximum height?

(A) $a_x = 0$ (B) $a_y = 0$ (C) $v_x = 0$ (D) $\Delta x = 0$

(b) At what angle should a projectile be launched so that its range is maximum?

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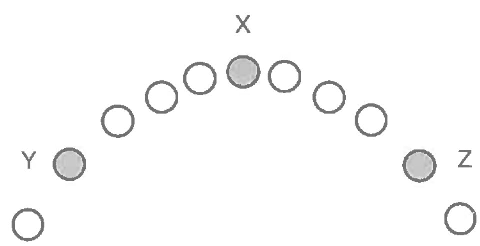
5.2.1.9 Consider three positions, X, Y and Z in the path of a projectile as shown by the darkened circles in the diagram.



(a) Which statement about the acceleration of the projectile at these three positions is correct?

(A) The acceleration at Y is less than the acceleration at X.

(B) The acceleration at X is the same as the acceleration at Z.

(C) The acceleration at X is greater than the acceleration at Y.

(D) The acceleration at Y is in the opposite direction to the acceleration at Z.

(b) Three projectiles are launched at 20°, 40° and 60° to the horizontal at 20, 30 and 40 m s^{-1} (in that order). Calculate the ratio of their accelerations.

....

5.2.1.10 A ball is thrown upwards from point P and follows a parabolic path. Its highest point is point X. Which statement about the acceleration of the ball is correct?

(A) It is zero at X. (B) It is maximum at X.

(C) It is maximum at P and minimum at X. (D) It is the same at X as it is at P.

5.2.1.11

(a) Which of the following statements was *not* one of Galileo's descriptions of projectile motion?

(A) Horizontal motion is constant. (B) Horizontal acceleration is zero.

(C) Vertical motion is accelerated. (D) Vertical acceleration is negative.

(b) Explain the concept of positive and negative velocity in physics. ....

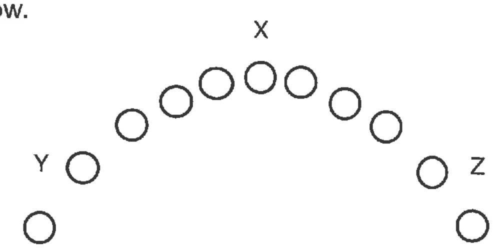
....

....

....

5.2.2 Projectile motion 2.

5.2.2.1 Consider the path of a projectile as shown in the diagram below.



(a) Which statement about the projectile is correct?

(A) The speed at X is the same as the speed at Z.
(B) The speed at Y is zero.
(C) The velocity at X is equal to the velocity at Z but in the opposite direction.
(D) The velocity at X, Y and Z is constant.

(b) Write a question which would make choice (c) correct. ....

....

....

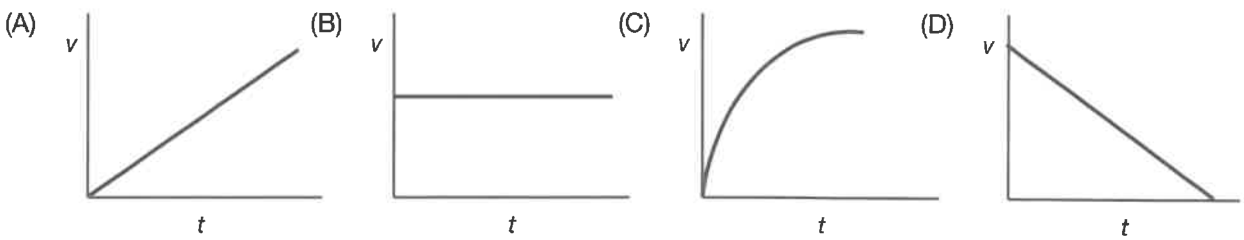
5.2.2.2 Which of the following statements about projectile motion is correct?

(A) The horizontal distance a projectile travels is proportional to the time of travel squared.
(B) The rate at which a projectile rises and falls is proportional to its mass.
(C) The square of the distance a projectile travels is proportional to the time of flight.
(D) The rate at which a projectile rises and falls is independent of its velocity.

5.2.2.3 Which of the following statements is in agreement with Galileo's analysis of projectile motion?

(A) The rate at which a projectile falls is proportional to its mass.
(B) The range of the projectile is proportional to the time elapsed.
(C) The range of the projectile is proportional to its initial vertical speed.
(D) The speed of the projectile is the vector sum of the vertical and horizontal components of that speed.

5.2.2.4 A ball is rolled at different speeds along a horizontal benchtop until it falls over the edge towards the floor. Which graph best shows the velocity of the ball as it falls to the floor?



5.2.2.5 Several balls are rolled at different speeds along a benchtop until they fall over the edge towards the floor. Which statement about these balls is correct?

(A) All four balls will hit the floor at the same time.
(B) The slowest ball will hit the floor first; the fastest will hit it last.
(C) The fastest ball will hit the floor first; the slowest will hit it last.
(D) All balls will land in the same position at the same time.

5.2.2.6 Four model rockets are launched with the velocity components shown in the table.

Rocket	Horizontal component of velocity (m s^{-1})	Vertical component of velocity (m s^{-1})
(A)	20	52
(B)	30	38
(C)	50	29
(D)	40	21

(a) Which rocket was launched closest to 30° to the horizontal?

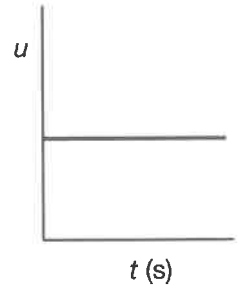
....

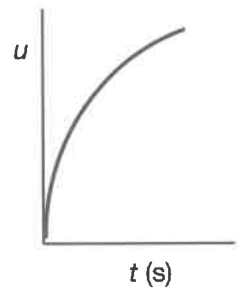
(b) What would be the time of flight of rocket (A)?

....

....

5.2.2.7 Which graph best shows the relationship between the time of flight of a projectile (t) and its launch velocity (u)?

(A)


(B)


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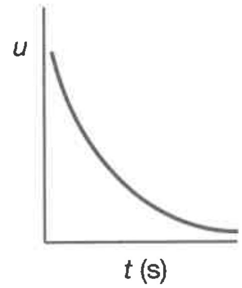
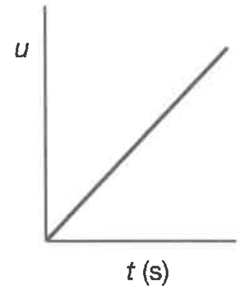
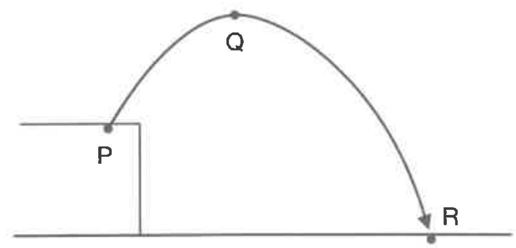


(D)


5.2.2.8 A projectile follows the pathway shown in the diagram.

Which statement about this projectile is correct?



(A) The time of flight from P to R is twice the time from P to Q.

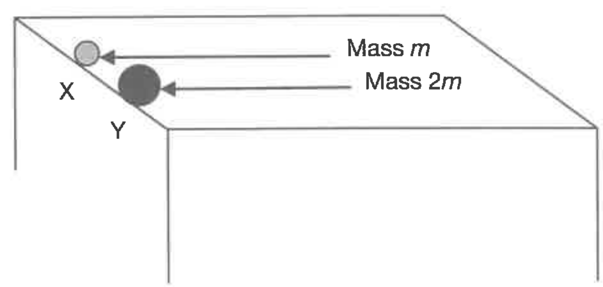
(B) The acceleration of the projectile is independent of its launch velocity.

(C) The vertical component of the velocity is the same at P, Q and R.

(D) The horizontal component of the velocity is greatest at Q.

5.2.2.9 A student rolls two balls X and Y, X with mass m and Y with mass $2m$ across a benchtop so that they leave the edge at the same time and with the same speed.

Four students made statements about the flight of the two balls.



Jacinta: Y hits the ground before X.

Chin: X and Y hit the ground at the same time.

Mario: X hits the ground twice as far away from the table compared to Y.

Pasqual: X hits the ground the same distance from the table as Y.

Whose statement about the two balls is correct?

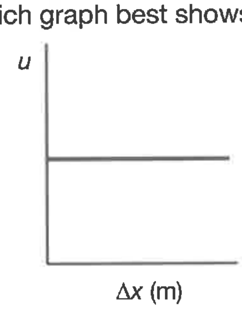
(A) Pasqual and Chin.

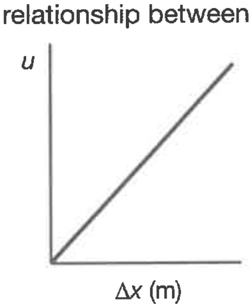
(B) Pasqual and Jacinta.

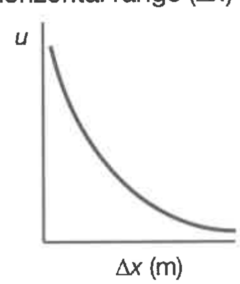
(C) Mario and Jacinta.

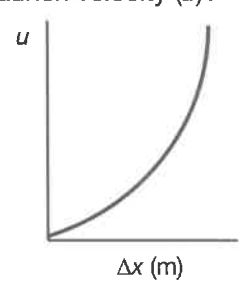
(D) Mario and Chin.

5.2.2.10 Which graph best shows the relationship between the horizontal range (Δx) and launch velocity (u)?

(A)


(B)


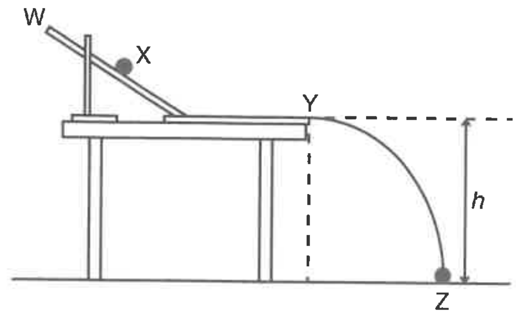
(C)


(D)


5.3 Solve problems, create models and make quantitative predictions by applying the equations of motion relationships for uniformly accelerated and constant rectilinear motion.

5.3.1 Solving projectile problems.

5.3.1.1 The diagram shows the apparatus used to do an experiment where a ball is rolled down the ramp from point X, across the benchtop to the edge Y, then allowed to fall onto the floor, landing at point Z.



What would the ball do if it was released from point W?

(A) Take a shorter time to fall from Y to the floor but land further out from the table.

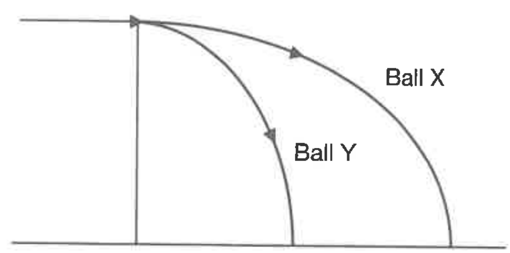
(B) Take the same time to fall from Y to the floor but land further out from the table.

(C) Take a shorter time to fall from Y to the floor but still land at Z.

(D) Take a longer time to fall from Y to the floor but land further out from the table.

5.3.1.2 Ball X is projected horizontally from a 1.2 m high table at 2.6 m s^{-1}. Ball Y is projected vertically out from the edge of the table at 1.5 m s^{-1}.

How much further out from the edge of the table does ball X land compared to Y?



5.3.1.3 A cannonball is fired at 80 m s^{-1}at an angle of 45° to the horizontal. Calculate the height at which the ball hits a vertical cliff 150 m away.

5.3.1.4 A ball is hit into the air at 45 m s^{-1} 30° to the horizontal. What is its speed 2 s later?

5.3.1.5 A projectile is fired horizontally at 150 m s^{-1} from the top of a 196 m high cliff. Calculate:

(a) Its time of flight.

(b) Its range.

(c) Its velocity on hitting the ground.

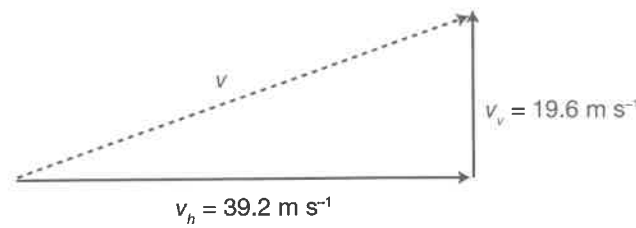
5.3.1.6 A projectile has a time of flight of 7.5 s and a range of 1200 m. Calculate:

(a) Its horizontal velocity. ....

(b) Its maximum height. ....

(c) The velocity with which it is projected. ....

5.3.1.7 The velocity of a projectile 2.0 s after its launch can be found from the vector diagram shown. What was the launch velocity of the projectile?



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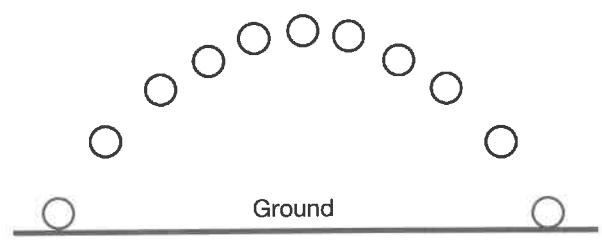
5.3.1.8 The diagram shows a stroboscopic photograph of a projectile which has a time of flight of 10.0 s.



(a) What was the initial vertical speed of the projectile?

....

(b) Calculate the maximum height of the projectile. ....

5.3.1.9 A cannon was fired at an elevation of 40°. It was then loaded with an identical charge and ball and fired again at an elevation of 50°.

(a) Which cannonball will rise to the highest height and how much higher than the other ball is it?

....

(b) Which cannonball will have the largest range and how much further than the other ball does it go?

....

Science Press

5.4 Conduct a practical investigation to collect primary data in order to validate the relationships derived for projectile motion.

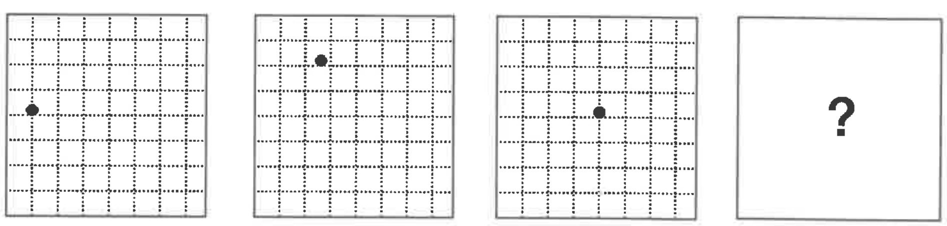
5.4.1 Analysing projectile data.

5.4.1.1 The table shows the results of an experiment where a ball was rolled along a smooth, horizontal surface at 15 m s^{-1} and then over the edge of a 150 m drop. The ball left the surface and started to fall at time zero.

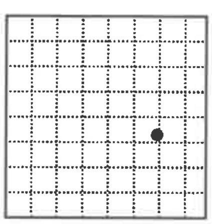
Time (s)	Speed of ball (m s^{-1})
1	17.92
2	24.68
3	33.01
4	41.97

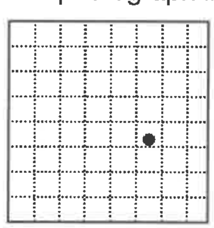
Assuming that the horizontal component of the motion of the projectile does not change, show that the vertical component is uniformly accelerated.

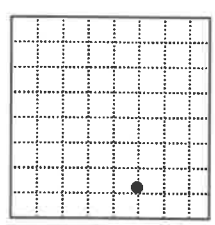
5.4.1.2 Some photographs are taken of a ball moving in a parabolic path in front of a grid. The time interval between photographs is identical. The diagrams show the first three photographs of the ball's flight.

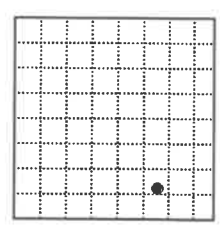


Which choice best shows the next photograph in the series?

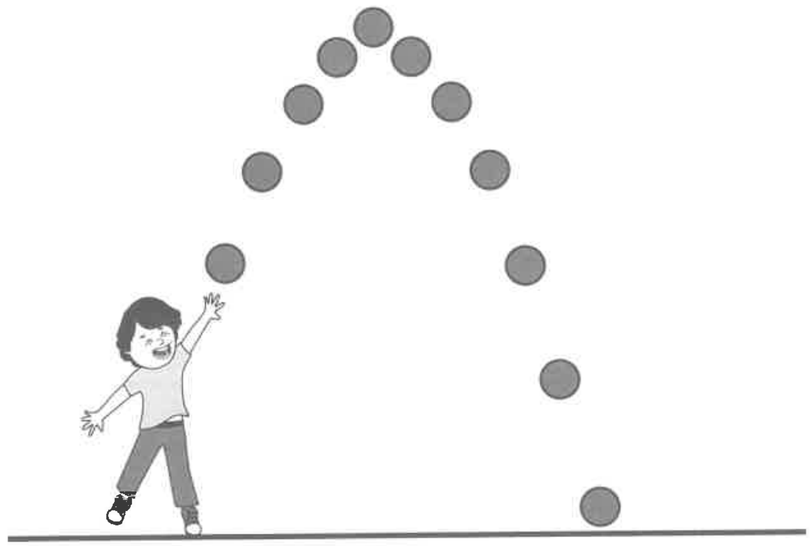
(A)


(B)


(C)


(D)


5.4.1.3 The diagram shows a film clip of a ball projected into the air. The camera took the clip at 2.5 frames per second.



(a) What was the time of flight of the ball?

(b) How long did it take to reach its maximum height?

(c) What was its initial vertical velocity?

(d) How high did it rise?

(e) What was its range?

(f) What was its initial horizontal velocity?

(g) Using a vector diagram, determine its initial velocity.

(h) From what height was the ball projected?

Science Press

Motion In Gravitational Fields

5.5 Apply qualitatively and quantitatively Newton's law of universal gravitation to determine the force of gravity between two objects $F = -\frac{GMm}{r^2}$.

INQUIRY QUESTION

How does the force of gravity determine the motion of planets and satellites?

5.5.1 Mass and weight.

5.5.1.1 Complete the table to compare mass and weight.

Mass	Weight

5.5.1.2

(a) Write down the equation that connects mass and weight. ....

(b) Rearrange this equation to make the gravitational field, g, the subject. ....

....

(c) Use your equation in (b) to define gravitational field. ....

....

....

(d) Give the two alternate units we use for gravitational field. ....

5.5.1.3 Two planets, X and Y have masses $4M$ and $9M$, and diameters $8R$ and $18R$ respectively. What is the ratio of the strengths of their gravitational fields on their surfaces?

....

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....

5.5.1.4 Two satellites, X, mass 600 kg, and Y, mass 1200 kg are orbiting the same planet at distances R and $4R$ from the centre of the planet. What is the ratio of the gravitational fields they experience?

....

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....

5.5.1.5 What is weight?

(A) A measure of the amount of matter in an object.

(B) A measure of the strength of the gravitational field the object is placed in.

(C) A measure of the gravitational acceleration of the planet.

(D) A measure of the force of gravity acting on an object.

5.5.1.6 Which statement about the weight of an object is correct?

(A) If gravitational acceleration is zero, then weight is zero.

(B) The weight of a particular object is constant on a particular planet.

(C) The weight of an object will not change when it is taken to a different planet.

(D) Weight is independent of the value of the acceleration due to gravity.

5.5.1.7 A traveller weighs herself at sea level and on top of a high mountain using the same set of scales. Which statement about her weight is correct?

(A) Weight will be the same at both locations because weight is independent of position.

(B) Weight will be greater on the mountain, since weight is proportional to distance from Earth's centre.

(C) Weight will be more at sea level because weight is inversely proportional to distance above Earth's surface.

(D) Weight will be less at sea level because weight is dependent on position above Earth's surface.

5.5.1.8 Which statement about weight is correct?

(A) Vector quantity, changes as gravitational force changes, measured in newtons.

(B) Scalar quantity, changes as gravitational force changes, measured in newtons.

(C) Vector quantity, constant in magnitude, measured in newtons.

(D) Vector quantity, changes as gravitational force changes, measured in kilograms.

5.5.1.9 An object has a mass of 15 kg on Earth. What would be its mass on Mars where the acceleration due to gravity is 0.38 that of Earth?

(A) 5.7 kg

(B) 15 kg

(C) 55.86 N

(D) 147 N

5.5.1.10 An object has a weight of 35.93 N on the Moon where the gravitational acceleration is about one sixth that of Earth. What would be the mass of the object on Earth?

(A) 3.67 kg

(B) 6.0 kg

(C) 22 kg

(D) 35.93 kg

5.5.1.11

(a) An object is placed on a set of scales on Earth and the scales read 8.0 kg. The mass and the scales are taken to Mars by astronauts. When they arrive, the astronauts place the mass on the scales. The gravitational acceleration on Mars is 3.72 m s^{-2}. What will the scales read?

(A) 3.0 kg (B) 8.0 kg (C) 21.08 N (D) 29.76 N

(b) Explain how we arrive at the correct answer for this question. ....

....

....

....

5.5.1.12 An object has a mass of 9.0 kg on Earth and a weight of 101.43 N on Saturn. According to this data, what is the value of the acceleration due to gravity on Saturn?

(A) 0.87

(B) 10.35 m s^{-2}

(C) 11.27 m s^{-2}

(D) 88.2 N

5.5.1.13 An object weighs 147 N on Earth and 84 N on planet X. What is the magnitude of the acceleration due to gravity on planet X?

(A) 0.86

(B) 2.7

(C) 5.6

(D) 15

5.5.1.14 The acceleration due to gravity on planet Y is twice that of planet X. What would be the weight of a mass on planet Y compared to its weight on planet X?

(A) 1 : 1

(B) 1 : 2

(C) 2 : 1

(D) Need to know the mass to determine this.

5.5.1.15 The acceleration due to gravity on Mercury is 0.41 that of Earth. On Uranus it is 0.88 that of Earth. An object weighs 500 N on Uranus. How much would it weigh on Mercury?

(A) 21 N

(B) 233 N

(C) 1073 N

(D) 1195 N

5.5.1.16 The acceleration due to gravity on planet X is one quarter that of planet Y. What would be the mass of a 6.0 kg object on planet X compared to its mass on planet Y?

(A) 1 : 1

(B) 1 : 3

(C) 1 : 4

(D) 4 : 1

5.5.1.17 Which choice gives the correct units for mass and weight respectively?

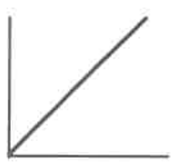
(A) kg and N kg^{-1}

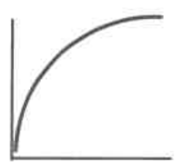
(B) kg and N m s^{-1}

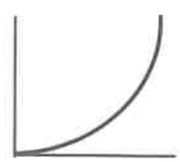
(C) N and kg

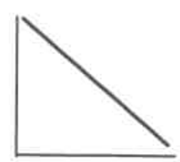
(D) kg and N

5.5.1.18 Which graph best shows the relationship between gravitational field at the surface of a planet and its mass?

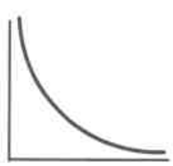
(A)


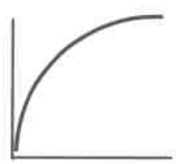
(B)


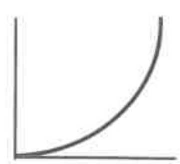
(C)


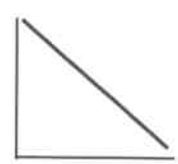
(D)


5.5.1.19 Which graph best shows the relationship between gravitational field and the distance from the surface of a planet?

(A)


(B)


(C)


(D)


5.5.2 Gravitational force 1.

5.5.2.1 Newton's law of universal gravitation is made up of three statements. Recall them.

5.5.2.2 Calculate the gravitational force between the Moon and the Earth. The mass of the Moon is 7.35×10^{22} kg, that of the Earth is 5.974×10^{24} kg, the diameter of the Moon is 3467 km, that of Earth is 12 756 km and the distance between them is about 406 676 km.

5.5.2.3 The mass of Jupiter is 1.9×10^{27} kg. Its diameter is 142 984 km. Calculate:

(a) The weight of a 10 kg object on its surface.

(b) The value of its acceleration due to gravity at its surface.

5.5.2.4 The radius of the Earth is 6378 km and its mass is 5.974×10^{24} kg. Calculate the acceleration at an altitude of 15 000 m.

5.5.2.5 Two moons, X and Y have masses M and $4M$ and radii R and $4R$ respectively. Compare the weight of a 10 kg object on the surface of each.

5.5.2.6 The mass of Mercury is 3.58×10^{23} kg. Its diameter is 4880 km. Compare its gravitational acceleration with that of Pluto, mass 1.27×10^{22} kg, diameter 2320 km.

5.5.2.7 Calculate the gravitational force between two 60 kg students 2 metres apart.

5.5.2.8 Predict the effect on the gravitational force between two objects of:

(a) Halving the distance between them.

(b) Doubling both masses.

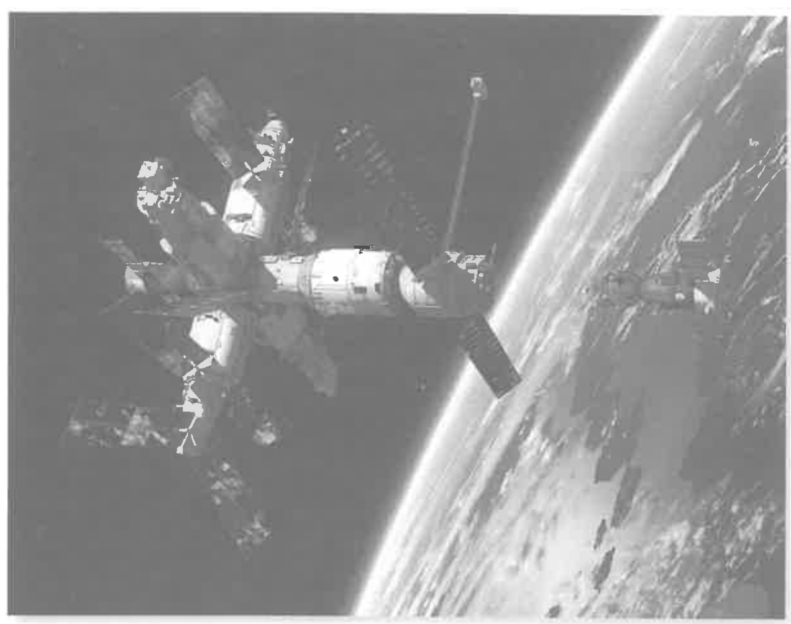
(c) Doubling one mass and halving the distance between them.

5.5.2.9 Calculate how far an astronaut would need to be away above the Earth in order for his weight to be 0.01 his weight on the Earth's surface.

5.5.2.10

(a) The Earth has a mass of 6×10^{24} kg and a diameter of 12 760 km. A 500 kg satellite in a stable orbit experiences a gravitational field of 0.4 m s^{-2}. What is the altitude of the orbit of the satellite?

(b) At what altitude would a 1000 kg satellite experience the same gravitational field?



5.5.3 Gravitational force 2.

5.5.3.1 The mass of Mars is 6.43×10^{23} kg and its diameter is 6794 km. What will be the weight of a 25 kg mass on its surface?

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....?

5.5.3.2 An astronaut has weight *W* on planet X. What would be his weight on planet Y which has half the mass and half the diameter of X?

(A) 0.25*W*
(B) 0.5*W*
(C) 2*W*
(D) 4*W*

5.5.3.3 An object of mass 12 kg weighs 156 N on planet X. What is the magnitude of the acceleration due to gravity on planet X?

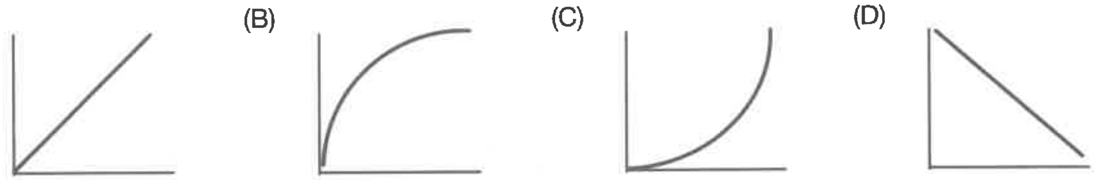
(A) 15.9
(B) 13
(C) 12
(D) 9.8

5.5.3.4 A gravitational force of *F* newtons exists between two objects. What would be the new gravitational force between them if the mass of one object was doubled, and the distance between them was halved?

(A) 0.5*F*
(B) 2*F*
(C) 4*F*
(D) 8*F*

5.5.3.5 Which graph best shows the relationship between gravitational force of a planet and its mass?

(A) (B) (C) (D)



5.5.3.6

(a) Imagine a hole drilled through the Earth. How would the mass and weight of an object placed in the hole at the centre of the Earth compare to its mass and weight on the surface?

(A) Its mass and weight would both be zero at the centre.
(B) Its mass and weight would be unchanged.
(C) Its mass would be zero and its weight unchanged.
(D) Its mass would be unchanged and its weight would be zero.

(b) Justify your answer. ....

....

....

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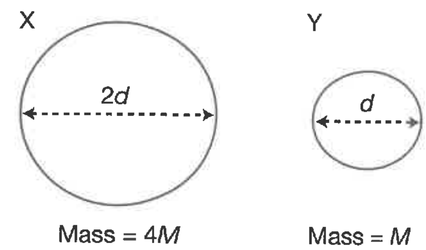
5.5.3.7 Consider the two planets shown. Their masses and diameters are given. The gravitational acceleration at the surface of planet X is 8 m s^{-2}. What is the gravitational acceleration at the surface of planet Y?

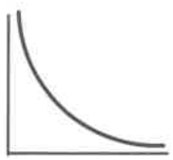
(A) 4.0 m s^{-2}
(B) 4.0 m s^{-2}
(C) 8.0 m s^{-2}
(D) 16.0 m s^{-2}

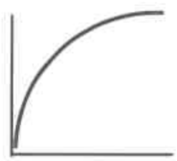


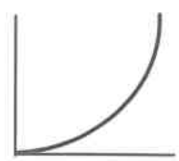
5.5.3.8 An astronaut weights 813 N on Earth and 739 N on Venus. Which statement below is correct?

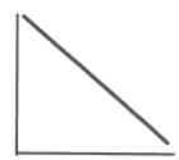
	Mass of astronaut (kg)	Acceleration due to gravity on Venus (m s^{-2})
(A)	75.4	8.9
(B)	75.4	9.8
(C)	83	8.9
(D)	83	9.8

5.5.3.9 Which graph best shows the relationship between gravitational force between two masses and the distance between them?

(A)


(B)


(C)


(D)


5.5.3.10 Two objects have a gravitational force of *F* newtons acting between them. What happens to this force if:

(a) The distance between the objects is doubled?

(b) The distance between the objects is halved?

(c) One of the objects is replaced by an object with twice the mass of the original object?

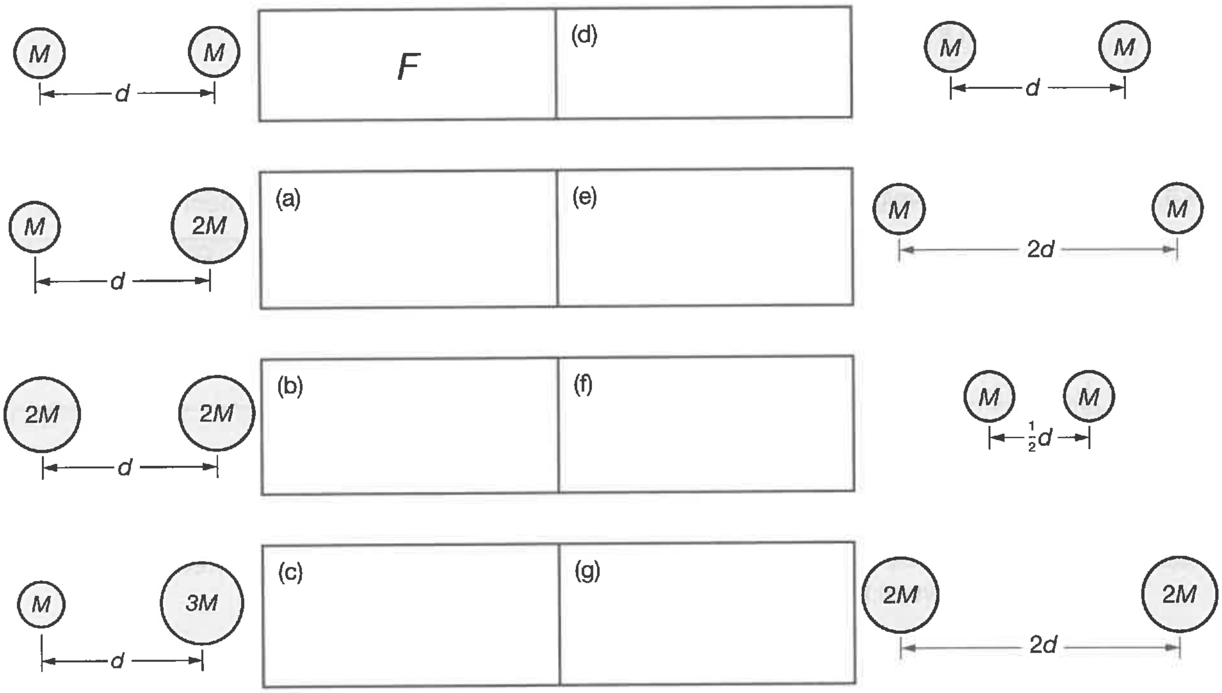
(d) Both objects are replaced by objects which each have three times the original mass?

(e) The distance between the objects is doubled *and* one of the objects is replaced by an object with twice the initial mass?

(f) The distance between the objects is tripled *and* one of the objects is replaced by an object with three times the initial mass?

5.5.4 Gravitational force 3.

5.5.4.1 The chart below shows the magnitude of the force acting between various combinations of masses and distances apart. Use the information given to complete the values for the missing forces.



5.5.4.2 Make calculations using the data in the table, to fill in the data missing from the table.

	Object 1	Mass 1 (kg)	Object 2	Mass 2 (kg)	Distance between objects (m)	Gravitational force between objects (N)
A	Football player	90	Earth	6.0×10^{24}	6.4×10^{6}	
B	Tennis player		Earth	6.0×10^{24}	6.4×10^{6}	635.1
C	Physics student	55	Earth	6.0×10^{24}	6.4×10^{6}	
D	Physics student	55	Physics student	55		8.07×10^{-9}
E	Physics student	55	Physics student		1.0 m	2.02×10^{-7}
F	Physics student	55	Surfing Physics book	1	0.5	
G	Physics student	55	Moon		1.74×10^{6} (surface)	88.94
H	Physics student	55	Mercury	3.29×10^{23}		202.1
I	Physics student	55	Mars	6.42×10^{23}	3.4×10^{6} (surface)	
J	Physics student	55	Jupiter		7.0×10^{7} (surface)	1422.5

5.6 Apply qualitatively and quantitatively Newton's law of universal gravitation to investigate the factors that affect the gravitational field strength: $g = \frac{GM}{r^2}$.

5.6.1 Falling objects – Analysing an experiment.

The information in the table was obtained from an experiment where the time it took an object to fall from different heights was measured. Use the information to answer the questions.

Distance fallen (m)	Time to fall (s)	(Time to fall)^2 (s^2)
0	0	
2	0.64	
4	0.90	
6	1.11	
8	1.28	
10	1.43	
12	1.56	
14	1.69	

5.6.1.1 Suggest a purpose of this experiment.

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5.6.1.2 Identify four factors which would have been controlled.

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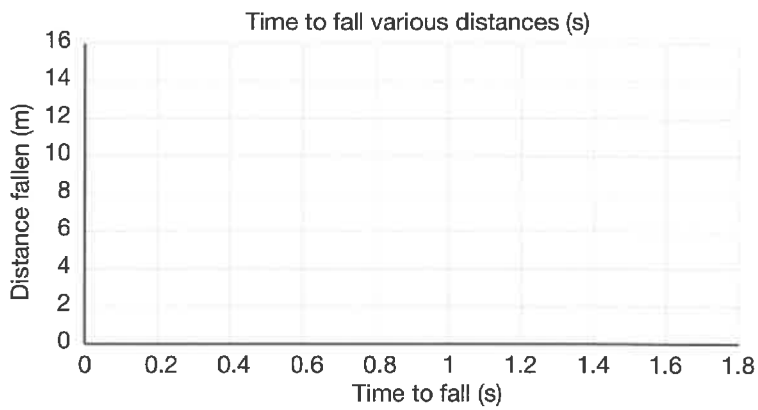
5.6.1.3 Identify the factors that varied. ....

....

5.6.1.4 Complete the third column headed (Time to fall)^2. You will need this data later.

5.6.1.5 Graph the information on the axes provided.



5.6.1.6 Predict the time to fall 5.0 m. ....

5.6.1.7 Predict the time to fall 25 m. ....

5.6.1.8 Comment on the accuracy and reliability of your predictions in 5.6.1.6 and 5.6.1.7. Explain your answer.

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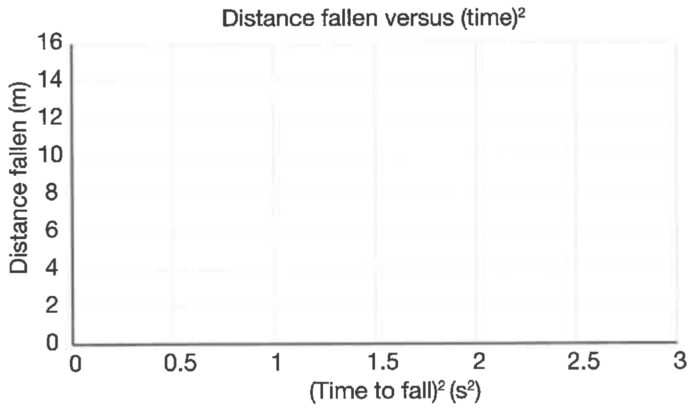
5.6.1.9 If it took 1.5 seconds to hit the ground, predict the height it fell from. ....

5.6.1.10 Can you write a conclusion from this graph? Explain your answer. ....

....

5.6.1.11 Graph distance fallen against t^2 on the grid provided.



5.6.1.12 What does this tell you about the rate at which the object falls?

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....

5.6.1.13 Given that twice the gradient of your graph is equal to the acceleration of the falling object, calculate the acceleration of the falling object.

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5.6.1.14 Is this object falling on Earth? Justify your answer.

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5.6.1.15 Write a conclusion for the experiment.

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5.6.1.16 Suggest at least one way this experiment could be improved.

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5.6.1.17 The diagram shows a stroboscopic picture of a falling ball. The frequency of the camera used to take the images was 11 Hz. The scale of the diagram is shown on it. Use this information to determine the acceleration due to gravity acting on the falling ball.

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5.7 Apply qualitatively and quantitatively Newton's law of universal gravitation to predict the gravitational field strength at any point in a gravitational field, including at the surface of a planet.

5.7.1 Gravitational field.

5.7.1.1 In physics, what is a field?

(A) The immediate space around a charge, mass or magnet.

(B) A region in which something experiences a force.

(C) The space in which objects are able to move.

(D) The region between two charges, masses or magnets.

5.7.1.2 What is a gravitational field?

(A) The space around any mass.

(B) The force holding the planets in orbit around the Sun.

(C) The force of attraction between any two masses.

(D) The region in which a mass experiences a force.

5.7.1.3 What would be the magnitude of the gravitational field at the midpoint between, and due to two identical planets?

(A) 0

(B) Depends on their masses.

(C) Depends on the total distance between them.

(D) Infinite.

5.7.1.4 A student said that an astronaut in an orbiting space station is weightless. Which choice correctly analyses this statement?

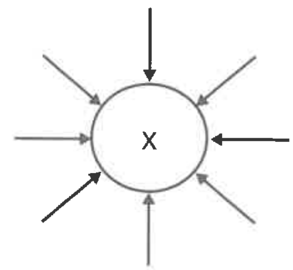
(A) The statement is correct because the gravitational force acting on the astronaut is cancelled by the equal but opposite centrifugal force.

(B) The statement is correct because no forces are acting on the astronaut.

(C) The statement is incorrect because only the centripetal force acts on the astronaut.

(D) The statement is incorrect because the gravitational force is acting on the astronaut.

5.7.1.5 The gravitational field lines are shown for planet X. Planet Y is smaller, but more massive than planet X.



Which statement about a similar diagram for planet Y is correct?

(A) It would have more field lines.

(B) It would have fewer field lines.

(C) It would have the same number of field lines.

(D) More information is required.

5.7.1.6 What is the effect of a gravitational field on a mass placed in it?

(A) It gives the mass an acceleration.

(B) It causes the mass to move towards the centre of curvature.

(C) It gives the object weight.

(D) It produces the mass of the object.

5.7.1.7 A gravitational force of F newtons exists between two objects. What would be the new gravitational force between them if the mass of one object was halved, and the distance between them was doubled?

(A) $0.125F$ (B) $0.25F$

(C) $0.5F$ (D) $2F$

5.7.1.8 Predict the weight of a 5 kg object on Earth compared to its weight on Jupiter, and explain the reasoning behind your prediction. The gravitational acceleration on Jupiter is about 24.8 m s^{-2}.

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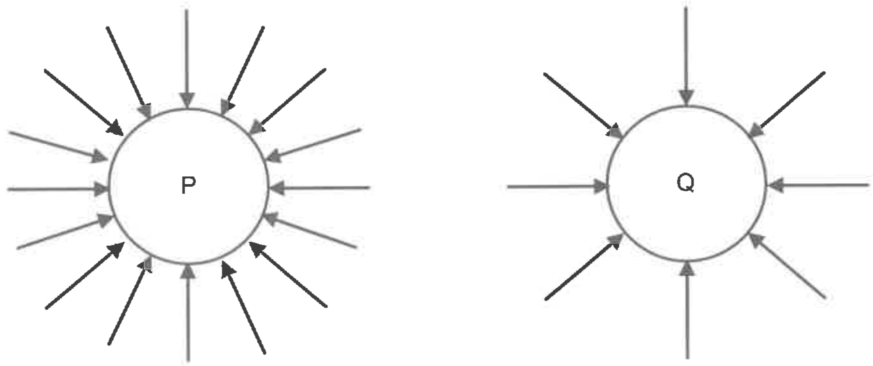
5.7.1.9 The field diagrams shown represent the relative strengths of the gravitational fields of two planets P and Q. The planets have the same radius.



Which statement about these two planets is correct?

(A) The gravitational field of each planet is the same.

(B) Planet P has a greater mass than planet Q.

(C) The gravitational force acting on an object above the surface of P will be less than the gravitational force acting on the same object the same distance above the surface of Q.

(D) The gravitational force on an object above the surface of P will be less than the gravitational force on the same object the same distance above the surface of Q.

5.7.1.10 The Earth has a mass about 80 times that of the Moon. Consider the diagram which shows four points in space between the Earth and the Moon. Point F is halfway between their centres.

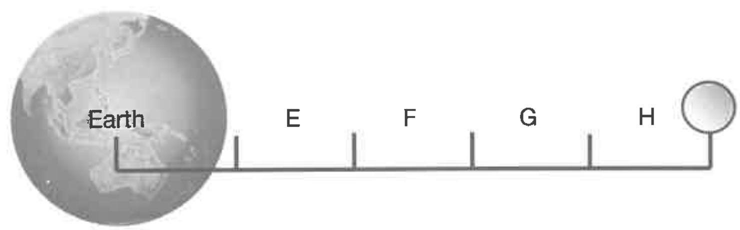
At which point would the gravitational fields due to the Earth and the Moon be closest to equal?

(A) E

(B) F

(C) G

(D) H



5.7.1.11 The gravitational field at point P, distance d from the centre of a planet is g m s^{-2}. What would be the gravitational field at each of the following points?

(a) Point Q, twice as far from the planet's centre.

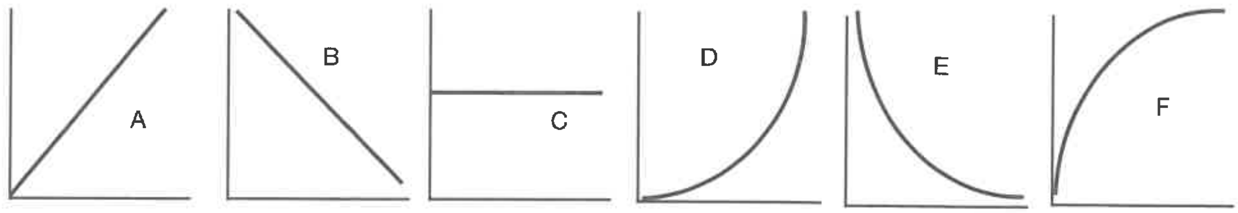
(b) Point R half the distance from the planet's centre.

(c) Point S, distance d from the centre of another planet with twice the mass.

(d) Point T, distance d from the centre of another planet with half the mass.

(e) Point U, distanced $2d$ from the centre of another planet with twice the mass.

5.7.1.12 Consider the graphs below.



Placing gravitational field always on the y-axis, which graph best shows the relationship between gravitational field strength and:

(a) Distance from a planet's centre? ☐

(b) The mass of the planet? ☐

(c) The mass of the object in the field? ☐

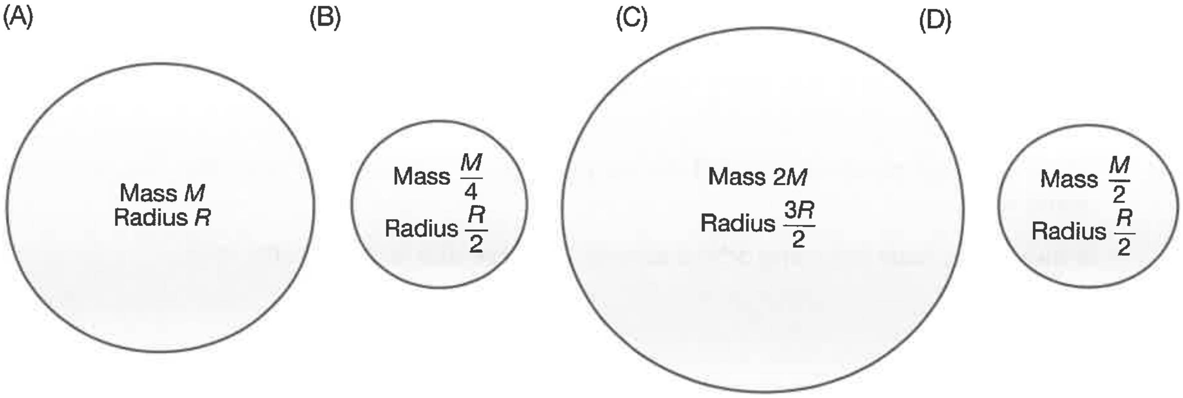
(d) (Inverse of the distance from the planet's centre)^2? ☐

(e) Radius of the planet? ☐

5.7.1.13

(a) Which of the following planets would have the largest surface gravitational field?

(A) (B) (C) (D)



(b) On which two planets would the surface field be the same? ....

5.8 Investigate the orbital motion of planets and artificial satellites when applying the relationships between the following quantities: gravitational force, centripetal force, centripetal acceleration, mass, orbital radius, orbital velocity and orbital period.

5.8.1 Orbital velocity.

5.8.1.1

(a) Define orbital velocity. ....

....

(b) Clarify the concept of a 'primary' as it relates to orbiting objects. Include an example.

....

....

(c) Clarify the idea of an orbital radius and compare it to altitude. ....

....

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5.8.1.2 Imagine identical satellites orbiting Earth and Jupiter, both at altitudes of 2000 km. Compare their orbital velocities (qualitatively only) and account for the difference.

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5.8.1.3 Three moons around planet X have masses M, $9M$ and $16M$.

(a) If all moons are the same distance from the planet's centre, calculate the ratio of their orbital speeds.

....

....

(b) If the distances of these moons from the planet's centre are R, $9R$ and $16R$ respectively, calculate the ratio of their orbital speeds.

....

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5.8.1.4 Three identical moons are in orbit around planets of masses M, $9M$ and $16M$. The planets have the same radii.

(a) If the moons have the same orbital speeds, find the ratio of their orbital radii. ....

....

....

(b) If the orbital radii of the planets are the same, find the ratio of their orbital speeds. ....

....

....

5.8.1.5 Calculate the orbital speed of the Earth around the Sun given the mass of the Sun is 1.99×10^{30} kg, and its diameter is 1 392 530 km. The mass of the Earth is 5.974×10^{24} kg, its diameter is 12 756 km, and the distance between the Sun and Earth is 150 000 000 km.

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5.8.1.6

(a) List the factors that affect the orbital velocity of a satellite. ....

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(b) How does gravitational field affect orbital velocity? ....

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5.8.1.7 Jupiter's mass is 1.9×10^{27} kg and its diameter is142 984 km. Saturn's mass is 5.7×10^{26} kg and its diameter is 20 000 km. Which statement about the velocity of satellites orbiting each at the same altitude is correct?

(A) The velocity of the satellite orbiting Jupiter will be greater than that of the satellite orbiting Saturn.
(B) The velocity of the satellite orbiting Jupiter will be less than that of the satellite orbiting Saturn.
(C) The velocity of the satellite orbiting Jupiter will be equal to that of the satellite orbiting Saturn.
(D) Additional information is needed before this can be determined.

5.8.1.8 Two satellites are in the same LEO. Satellite X has three times the mass of satellite Y. What is the ratio of their orbital speeds?

(A) X : Y = 1 : 1 (B) X : Y = 1 : 3 (C) X : Y = 3 : 1 (D) X : Y = 9 : 1

5.8.1.9 Which statement about the orbits of satellites is correct?

(A) The greater the mass and altitude, the slower the satellite travels.
(B) The greater the mass and altitude, the faster the satellite travels.
(C) The higher the altitude of the orbit, the faster the satellite travels.
(D) The higher the altitude of the orbit, the slower the satellite travels.

5.8.1.10

(a) Three identical moons orbit planets P, Q and R which have identical masses and radii R, $4R$ and $16R$. The moons all have the same orbital velocity. What is the ratio of the orbital radii of the moons?

(A) 1 : 1 : 1 (B) 1 : 2 : 4 (C) 1 : 4 : 16 (D) 12 : 4 : 3

(b) If the moons had the same orbital radii, what would be the ratio of their orbital velocities?

....

5.8.1.11

(a) Satellite X is at an altitude of 350 km in a low Earth orbit while identical satellite Y is at an altitude of 700 km, also in a low Earth orbit. Which statement about these two satellites is correct?

(A) X is moving faster and has more gravitational potential energy than Y.
(B) X is moving faster and is in a stronger gravitational than Y.
(C) X is in a weaker gravitational field and has less gravitational potential energy than Y.
(D) X is moving slower and has more gravitational potential energy than Y.

(b) Justify your answer. ....

....

....

5.8.1.12 Two satellites, X mass 2000 kg and Y mass 3000 kg are placed into orbits above Mars. The altitude of these orbits is two and three times the radius of Mars respectively. What is the ratio of their orbital speeds?

(A) X : Y = 1 : 1 (B) X : Y = 3 : 2 (C) X : Y = 2 : 3 (D) X : Y = 11.5 : 10

5.8.1.13 Satellite X has a mass of M and is orbiting Earth with an orbital radius of $2R$ while satellite Y has a mass of $2M$ and is orbiting Earth with an orbital radius of R. Which statement about these two satellites is correct?

(A) X is moving faster and has more gravitational potential energy than Y.
(B) X is moving faster and has less gravitational potential energy than Y.
(C) X is moving slower and has more gravitational potential energy than Y.
(D) X is moving slower and has less gravitational potential energy than Y.

5.9 Predict quantitatively the orbital properties of planets and satellites in a variety of situations, including near the Earth and geostationary orbits, and relate these to their uses.

5.9.1 Types of orbits.

5.9.1.1 Research information to find the answers to this question.

(a) What are the Van Allen belts? ....

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(b) How do the Van Allen belts form? ....

....

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(c) In what way(s) do the Van Allen belts provide problems for astronauts and their equipment?

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(d) What are the orbital altitude restrictions on orbital spacecraft because of the Van Allen belts?

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(e) What is the minimum orbital altitude to avoid significant atmospheric friction? ....

....

(f) What will happen to orbiting spacecraft if they are subject to significant atmospheric friction?

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5.9.1.2

(a) Recall the main uses for satellites placed in geostationary orbits. ....

....

(b) Explain why they are useful for these purposes. ....

....

5.9.1.3

(a) Recall a use for low Earth orbit satellites. ....

....

(b) Explain why low Earth orbits are useful for these satellite uses. ....

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5.9.1.4 Recall a use for satellites in geosynchronous orbits and explain why they are useful for this purpose.

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5.9.1.5 Complete the table to compare low Earth and geostationary and geosynchronous satellites.

Characteristics of ...		
Low Earth satellites	**Geostationary satellites**	**Geosynchronous satellites**

5.9.1.6 Complete the table to compare low Earth and geostationary and geosynchronous satellites.

Advantages of ...		
Low Earth satellites	**Geostationary satellites**	**Geosynchronous satellites**

5.9.1.7 Complete the table to compare low Earth and geostationary and geosynchronous satellites.

Disadvantages of ...		
Low Earth satellites	**Geostationary satellites**	**Geosynchronous satellites**

5.9.1.8 Which choice correctly compares low Earth orbit and geostationary satellites?

	LEO altitude (km)	LEO orbit	Geo altitude (km)	Geo orbit
(A)	35 000	Equatorial	300 to 1000	Polar
(B)	35 000	Polar	300 to 1000	Equatorial
(C)	300 to 1000	Equatorial	35 000	Polar
(D)	300 to 1000	Polar	35 000	Equatorial

5.9.1.9 Which choice gives correct information about geostationary satellites?

(A) Altitude 35 000 km, used for communications.

(B) Altitude 35 000 km used as spy satellites.

(C) Altitude between 300 and 1000 km, used as spy satellites.

(D) Altitude between 300 and 1000 km, used in weather forecasting.

5.9.1.10 Which choice best describes the concept of satellite tracking?

(A) Refers to the differences between the ways satellites move in their orbits around Earth.

(B) Refers to the fact that satellite receiving dishes do not have to move to follow the path of a geostationary satellite across the sky.

(C) Refers to the movement of a satellite signalling or receiving dish to follow the path of the satellite across the sky.

(D) Refers to the movement of a satellite through the atmosphere as it travels the orbital path it is in.

5.9.1.11 A geostationary satellite orbits the Earth from west to east above the equator. Which statement is correct?

(A) The satellite will always be above the same position on the Earth's surface.

(B) The satellite will orbit in the opposite direction to the Earth's motion.

(C) The satellite will continually move over different parts of the Earth's surface.

(D) The satellite will move over different parts of the Earth's surface but only along the equator.

5.9.1.12 Compared to a geostationary satellite, a low Earth orbit satellite will have a period which is:

(A) The same.

(B) Shorter.

(C) Longer.

(D) Up to 32 times shorter.

5.9.1.13 Satellite X has an orbital period which is twice that of satellite Y. Which statement is correct?

(A) X is moving slower and at a lower altitude than Y.

(B) X is moving faster and at a lower altitude than Y.

(C) X is moving slower and at a higher altitude than Y.

(D) X is moving faster and at a higher altitude than Y.

5.9.1.14 Satellite Y with twice the mass of X is placed into the same orbit as X. Which statement about their orbital speeds is correct?

(A) X is moving slower with a shorter period than Y.

(B) X is moving faster with a shorter period than Y.

(C) X is moving slower with a longer period than Y.

(D) X is moving at the same speed as Y.

5.9.1.15 Which choice gives an advantage of the low orbital altitude of spy satellites?

(A) They can orbit the Earth in a much shorter time.

(B) They can take close-up photographs of the areas they fly over.

(C) They carry extremely expensive cameras to record their passage over the Earth.

(D) The can travel much faster than in a higher orbit.

5.10 Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to the concept of escape velocity: $v_{esc} = \sqrt{\dfrac{2GM}{r}}$.

5.10.1 Escape velocity 1.

For relevant questions in this set, take the radius of the Earth as 6400 km, and its mass as 6×10^{24} kg.

5.10.1.1

(a) Clarify the concept of escape velocity. ....

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(b) How will the surface escape velocity (the escape velocity from the surface of a planet) compare with the orbital escape velocity of a satellite (the escape velocity needed from the orbital altitude). Justify your answer.

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(c) Explain how a rocket can escape Earth's gravitational field at a speed less than the escape velocity.

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5.10.1.2 The escape velocity of Jupiter is 5.95×10^4 m s^{-1} and its radius is 7.0×10^7 km. According to this data, what is the mass of Jupiter?

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5.10.1.3 Calculate the escape velocity of a spacecraft in an Earth orbit with an altitude of 350 km.

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5.10.1.4

(a) If an object is given kinetic energy equal to its gravitational potential energy on the surface of the Moon, then it will escape the gravitational field of the Moon and reach infinity. Use this concept to derive an equation for the escape velocity, v_e, of an object, mass m, from a planet, mass M.

(b) A particular neutron star has radius of 1.6×10^3 m and a mass of 4.5×10^{22} kg. Use your equation to determine the escape speed, v_e, from the surface of the star.

(c) Determine the gravitational field strength on the surface of this star.

(d) The period, T, of rotation of the star is 4 minutes. Use your answer to (c) to prove that matter is not lost from the surface of the star as a result of its high speed of rotation.

5.10.1.5

(a) Find the escape velocity for a 5000 kg projectile from the surface of the Earth.

(b) Find the escape velocity for a 500 kg projectile from the surface of the Earth.

(c) Explain any similarity or difference in your answers to (a) and (b).

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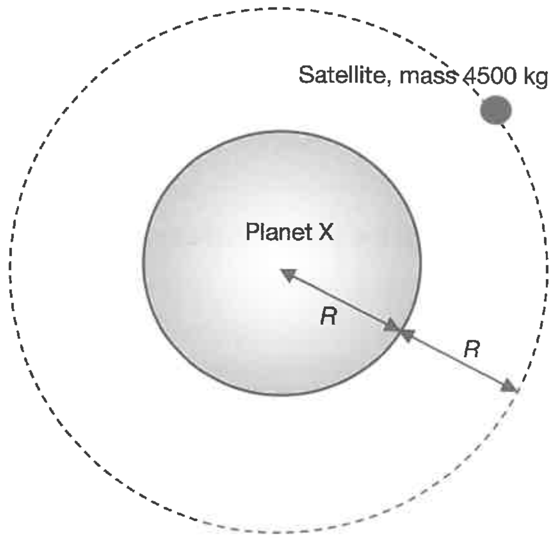
5.10.2 Escape velocity 2.

5.10.2.1 A satellite of mass 4500 kg is in orbit around a planet at an altitude of R m which is equal to the radius of the planet. The planet has a mass of 6×10^{23} kg and radius R equal to 5600 km.



(a) Find the surface escape velocity for planet X.

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(b) Determine the escape velocity from the orbital position.

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(c) Explain the difference in the two values.

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5.10.2.2

(a) Consider two planets A and B. Planet A has double the mass and double the radius of planet B. Which has the larger escape velocity? Justify your answer.

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(b) Suppose that the mass of A was 4 times the mass of B. How does the escape velocity from A compare to B?

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5.10.2.3 The radius of the planet Uranus is about 4 times Earth's. Given the Earth's escape velocity from Earth's surface is 11 200 m s^{-1} and the escape velocity from the surface of Uranus is about 21 700 m s^{-1}, find the mass of Uranus.

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5.10.2.4

(a) A moon has a radius of 1600 km and has a gravitational acceleration at the surface of 2.5 m s^{-2}. What is the mass of the moon?

(b) What is the escape velocity for this moon?

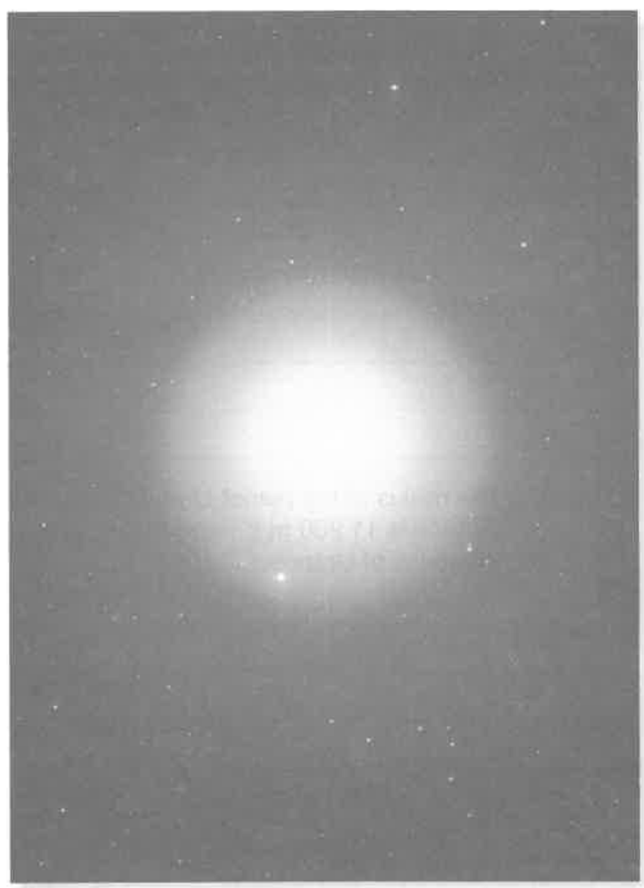
(c) What will happen to a projectile fired from the moon's surface with a vertical speed of 2500 m s^{-1}?

5.10.2.5 What is the escape velocity from Saturn given that its mass is about 95 times that of the Earth and its radius is 9.1 times larger. Take the Earth's escape velocity as 11 200 m s^{-1}.

5.10.2.6 The radius of Arcturus, the fourth brightest star in the night sky is about 25.4 times that of our Sun (radius 695 700 km) and a mass 1.08 times that of the Sun (2×10^{30} kg).

(a) Calculate the escape velocity from the surface of the Sun.

(b) Calculate the escape velocity from the surface of Arcturus.



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5.11 Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to total potential energy of a planet or satellite in its orbit: $U = -\frac{GMm}{r}$.

5.11.1 Gravitational potential energy 1.

For relevant questions in this set, take the radius of the Earth as 6400 km, and its mass as 6×10^{24} kg.

5.11.1.1 Where would an object be if its gravitational potential energy was zero? Explain your answer.

5.11.1.2 Define gravitational potential energy for an object which is a significant distance above the surface of the Earth (or any other planet), giving the equation we use to find it, and the units we use to measure it.

5.11.1.3 In year 9 or 10 science, you may have used the equation $\Delta E_p = mg\Delta h$ to find the change in gravitational potential energy of an object close to the Earth's surface. Explain why we do not use this equation to calculate the gravitational potential energy of an object in space or the change in the gravitational potential energy of, say, a satellite that changes its orbital altitude.

5.11.1.4 Explain, using appropriate laws of physics and mathematical equations if appropriate, why the gravitational potential energy of an object at a particular point in space is always a negative quantity.

5.11.1.5 Derive, with appropriate explanations of what you are doing for each step in the derivation, the formula we use for the gravitational potential energy (U) of a planet or satellite in orbit from our concept of gravitational field, our definition of gravitational potential energy, and the concept of work done.

5.11.1.6

(a) Derive a suitable formula so you can calculate the change in gravitational potential energy for a satellite which moves from orbital radius $R_{initial}$ to orbital radius R_{final}.

(b) What will be the nature of the orbital change for a satellite if work has to be done on it by an external force?

(c) In the situation in (b) will the gravitational potential energy of the satellite increase or decrease? Justify your answer.

(d) What will be the nature of the orbital change for a satellite if work is done on it by the gravitational field?

(e) In the situation in (d) will the gravitational potential energy of the satellite increase or decrease? Justify your answer.

5.11.2 Gravitational potential energy 2.

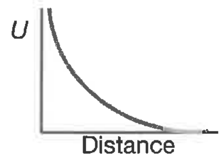
5.11.2.1 Calculate the gravitational potential energy of a 2000 kg satellite which orbits the Earth at an altitude of 35 000 km. The radius of Earth is 6378 km.

5.11.2.2 Explain, in terms of the principles of physics involved, why gravitational potential energy is a negative quantity.

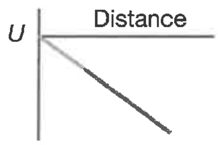
5.11.2.3 Which of the graphs best shows the relationship between the gravitational potential energy of an object and its distance from the centre of the Earth?

(A)

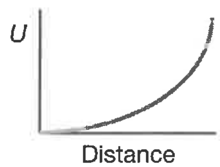
(B)



(C)



(D)



5.11.2.4

(a) When will the gravitational potential energy of an object be zero?

(A) When it is at infinity.

(B) When it is on the surface of a planet.

(C) When it is in outer space.

(D) When its acceleration is 9.8 m s^{-2}.

(b) Justify your choice.

5.11.2.5

(a) What is the gravitational potential energy of a 200 kg satellite on the surface of the Earth? The diameter of the Earth is 12 756 km.

(A) -1.96×10^{3} J

(B) -1.25×10^{10} J

(C) -8.49×10^{12} J

(D) -1.25×10^{13} J

(b) Would the gravitational potential energy of this satellite be greater or less if the satellite had a mass of 400 kg? Explain.

5.11.2.6

(a) What is the gravitational potential energy of a 200 kg satellite 300 km above the surface of the Earth? The diameter of the Earth is 12756 km.

(A) -1.79×10^{3} J

(B) -8.59×10^{9} J

(C) -1.19×10^{10} J

(D) -2.00×10^{13} J

(b) Would the gravitational potential energy of this satellite be greater or less if it was at an altitude of 600 km? Explain.

5.11.2.7

(a) What is the gravitational potential energy of a 200 kg satellite 3000 km above the surface of the Earth? The diameter of the Earth is 12756 km.

(A) -9.06×10^{2} J

(B) -8.50×10^{9} J

(C) -1.25×10^{10} J

(D) -8.50×10^{12} J

(b) Would the gravitational potential energy of this satellite be greater or less if it was at an altitude of 3000 km above the Moon? Explain your answer.

5.11.2.8 Find the gravitational potential energy of Phobos, one of the two moons of Mars with respect to Mars. The mass of Phobos is 1.07×10^{16} kg and the mass of Mars is 6.4×10^{23} kg. The orbital radius of Phobos about Mars averages about 9390 km.

5.11.2.9 A 5 tonne satellite orbiting Earth has an orbital radius of 7500 km. What is its gravitational potential energy?

5.12 Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to total energy of a planet or satellite in its orbit: $E = -\frac{GMm}{2r}$.

5.12.1 Total energy of an orbiting object.

5.12.1.1

(a) In terms of the circumference of an orbit and the period of a satellite in the orbit, derive an equation for the orbital velocity of the satellite.

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(b) By equating the centripetal and gravitational forces acting on a satellite, derive another equation for the orbital velocity of the satellite.

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(c) Use this equation (b) to derive an equation for the kinetic energy of a satellite in orbit.

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(d) Recall the formula for the gravitational potential energy of a satellite in orbit. ....

(e) Using your answers for (c) and (d), derive an equation for the total energy of a satellite in orbit.

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(f) Explain why the total energy of a satellite in orbit is negative. ....

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(g) What is the relationship between the kinetic energy of an orbiting satellite and its gravitational potential energy?

....

(h) What is the relationship between the total energy of an orbiting satellite and its gravitational potential energy?

....

(i) What is the relationship between the total energy of an orbiting satellite and its orbital kinetic energy?

....

5.12.1.2 The planet Mars has a mass of 6.42×10^{23} kg and a diameter of 6.79×10^{3} km. A satellite, mass 200 kg is in orbit 350 km above the surface.

(a) What is the gravitational potential energy of the satellite?

(b) What is the orbital kinetic energy of the satellite?

(c) What is the orbital velocity of the satellite?

(d) What is the total energy of the satellite?

5.12.1.3 The planet Jupiter has a diameter of 1.43×10^{5} km. A 400 kg research satellite orbits Jupiter at an altitude of 750 km. Its orbital kinetic energy is 3.51×10^{11} J.

(a) What is its orbital velocity?

(b) What is its total energy while it remains in orbit?

(c) What is the gravitational potential energy of the satellite?

(d) What, according to this data, is the mass of Jupiter?

5.12.1.4 The planet Saturn has a mass of 5.68×10^{26} kg and a diameter of 1.16×10^{5} km. A satellite in orbit around Saturn at an altitude of 2500 km has gravitational potential energy equal to -2.44×10^{11} J.

(a) What is its orbital kinetic energy?

(b) What is the total energy of the satellite?

(c) What is the mass of the satellite?

(d) What is the orbital velocity of the satellite?

5.12.1.5 The planet Uranus has a mass of 8.68×10^{25} kg and a diameter of 5.07×10^{4} km. A 800 kg satellite orbits Uranus with orbital kinetic energy equal to 7.9×10^{10} J.

(a) What is its gravitational potential energy?

(b) What is its total energy?

(c) What is its orbital velocity?

(d) What is its altitude above the surface of Uranus?

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5.12.1.6 A 1500 kg satellite orbits Earth at an altitude of 12 000 km. If the mass of the Earth is 6.0×10^{24} kg and its radius is 6.4×10^{7} km:

(a) What is its orbital kinetic energy?

(b) What is its orbital speed?

(c) What is its gravitational potential energy?

(d) What is its total orbital energy?

5.12.1.7 A 2500 kg satellite orbits the Moon at an altitude of 1500 km. If the mass of the Moon is 7.35×10^{22} kg and its radius is 1.74×10^{3} km:

(a) What is its orbital kinetic energy?

(b) What is its orbital speed?

(c) What is its gravitational potential energy?

(d) What is its total orbital energy?

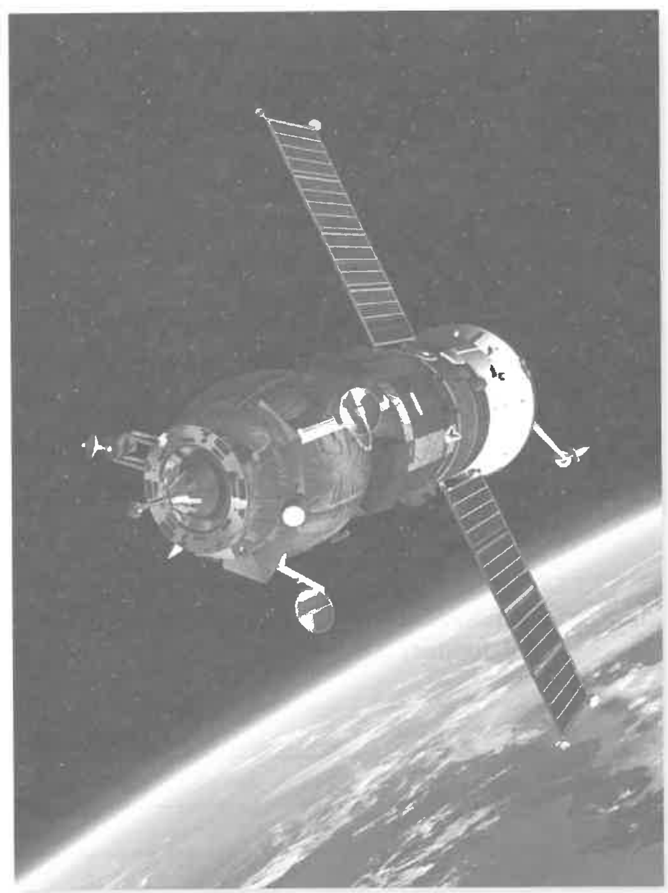
5.12.1.8 A 600 kg satellite orbits Venus at an altitude of 900 km. The mass of Venus is 4.87×10^{24} kg, and its radius is 6052 km.

(a) What is the orbital kinetic energy of the satellite?

(b) What is its orbital speed?

(c) What is its gravitational potential energy?

(d) What is its total orbital energy?



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5.13 Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to energy changes that occur when satellites move between orbits.

5.13.1 Changes in gravitational potential energy.

5.13.1.1

(a) A satellite of mass 500 kg is boosted from an orbit of altitude10 000 km to one of altitude 20 000 km. Given the diameter of Earth as 12 756 km, its mass as 5.97×10^{24} kg, calculate the change in the gravitational potential energy of the satellite.

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(b) Because there is a change in the energy of the satellite, work has been done. What does the work? Justify your answer.

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5.13.1.2

(a) Calculate the change in the gravitational potential energy of a 90 kg satellite if its orbit is changed from 1000 km above the surface of the Earth to 350 km altitude. The mass of the Earth is 6×10^{24} kg and its radius is 6.38×10^{6} km.

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(b) If this energy changed to kinetic energy, by how much would the speed of the satellite change?

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(c) How much work is done on the satellite in this orbital change, and what does the work?

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5.13.1.3 A satellite is in orbit at a distance $2R$ from the centre of a planet. It takes W joules of work to decrease the orbit to distance R from the centre of the planet – i.e. to the surface of the planet.

(a) What does the work required to move this satellite? ....

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(b) How much additional work is required to move the satellite from the original orbit ($2R$ from the planet centre) into an orbit at a distance of $3R$, and, what would do the work in this case?

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5.13.1.4 If it requires E joules of energy to raise a 500 kg mass from the surface of the Earth to an altitude of 8000 km above the Earth, how much energy is required to raise it from the surface to an altitude of 16 000 km?

5.13.1.5

(a) A satellite is moved into a higher altitude orbit. Which statement about this satellite is correct?

(A) Work is done by the satellite engines and its U increases.

(B) Work is done by the satellite engines and its U decreases.

(C) Work is done by gravity and its U increases.

(D) Work is done by gravity and its U decreases.

(b) What would happen to the orbital speed and period of this satellite? Explain your answer.

5.13.1.6 A rocket is in orbit at distance R from the centre of the Earth. At this height it has gravitational potential energy (U) equal to E joules. The rocket is then boosted to an orbit where its U is $3E$. Which statement about this rocket is correct?

(A) It is in a higher orbit and $2E$ work has been done on it by its engines.

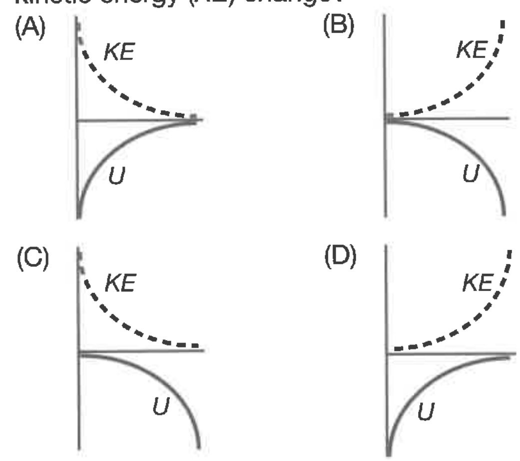
(B) It is in a higher orbit and $2E$ work has been done on it by gravity.

(C) It is in a lower orbit and $2E$ work has been done on it by its engines.

(D) It is in a lower orbit and $2E$ work has been done on it by gravity.

5.13.1.7

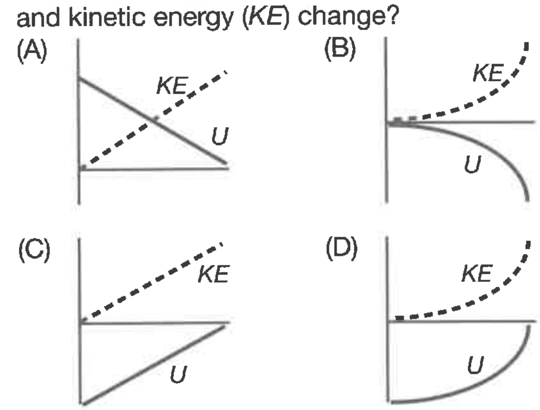
(a) A projectile is fired vertically into the air. It rises until it escapes from the Earth's gravitational field. Which graphs show how its gravitational potential energy (U) and kinetic energy (KE) change?



(b) Justify your answer.

5.13.1.8

(a) A rocket is launched and rises under constant thrust until it escapes the Earth's gravitational field. Which graph best shows how its gravitational potential energy (U) and kinetic energy (KE) change?



(b) Justify your answer.

5.13.1.9

(a) What work needs to be done against gravity to lift a 200 kg satellite to an altitude of 3000 m?

(A) $+1.05 \times 10^3$ J (B) -4.00×10^9 J (C) $+4.00 \times 10^9$ J (D) $+8.48 \times 10^{12}$ J

(b) Would the extra work be greater for a satellite of mass 400 kg? Explain.

5.13.1.10

(a) Much more work needs to be done to put a 200 kg satellite into orbit at an altitude of 3000 m than just the work equivalent to its change in gravitational potential energy. Which choice best explains this?

(A) Extra energy is needed to overcome air resistance.

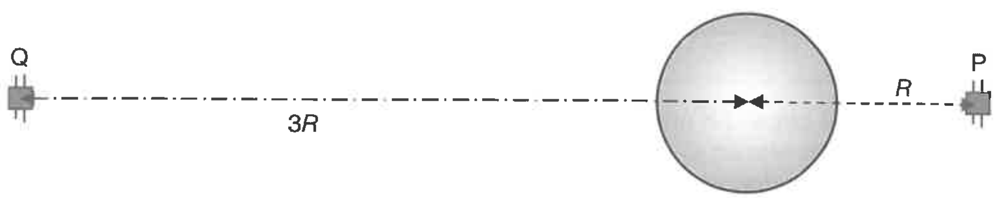
(B) The satellite also needs to be given orbital velocity.

(C) To go into orbit the centripetal force needs to be overcome as well as the gravitational force.

(D) Orbital potential energy is measured relative to the Earth's centre not the surface.

(b) Would even more work be required to put a 400 kg satellite into the same orbit? Explain.

5.13.1.11 A satellite, X, is in orbit around the Earth with an orbital radius of R km, in position P as shown in the diagram. In this position it has $-E$ joules of gravitational potential energy.

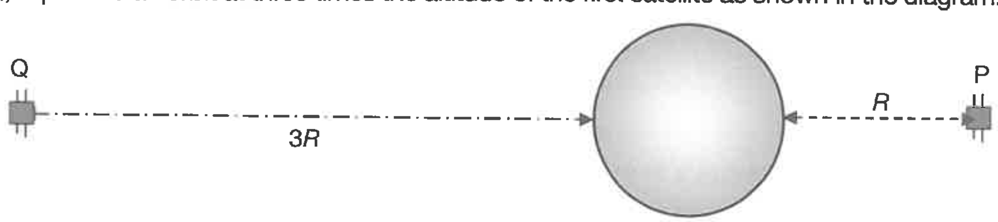


(a) What would be the gravitational potential energy of this satellite if it was moved to position Q, with an orbital radius of $3R$ km?

(b) A new satellite with triple the mass of X is placed into orbit in position P. What will be its gravitational potential energy at P?

(c) By how much will this new satellite's gravitational potential energy change if it is moved to position Q?

5.13.1.12 E joules of work are done to put satellite P into orbit at an altitude of R km above the Earth. A second, identical satellite, Q, is put into an orbit at three times the altitude of the first satellite as shown in the diagram.



(a) Would three times as much work need to be done to put this second satellite into orbit? Justify your answer.

(b) What would be the value of the altitude of the second satellite if three times the amount of work was done on it in putting it into orbit compared to the first satellite?

5.14 Derive quantitatively and apply the concepts of gravitational force and gravitational potential energy in radial gravitational fields to Kepler's laws of planetary motion.

5.14.1 Deriving Kepler's third law.

5.14.1.1

(a) Use the fact that the centripetal force acting on an object in uniform circular motion is equal to the gravitational force acting on it to derive an equation for the orbital velocity of the body.

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(b) Use Newton's simple equation for the linear velocity of an object, $v = \frac{s}{t}$, to derive another equation for the orbital velocity of the body.

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(c) Equate these two equations and derive the equation we use for Kepler's third law of planetary motion.

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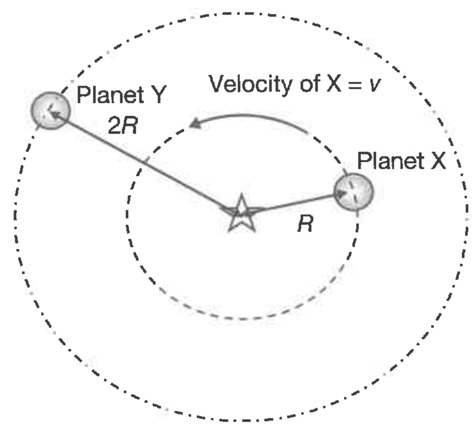
5.14.1.2 Two identical planets X and Y orbit the same star at distances of R and $2R$ as shown in the diagram. The orbital velocity of X is v, and its period of revolution is T.



(a) Determine the period of the orbit of planet Y in terms of T.

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(b) Determine the orbital velocity of planet Y in terms of v.

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(c) How would your answers to (a) and (b) vary if planet Y had twice the mass of planet X? Justify your answer.

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(d) How would your answers to (a) and (b) vary if the mass of the star was double its present value? Justify your answer.

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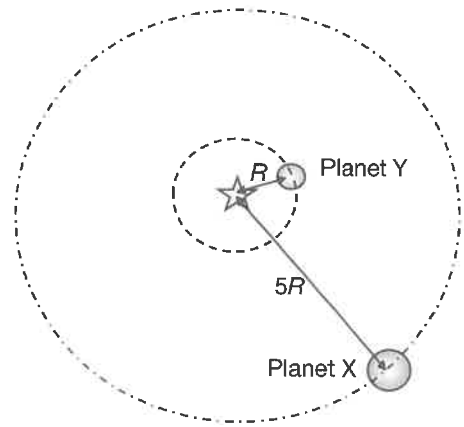
5.14.1.3 Planets X and Y orbit the same star. The mass of planet X is 4 times the mass of planet Y. The orbital radius of planet X is 5 times that of planet Y.



(a) What is the ratio of the orbital period of planet X to that of planet Y?

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(b) What is the ratio of the orbital velocity of planet X to that of planet Y. Justify your answer.

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(c) What is the ratio of the gravitational force between the star and planet X to that of planet Y? Justify your answer.

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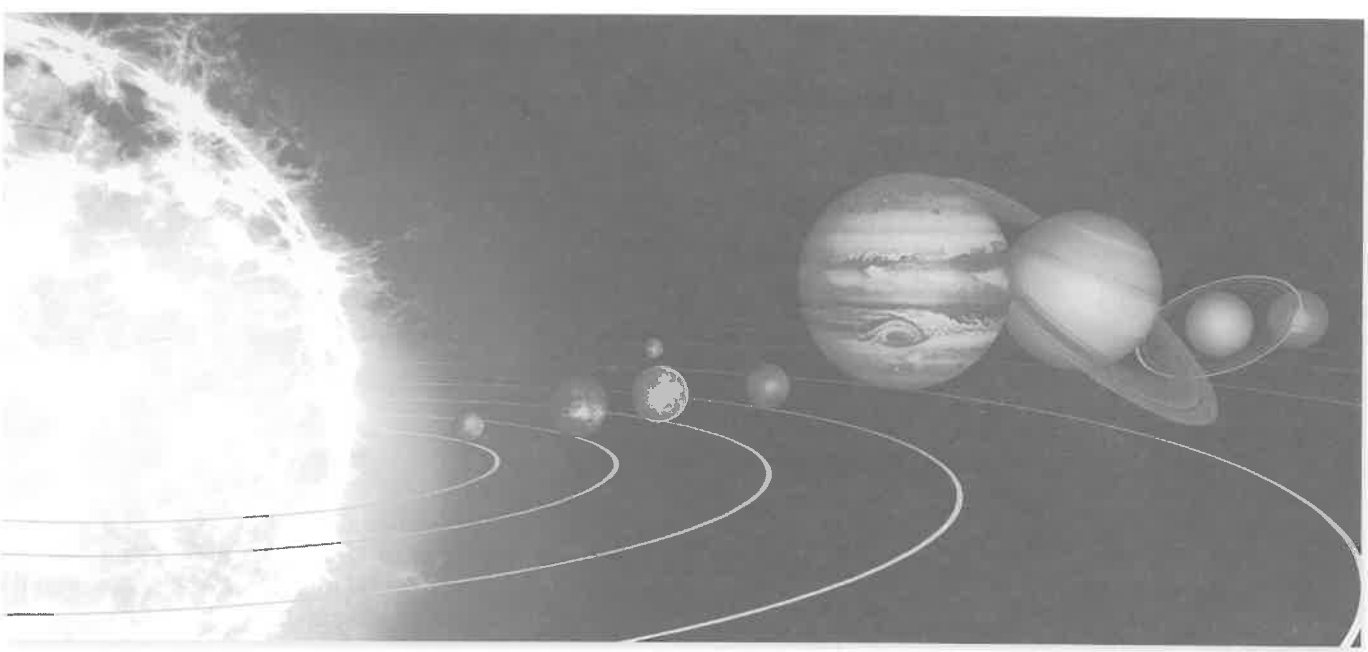

5.15 Investigate the relationship of Kepler's laws of planetary motion to the forces acting on, and the total energy of, planets in circular and non-circular orbits using: $v_o = \frac{2\pi r}{T}$ and $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$.

5.15.1 Applying Kepler's third law.

5.15.1.1

(a) State Kepler's first law of planetary motion.

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(b) State Kepler's second law of planetary motion.

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(c) State Kepler's third law of planetary motion.

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5.15.1.2 Calculate the orbital period of Deimos, one of the two moons of Mars. Its average distance from Mars is 23 400 km and its irregular shape averages about 13 km across. The mass of Mars is 6.42×10^{23} kg, and its diameter is 6794 km.

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5.15.1.3 Calculate the altitude of an Earth satellite with a period of 12 hours. The mass of Earth is 5.974×10^{24} kg.

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5.15.1.4 Jupiter has a mass of 1.9×10^{27} kg. Halley's Comet has a mass of about 7.5×10^{15} kg. What is the Kepler's law ratio of $\frac{R^3}{T^2}$ for Jupiter compared to that for Halley's Comet?

(A) 1 : 1
(B) About 2.5×10^{11} : 1
(C) About 1 : 2.5×10^{11}
(D) Is not calculable because Halley's Comet is not a planet.

5.15.1.5 The table gives information about four of the moons of the planet Uranus. Use Kepler's law of periods to calculate the missing data in the table.

Moon	Radius of orbit (km)	Orbital period (Earth days)
Miranda	A =	1.41
Ariel	190 900	B =
Titania	C =	8.71
Oberon	583 400	13.46

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5.15.1.6 Planet Q has a mass of 6×10^{24} kg and a diameter of 12 000 km. A satellite orbits planet Q in 90 minutes. What is the orbital altitude of the satellite?

(A) 6.61×10^2 km
(B) 6.66×10^6 km
(C) 2.96×10^{17} m
(D) 2.96×10^{20} km

5.15.1.7 Geostationary satellites orbit with a radius of 42 260 km. Use this information to find:

(a) The period of a satellite which orbits with a radius of 15 000 km.

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(b) The orbital radius of a satellite which has an orbital period of 4.0 hours.

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5.15.1.8

(a) Planet P has a mass of 4×10^{24} kg and a diameter of 10 000 km. A satellite orbits planet P at an altitude of 2000 km. What is the period of the satellite?

(A) 1.98 hours (B) 1.61 days
(C) 1.98 days (D) 1.61 years

(b) Would the period be doubled if the altitude of the satellite was 4000 km? Explain.

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5.15.1.9

(a) Kepler's law of periods, summarised in the equation $T^2 = kR^3$, shows the relationship between the orbital period and radius of a planet orbiting a star. Which of the following would result in a change in the value of the constant, k?

(A) A planet of different mass orbiting the same star.
(B) A planet of greater orbital radius.
(C) A planet of greater orbital period.
(D) An identical planet orbiting a different star.

(b) What did (and still does) Kepler's law of periods enable astronomers to do with much greater accuracy?

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5.15.1.10 The table gives information about two of the moons orbiting planet R.

Moon	Radius of orbit (km)	Orbital period (days)
X	100 000	2.0
Y	400 000	T

(a) What is the orbital period of moon Y?

(A) 1.4 days (B) 4.0 days
(C) 16 days (D) 32 days

(b) Is the altitude of moon Y four times that of moon X? Explain.

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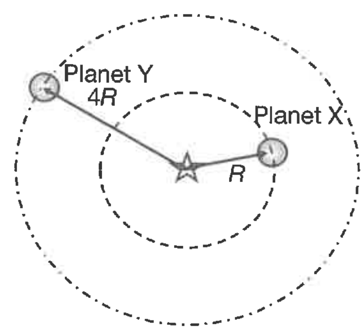
5.15.1.11 Two planets, X and Y orbit the same star as shown. Planet X completes one orbit around the star in time T. The radii of the orbits are in the ratio 1 : 4.

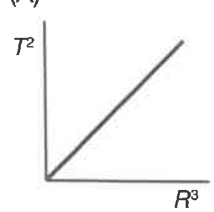


How many orbits does planet Y make in time T?

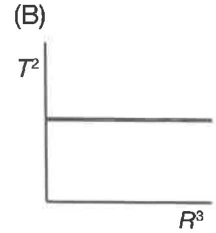
(A) $\frac{1}{8}$ (B) $\frac{1}{4}$ (C) 4 (D) 8

5.15.1.12 Which graph best shows the relationship between the square of the period of the planets (T^2) and the cube of their distance from the Sun, (R^3)?

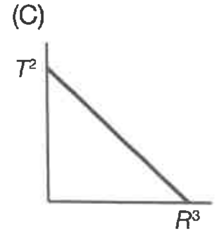
(A)



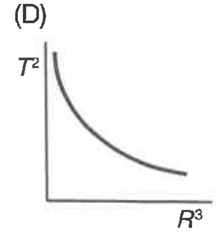
(B)



(C)



(D)



Circular Motion

5.16 Conduct investigations to explain and evaluate, for objects executing uniform circular motion, the relationships that exist between centripetal force, mass, speed and radius of turn.

INQUIRY QUESTION

Why do objects move in circles?

5.16.1 Uniform circular motion.

5.16.1.1

(a) What is the essential characteristic in physics for uniform circular motion? ....

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(b) Given this characteristic, how can we classify the force which keeps an object in uniform circular motion?

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5.16.1.2 A particle is performing uniform circular motion in a horizontal plane. Which statement regarding its motion is *incorrect*?

(A) The velocity vector is tangential to the circle.

(B) The acceleration vector is tangential to the circle.

(C) The acceleration vector is directed towards the centre of the circle.

(D) The velocity and acceleration vectors are perpendicular to each other.

5.16.1.3 A particle is performing uniform circular motion in a horizontal plane in a circular path of radius r and a uniform speed v. Which choice gives their correct tangential and radial acceleration respectively?

(A) Zero and zero

(B) $\frac{v^2}{r}$ and zero

(C) Zero and $\frac{v^2}{r}$

(D) $\frac{v^2}{r}$ and $\frac{v^2}{r}$

5.16.1.4 A particle moves in a circular path of radius r. What will be its displacement and distance covered in half a period?

(A) $2r$, $2\pi r$

(B) $\sqrt{2} \times r$, πr

(C) $2r$, πr

(D) r, πr

5.16.1.5 A particle is moving in a horizontal circle of radius 25 cm at 2 Hz. What will be the acceleration of the particle?

(A) π^2

(B) $2\pi^2$

(C) $3\pi^2$

(D) $4\pi^2$

5.16.1.6 A particle of mass 'm' moves in a circular horizontal path of radius r. The centripetal force acting on it is F. Which equation can be used to find its linear speed?

(A) $\sqrt{\frac{Fr}{m}}$

(B) $\sqrt{\frac{F}{mr}}$

(C) $\sqrt{\frac{F}{r}}$

(D) $\sqrt{\frac{mr}{F}}$

5.16.1.7 A tube of length L is filled completely with an incompressible liquid of mass M and closed at both the ends. The tube is rotated in a horizontal plane about one of its ends with a uniform velocity v. What will be the force the liquid in the tube exerts on the stopper at the outer end of the tube?

(A) $-\frac{mv^2}{r}$ (B) $\frac{mv^2}{r}$

(C) $-T$ (D) T

5.16.1.8 What is the angle between the radius and the direction of centripetal acceleration?

(A) Zero

(B) $\frac{\pi}{2 \text{ rad}}$

(C) π rad

(D) 2π rad

5.16.1.9 A stone is tied to one end of a string. Holding the other end, the string is whirled in a horizontal plane with progressively increasing speed. At some instant in time, the string breaks. Which choice best describes why this happens?

(A) The gravitational force of the Earth is greater than the tension in the string.

(B) The centripetal force is less than the tension in the string.

(C) The centripetal force is greater than the weight of the stone.

(D) The centripetal force is greater than the tension sustained by the string.

5.16.1.10 The angle described in 0.2 sec by an object rotating at a rate of 60 Hz is:

(A) 12 π rad

(B) 20 π rad

(C) 24 π rad

(D) 120 π rad

5.16.1.11 A satellite has mass m speed v and radius *r*. Which choice bests identifies the force(s) that act on it?

(A) Zero.

(B) The force of gravity and the centripetal force.

(C) Only the centripetal force.

(D) Only the gravitational force.

5.16.1.12 What is the angular speed of a flywheel making 180 revolutions per minute?

(A) 2π rad s^{-1}

(B) 4π rad s^{-1}

(C) 6π rad s^{-1}

(D) 360π rad s^{-1}

5.16.1.13 A car is moving on a circular path and takes a turn. If R_{inner} and R_{outer} are the reaction forces on the inner and outer wheels respectively, then which statement about these forces is correct?

(A) $R_{inner} = R_{outer}$

(B) $R_{inner} < R_{outer}$

(C) $R_{inner} > R_{outer}$

(D) $R_{inner} \geq R_{outer}$

5.16.1.14 A car is moving in a circular track of radius 10 metres with a constant speed of 10 m s^{-1}. A plumb bob is suspended from the roof of the car by a light string 1.0 m long.

(a) Find the angle made by the roof with the vertical. Include a vector diagram in your answer.

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(b) What is the tension in the string holding the bob?

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5.16.1.15 A coin on a rotating disc just begins to slip if its centre is at a distance of 16 cm from the centre of the disc. The angular velocity of the disc is then doubled. Where should the coin be placed now so that when the disc spins, the coin just begins to slip?

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5.17 Analyse the forces acting on an object executing uniform circular motion for cars moving around horizontal circular bends.

5.17.1 **Forces in circular motion.**

5.17.1.1

(a) A 2 tonne truck takes a horizontal curve on a level roadway at a speed of 18 m s^{-1}. The radius of the curve is 120 m. Determine the total frictional force required to keep the car on the curve.

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(b) Which way does the frictional force act? ....

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(c) Explain why the friction *must* act this way. ....

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5.17.1.2 A 1500 kg racing car goes around a circular track of radius 200 m at a constant speed of 270 km h^{-1}.

(a) Calculate the speed of the car in m s^{-1}. ....

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(b) Calculate the acceleration of the car. ....

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(c) What force holds the car to the road as it speeds around this corner? ....

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(d) Calculate the value of this force. ....

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(e) State the direction this force acts. ....

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(f) Predict the value of this force if the speed of the car was to halve. ....

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(g) Predict the value of this force if the speed of the car was to double. ....

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5.17.1.3 Two 60 kg boys on 20 kg bikes are riding at 15 m s^{-1} directly towards a wall which is 30 m from them. X continues towards the wall, but slams on his brakes applying a 400 N force. Y does not put on his brakes, but turns his bike with the same force in a circular path in the hope of not hitting the wall.

Analyse this information to determine whether or not the boys hit the wall.

5.17.1.4 A toy racing car of mass 150 g is racing around a circular track of diameter 80 cm. It takes 8.4 s to do one lap of the track. Calculate:

(a) The speed of the car.

(b) The acceleration of the car.

(c) The centripetal force acting on the car.

(d) What would be the new force on the car if its speed stayed the same but it was put onto a different track with double the diameter?

5.17.1.5

(a) Calculate the rotational speed (also called the linear or tangential speed) of a point on the surface of Earth at the equator in m s^{-1} and km h^{-1}.

(b) Use your answer to (a) to calculate the magnitude of the centripetal acceleration on the surface of the Earth at the equator.

(c) If the Earth was a perfect sphere, how would this affect the gravitational field of the Earth on the surface at the equator compared to the value at the poles? Justify your answer.

5.17.1.6 A driver makes a turn off a road at 12.0 m s^{-1}. The turning radius of the level curve is 56.0 m. If the car has a mass of 900 kg, determine:

(a) The acceleration of the car as it goes through the corner.

(b) The centripetal force acting on the car.

(c) The minimum frictional force between each tyre and the road to ensure that the car does not slide out of the corner.

5.17.1.7 A 1500 kg car takes a horizontal curve on a level roadway at a speed of 23 m s^{-1}. The radius of the curve is 65 m. Determine the total frictional force required to keep the car on the curve.

5.17.1.8 A 750 kg satellite orbits 400 km above the surface of the Earth at 7683 m s^{-1}.

(a) Using the formula for gravitational field strength, calculate the strength of the gravitational field at the position of this satellite.

(b) Using the formula for centripetal acceleration, calculate the acceleration of the satellite.

(c) Compare your answers to (a) and (b) and account for any similarity or difference.

(d) Using Newton's formula for gravitational force, calculate the gravitational force acting on the satellite.

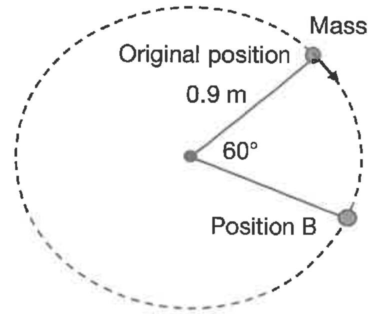
(e) Using the formula for centripetal force, calculate the centripetal force acting on the satellite.

(f) Compare your answers to (d) and (e) and account for any similarity or difference.

5.18 Analyse the forces acting on an object executing uniform circular motion for a mass on a string.

5.18.1 Circular motion on a string.

5.18.1.1 A mass of 3.0 kg lies on a perfectly smooth horizontal surface and is connected to a light string which is 1.2 m long as shown in the diagram. The mass completes 5 rotations per second.



(a) Calculate the linear speed of the mass.

(b) Find its angular velocity.

(c) Calculate the magnitude of the acceleration of the mass.

(d) Calculate the magnitude of the tension in the string.

(e) Calculate how long it takes the mass to move from its original position to position B.

(f) Draw a vector diagram in the space provided to determine the magnitude and direction of its acceleration as it moves from its original position to B.

(g) Compare your answers to (b) and (e).

5.18.1.2 A 5.0 kg mass on a 2.5 m long string is executing uniform circular motion in a horizontal plane. The frequency of its rotation is 3.0 Hz.

(a) What is the linear speed of the mass?

(b) What is its angular velocity?

(c) Calculate its centripetal acceleration.

(d) What is the tension in the string?

(e) What would be the tension in the string if the frequency of the rotation was doubled?

5.18.1.3 A mass on a 50 cm long string is executing uniform circular motion in a horizontal plane. The period of its rotation is 0.125 s. The tension in the string is 144 N.

(a) What is the frequency of rotation of the mass?

(b) What is its angular velocity?

(c) What is its linear speed?

(d) Calculate its centripetal acceleration.

(e) What is the magnitude of the mass?

5.19 Analyse the forces acting on an object executing uniform circular motion for objects on banked tracks.

5.19.1 Circular motion on a banked track.

5.19.1.1

(a) What is the smallest radius of an unbanked (flat) track around which a 70 kg motorcyclist riding a 150 kg bike can travel if her speed is 40 km h^{-1} and the friction between the tyres and the road is 0.25 N kg^{-1}?

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(b) What would be the maximum speed for this motorcyclist on the same track if it was banked at 25°?

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5.19.1.2 A train travels at a constant speed around a curve of radius 450 m. A lamp hanging on a light cord swings out to an angle of 12.0° while the train turns. Find the speed of the train. Use a vector diagram in your answer.

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5.19.1.3 Determine the minimum angle at which a road should be banked so that a car travelling at 28.0 m s^{-1} can safely negotiate the curve if its radius is 600 m.

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5.19.1.4 An airplane is flying in a horizontal circle at a speed of 550 km h^{-1}. Its wings are tilted 45° to the horizontal and force is provided by lift that is perpendicular to the wing surface. What is the radius of the circle?

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5.19.1.5 A jet fighter is flying around the airport with a speed of 1100 km h^{-1} along a circular path with a radius of 4 km.

(a) What acceleration is the pilot experiencing?

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(b) At what angle must the wings of the plane be banked?

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5.19.1.6 The curves at either end of the track at a velodrome have a radius of curvature of 60 m banked at 20°.

(a) What is the maximum speed a cyclist could take these curves?

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(b) If the maximum safe speed for a different velodrome track, same radius of curvature, was 85 km h^{-1}, at what angle would the end curves need to be banked?

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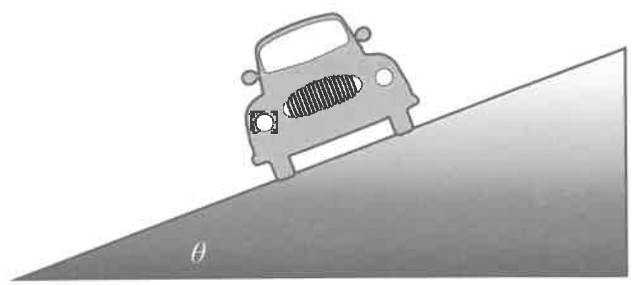
5.19.1.7 A car is driven around a circle with a radius of 80 m, and bank angle 30 degrees. Calculate the maximum safe velocity of the car if friction is negligible.

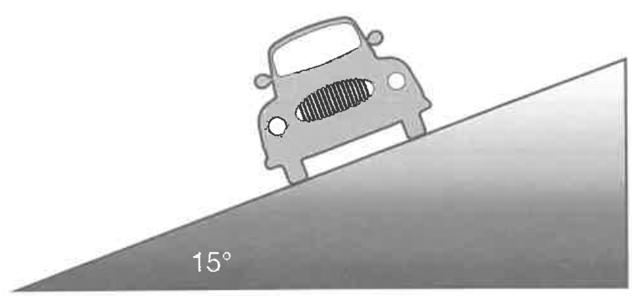
5.19.1.8 A curve has a radius of 510 metres and a banking angle of 9°. What is the maximum safe speed for a car on this curve?

5.19.1.9 A turn of radius 80 m is being designed for a maximum speed of 30 m s^{-1}. At what angle should the turn be banked?

5.19.1.10 A banked curved road has a radius of 60 m and a recommended maximum speed of 11.1 m s^{-1}. At what angle is this curve banked? Use the diagram to construct the vector diagram you will need to solve this problem.



5.19.1.11 A curve has a radius of 50 metres and a bank angle of 15°. What is the maximum speed that a car could negotiate this curve? Use the diagram to construct the vector diagram you will need to solve this problem.



5.20 Solve problems, model and make quantitative predictions about objects executing uniform circular motion in a variety of situations, using the relationships: $a = \frac{v^2}{r}$, $\Sigma F = \frac{mv^2}{r}$ and $\omega = \frac{\Delta\theta}{t}$.

5.20.1 Solving circular motion problems.

5.20.1.1 A 60 kg wheel is 120 m across and takes about 24 minutes to complete one revolution.

(a) What is the linear speed of the wheel?

(b) What is its angular velocity?

(c) What is its centripetal acceleration?

(d) What would be the centripetal force?

5.20.1.2 In an amusement park, a train travels in a horizontal circle of radius 35 m and completes one revolution every 8.0 s at its highest speed.

(a) What is the highest speed of the train?

(b) What is its maximum angular velocity?

(c) What is the acceleration of the students riding the train when it is travelling at its highest speed?

(d) What would be the centripetal force experienced by a 55 kg passenger on the train?

5.20.1.3 A 300 g mass on a 1.2 m long string is rotating at 13 m s^{-1}.

(a) What is its angular velocity?

(b) What will be its centripetal acceleration?

(c) What will be the tension in the string?

5.20.1.4 A 1200 kg car takes a horizontal curve on a level roadway at a speed of 25 m s^{-1}. The radius of the curve is 70 m. Determine:

(a) Its angular velocity.

(b) The total frictional force required to keep the car on the curve.

5.20.1.5 A driver makes a turn off a road at 15.0 m s^{-1}. The turning radius of the level curve is 42.0 m. If the car has a mass of 800 kg, determine:

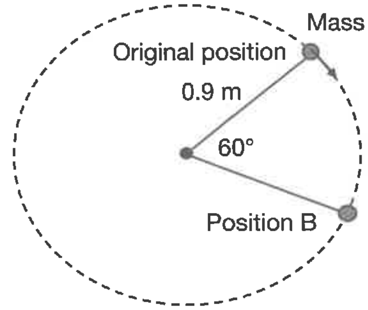
(a) The angular velocity of the car.

(b) The acceleration of the car as it goes through the corner.

(c) The centripetal force acting on the car.

(d) The minimum frictional force between each tyre and the road to ensure that the car does not slide out of the corner.

5.20.1.6 A mass of 4.0 kg lies on a perfectly smooth horizontal surface and is connected to a light string which is 0.9 m long as shown in the diagram. The mass completes 5 rotations per second.



(a) Find the angular velocity of the mass. ....

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(b) Calculate the linear speed of the mass. ....

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(c) Calculate the magnitude of the acceleration of the mass. ....

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(d) Calculate the magnitude of the tension in the string. ....

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(e) Calculate how long it takes the mass to move from its original position to position B. ....

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(f) Draw a vector diagram to determine the magnitude and direction of its acceleration as it moves from its original position to B.

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(g) Compare your answers to (c) and (f).

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5.20.1.7 An 50 kg ice skater is spinning on one skate making 2 revolutions per second. With her arms stretched out, the radius of the rotation is 150 cm.

(a) What is the angular velocity of her fingertips?

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(b) What is the linear speed of the fingertips?

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(c) What is their centripetal acceleration?

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5.20.1.8 A 2 kg ball on a string is rotated about a circle of radius 10 m. The maximum tension allowed in the string is 50 N. What is the maximum speed of the ball?

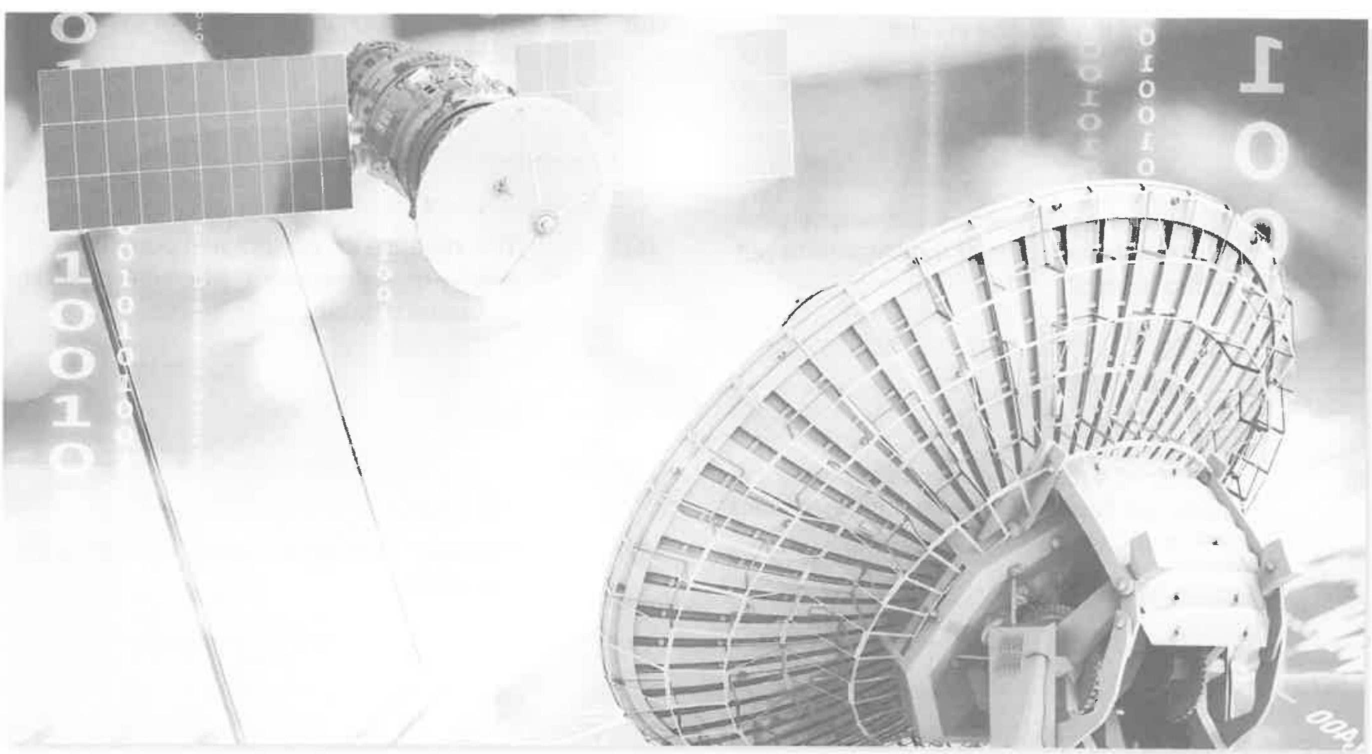
5.20.1.9 During the course of a turn, an automobile doubles its speed. How much additional frictional force must the tyres provide if the car safely makes it around the curve?

5.20.1.10 A satellite is said to be in geosynchronous orbit if it rotates around the Earth once every day (say 23.93 hours). For the Earth, all satellites in geosynchronous orbit must rotate at a distance of 4.22×10^4 km from the Earth's centre.

(a) What is the angular velocity of a geosynchronous satellite?

(b) What is the linear speed of this satellite?

(c) What is the magnitude of the gravitational field acting on a geosynchronous satellite?



5.21 Investigate the relationship between the total energy and work done on an object executing uniform circular motion.

5.21.1 Total energy of a satellite and work done.

5.21.1.1 A satellite is in orbit above the surface of a planet at an altitude of r metres. The mass of the planet is M kg, the mass of the satellite is m kg, and the radius of the planet is R metres.

(a) Write an equation you could use to find the gravitational potential energy of the satellite on the surface of the planet before it is launched.

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(b) Write an equation you could use to find the gravitational potential energy of the satellite in orbit above the surface of the planet.

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(c) Write an equation we can use to find the orbital kinetic energy of the satellite in orbit.

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(d) Use these equations to find the total energy of the satellite in orbit.

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(e) Use these equations to find the total work done by the engines of the satellite to put it into its orbit.

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(f) Explain the reason for the difference between the work done to put the satellite into orbit and its total energy.

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5.21.1.2 The Hubble Telescope has a mass of 11 110 kg and orbits the Earth at an altitude of 540 km. Taking the mass of Earth as 6×10^{24} kg and its radius as 6380 km, find:

(a) The gravitational potential energy of the telescope in orbit.

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(b) The orbital velocity of the telescope.

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(c) The kinetic energy of the orbiting telescope.

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(d) The total mechanical energy of the orbiting telescope.

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(e) The increase in gravitational potential energy of the telescope when it is raised to its orbital altitude.

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(f) The total work done putting the telescope into orbit.

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5.21.1.3 A satellite of mass 750 kg orbits the Moon at an altitude of 300 km. Given the diameter of the Moon as 3470 km and its mass as 7.35×10^{22} kg, find:

(a) Its gravitational potential energy.

(b) Its orbital velocity.

(c) Its kinetic energy.

(d) Its total mechanical energy.

(e) The increase in gravitational potential energy of the satellite when it is raised to its orbital altitude.

(f) The total work done putting the satellite into orbit from the surface of the Moon.

5.21.1.4 A satellite of mass 500 kg orbits Mars at altitude of 300 km. Given the diameter of Mars as 6790 km and its mass as 6.42×10^{23} kg, find:

(a) Its gravitational potential energy.

(b) Its orbital velocity.

(c) Its kinetic energy.

(d) Its total mechanical energy.

(e) The increase in gravitational potential energy of the satellite when it is raised to its orbital altitude.

(f) The total work done putting the satellite into orbit from the surface of Mars.

5.22 Investigate the relationship between the rotation of mechanical systems and the applied torque: $\tau = rF_{\perp} = rF \sin \theta$.

5.22.1 **Rotational torque.**

5.22.1.1 What is torque and what are the units used to measure it? ....

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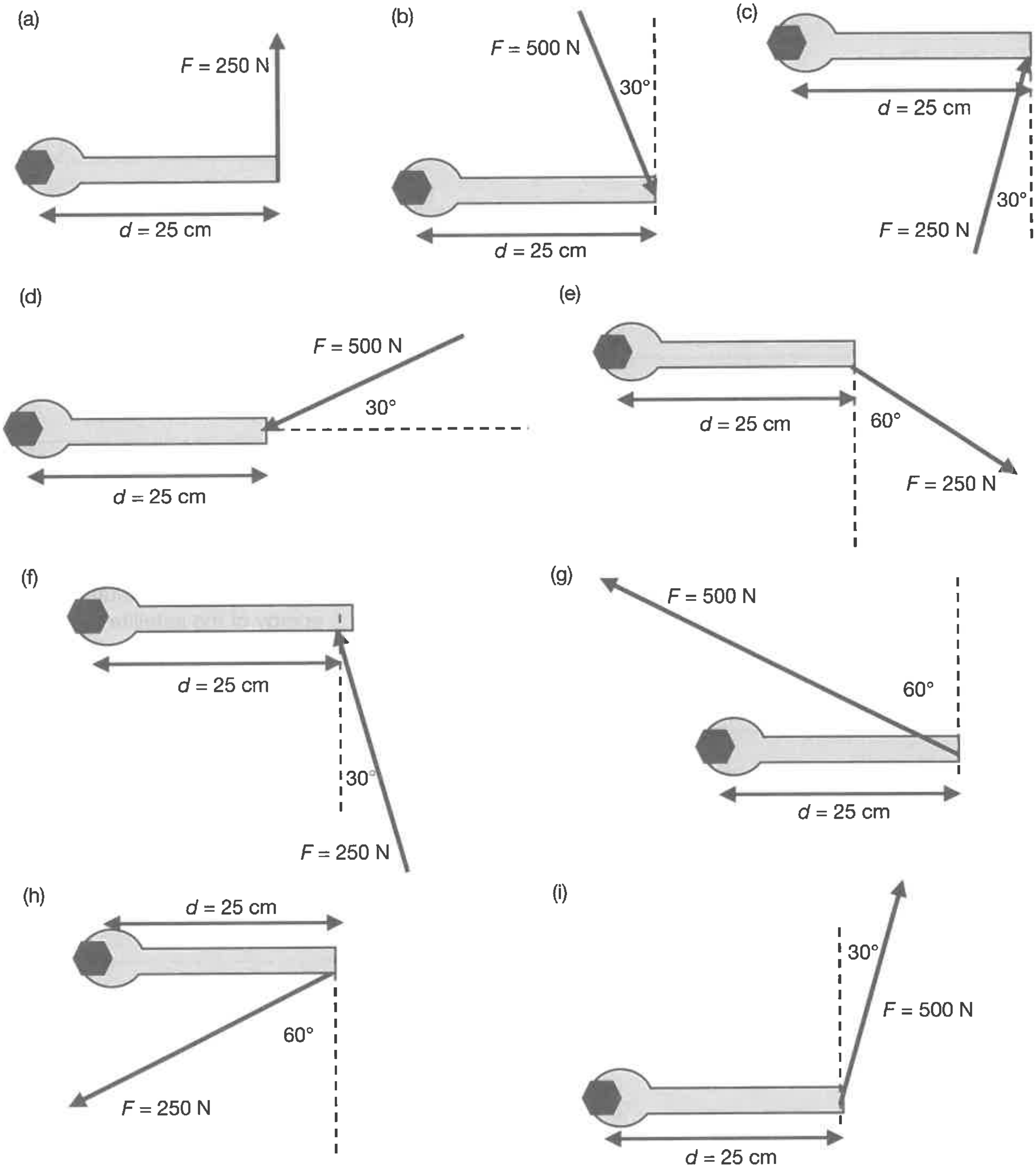
5.22.1.2 A number of wrenches of different lengths are used to tighten a hexagonal nut as shown. Calculate the torque applied relative to the centre of each nut.



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DOT POINT

MODULE 6

Electromagnetism

In this module you will:

- Develop and evaluate questions and hypotheses for scientific investigation.
- Design, evaluate and conduct investigations in order to obtain valid and reliable primary and secondary data and information.
- Select and process qualitative and quantitative data and information using a range of media.
- Explain and analyse the electric and magnetic interactions due to charged particles and currents and evaluate their effect both qualitatively and quantitatively.
- Understand the similarities and differences in the interactions of single charges in electric and magnetic fields.
- Study the force produced on a current carrying wire in a magnetic field, the force between current carrying wires, Faraday's law of electromagnetic induction, the principles of transformers the workings of motors and generators and the role of the law of conservation of energy in these interactions.
- Engage with all the Working Scientifically skills for practical investigations involving the focus content to examine trends in data and to solve problems related to electromagnetism.

Notes

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Charged Particles, Conductors and Electric and Magnetic Fields

6.1 Investigate and quantitatively derive and analyse the interaction between charged particles and uniform electric fields, including the electric field between parallel charged plates: $E = -\dfrac{V}{d}$.

INQUIRY QUESTION

What happens to stationary and moving charged particles when they interact with an electric or magnetic field?

6.1.1 Electric field between parallel plates.

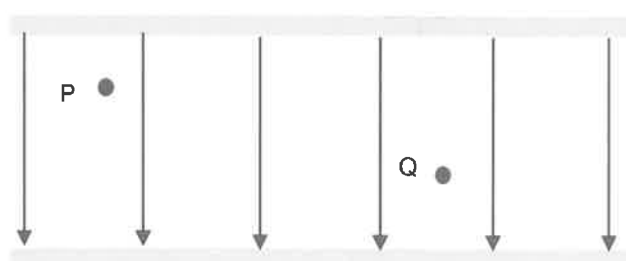
6.1.1.1

(a) Describe the nature of the field between two parallel plates.

(b) How do we represent this field by vector arrows?

(c) Explain how we represent the relative strength of this field.

6.1.1.2 The diagram shows the electric field lines between two parallel plates and two positions, P and Q between them. A charge of $+3.2 \times 10^{-10}$ C is placed at point P.



(a) Identify the positive plate.

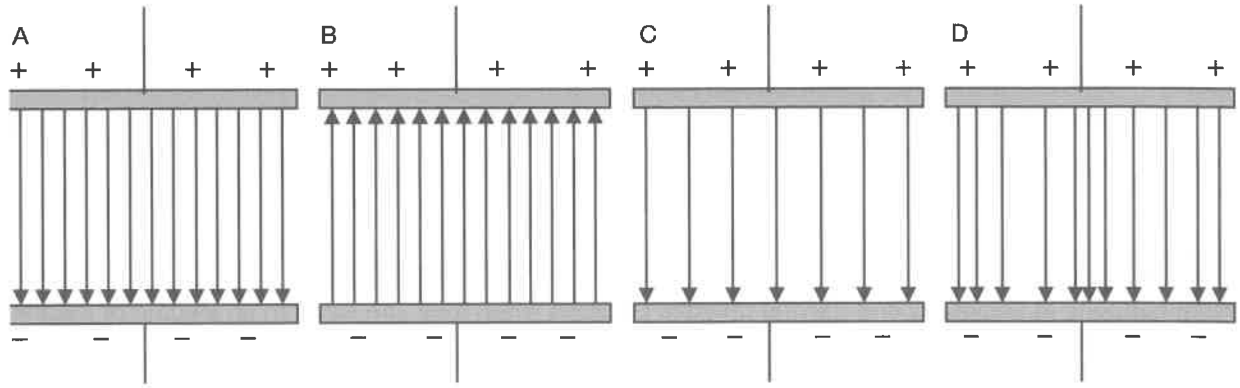
(b) Describe what happens to the charge at P.

(c) The charge is moved from P to Q. Identify any changes to the force on it. Justify your answer.

(d) In moving from P to Q, is any work done on the charge? If so, identify the source of the work.

(e) If a similar, but negative charge was moved from P to Q, identify the change in the force acting on it and the work done (if any). Explain your answer.

6.1.1.3 The diagrams show electric field lines drawn between four sets of parallel plates.



(a) Identify the correct diagrams and justify your answer. ....

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(b) Identify the plates which show uniform fields. Justify your answer. ....

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(c) Identify the strongest, correct electric field and justify your choice. ....

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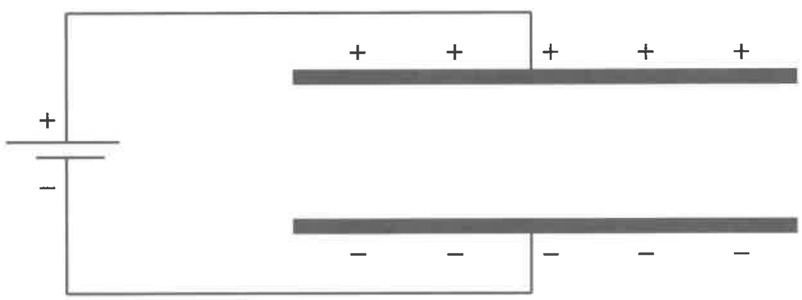
6.1.1.4

(a) Using appropriate vectors, complete the diagram to show the shape, intensity and direction of the electric field between the pair of charged, parallel plates.



(b) Explain each property of the vectors you have drawn.

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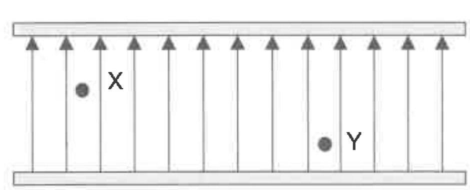
6.1.1.5 Which statement about the strength of the electric field at X and Y is correct?

(A) The field at X is stronger than the field at Y.
(B) The field at Y is stronger than the field at X.
(C) The fields at X and Y are of equal strength.
(D) We need to know the distance between X and Y in order to determine this.



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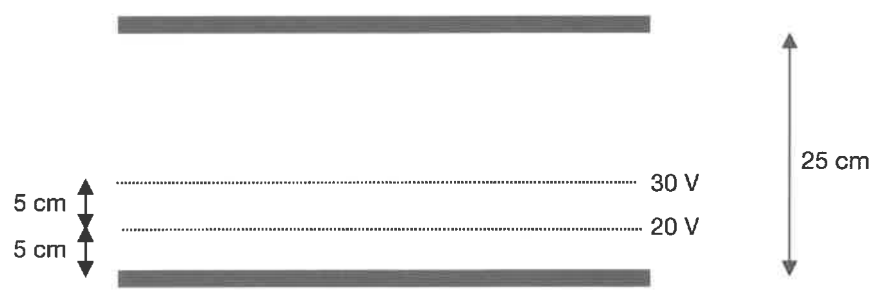
6.1.1.6 Two parallel electrically charged plates have a potential difference of 400 V and an electric field of 8.0×10^3 V m^{-1} between them. Determine how far apart they are.

6.1.1.7 Two parallel electrically charged plates have a potential difference of 250 V and an electric field of 5.0×10^5 V m^{-1} between them. Determine how far apart they are.

Use the following information to answer the next FOUR questions

The diagram shows two equipotential lines 5.0 cm apart, and 5 cm from the bottom plate between two charged, parallel plates. The plates are 25 cm apart.



6.1.1.8 According to the information in the diagram, what is the potential of the bottom plate?

(A) −10 V
(B) 0 V
(C) 10 V
(D) Unable to be determined with this data.

6.1.1.9 What is the potential of the top plate?

(A) 50 V
(B) 60 V
(C) 70 V
(D) Unable to be determined with this data.

6.1.1.10 What is the strength of the electric field between the plates?

(A) 150 V m^{-1}
(B) 200 V m^{-1}
(C) 250 V m^{-1}
(D) Unable to be determined with this data.

6.1.1.11 What is the potential difference between the plates?

(A) 40 V
(B) 50 V
(C) 60 V
(D) Unable to be determined with this data.

6.1.1.12 Two parallel plates have a potential difference of V volts across them. They are 2.5 cm apart. At point X, midway between the two plates, the strength of the electric field is E N C^{-1}.

(a) What will be the strength of the electric field at point P, 0.5 cm from the positive plate?

(b) What will be the strength of the electric field at point Q, 0.75 cm from the negative plate?

(c) What will be the strength of the field at point P if a charge of 6.0×10^{-8} C is placed there?

(d) What will be the strength of the field at point Q if a charge of 4.0×10^{-8} C is placed there?

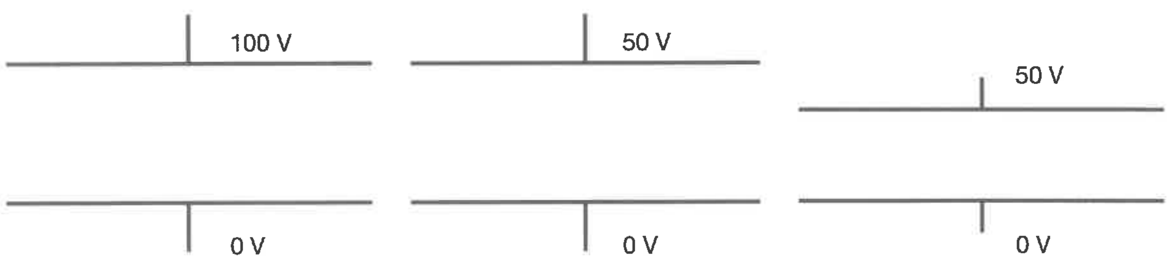
(e) What will be the ratio of the forces acting on a charge if 2.0×10^{-8} C is placed at P and at Q?

(f) What will be the strength of the electric field at point P if the voltage across the plates is doubled?

(g) What will be the strength of the electric field at point P, if the distance between the plates is halved?

(h) What will be the strength of the electric field at point Q, if the distance between the plates is doubled?

6.1.1.13 Draw field lines to represent the electric field between the three sets of parallel plates.



6.1.1.14 The electric field between two parallel plates is E V m^{-1}. Predict the new field if:

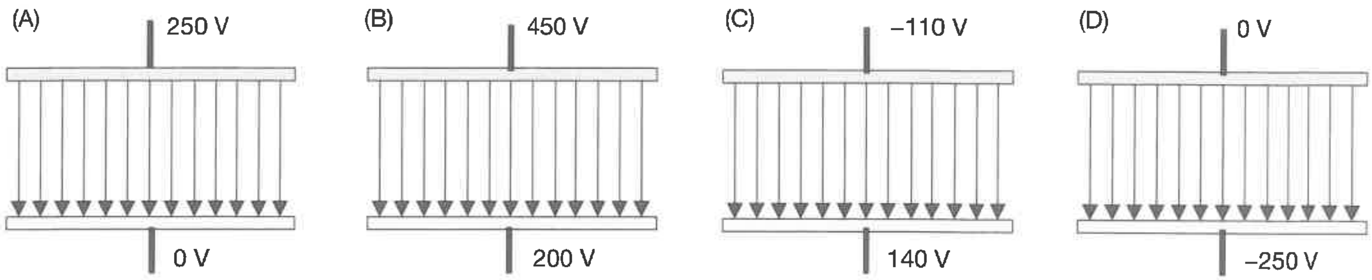
(a) The distance between the plates is doubled.

(b) The voltage across the plates is tripled.

(c) The distance between the plates is doubled and the voltage across them halved.

(d) The charge on a particle placed between the plates is doubled.

6.1.1.15 Consider the four pairs of charged parallel plates below. Each pair of plates is separated by 10 mm of air.



(a) Calculate the strength of the electric field between each pair of parallel plates. ....

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(b) Explain the similarity of your answers. ....

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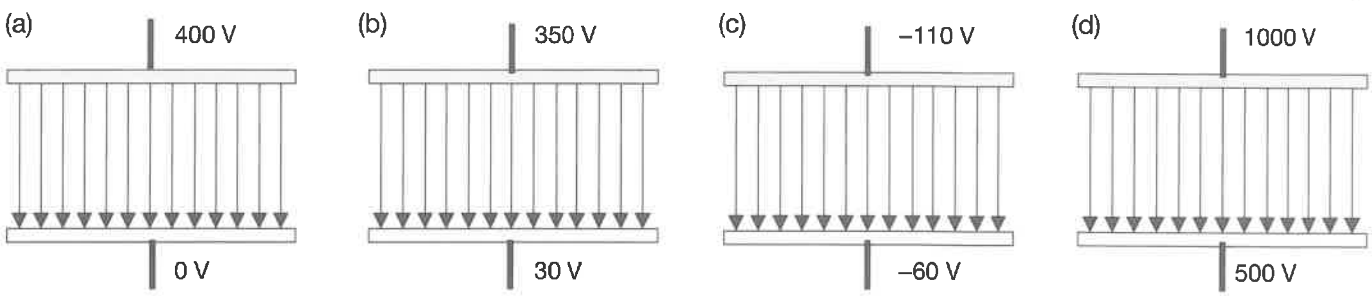
6.1.1.16 Consider the four pairs of charged parallel plates below. Each pair of plates is separated by 10 mm of air.



Calculate the strength of the electric field between each pair of parallel plates. ....

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6.2 Investigate and quantitatively derive and analyse the interaction between charged particles and uniform electric fields, including acceleration of charged particles by the electric field: $F = ma$, $F = qE$.

6.2.1 Interaction between charged particles and uniform electric fields.

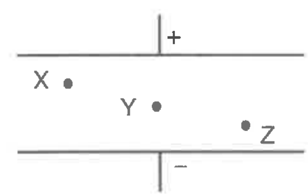
6.2.1.1 A charge of 4.2 μC experiences a force of 1.36 mN when it is placed in between two parallel charged plates which have a potential difference of 300 V across them.

(a) Calculate the magnitude of the electric field between the plates.

(b) Determine the distance between the plates.

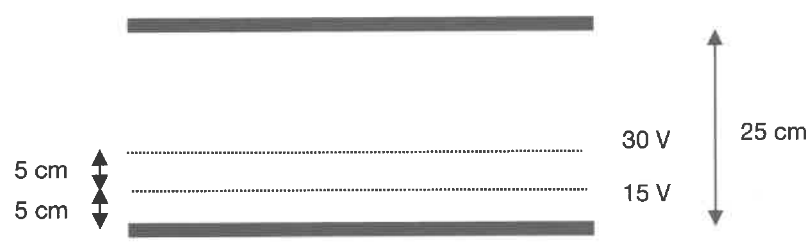
(c) If the charged particle has an acceleration of 1.2×10^6 m s^{-2}, what is its mass?

6.2.1.2 The diagram shows three identically charged particles in an electric field between two plates. Which statement about the forces acting on these charges due to the electric field is correct?



(A) $F_X > F_Y > F_Z$
(B) $F_X > F_Z$, and $F_Z = 0$
(C) $F_Z > F_Y > F_X$
(D) $F_X = F_Y = F_Z$

6.2.1.3 What force would act on an electron placed midway between the plates shown in the diagram?

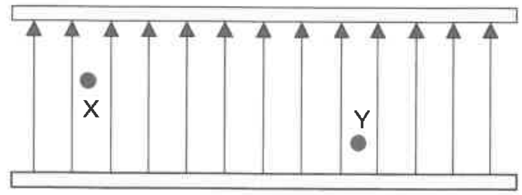


(A) 9.6×10^{-18} N towards the bottom plate.
(B) 9.6×10^{-18} N towards the top plate.
(C) 3.2×10^{-17} N towards the bottom plate.
(D) 3.2×10^{-17} N towards the top plate.

6.2.1.4 A charge of 8 mC experiences a force of 2.0×10^{-5} N when it is placed between two parallel plates. What is the strength of the electric field where the charge is?

(A) 4.0×10^{2} N C^{-1}
(B) 2.5×10^{-3} N C^{-1}
(C) 4.0×10^{-3} N C^{-1}
(D) 1.6×10^{-8} N C^{-1}

6.2.1.5 Consider two points X and Y in an electric field between two parallel plates as shown.



Which statement about the strength of the force acting on a charge placed at X and Y is correct?

(A) The force at X is stronger than the force at Y.

(B) The force at Y is stronger than the force at X.

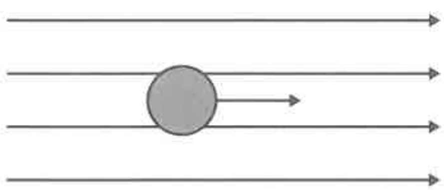
(C) The forces at X and Y are of equal strength.

(D) We need to know the distance between X and Y in order to determine this.

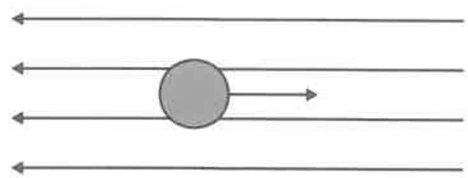
6.2.1.6

(a) The diagrams show charges placed in electric fields. Which diagrams show the correct direction of the forces acting on the charges due to the electric fields?

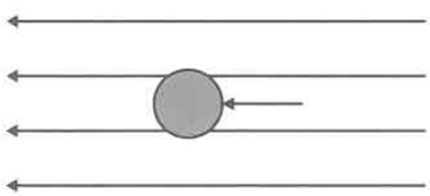
(A)



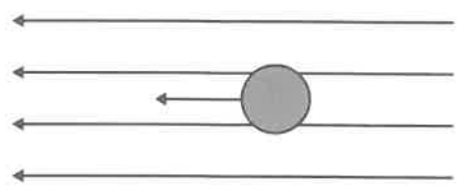
(B)



(C)



(D)



(b) Do these diagrams represent fields around charged particles? Justify your answer. ....

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(c) Describe the motion of a charged particle in an electric field like those above. Justify your answer.

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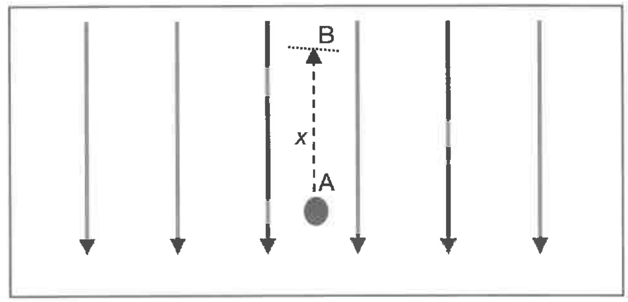
6.3 Investigate and quantitatively derive and analyse the interaction between charged particles and uniform electric fields, including the work done on the charge: $W = qV$, $W = qEd$, $K = \frac{1}{2}mv^2$.

6.3.1 Work done by electric fields.

6.3.1.1 Imagine that a positive charge is moved from point A to point B, distance x metres, in an electric field as shown in the diagram.



(a) Write an expression for the work done on the charge in moving from A to B in terms of the applied force and the distance it moves.

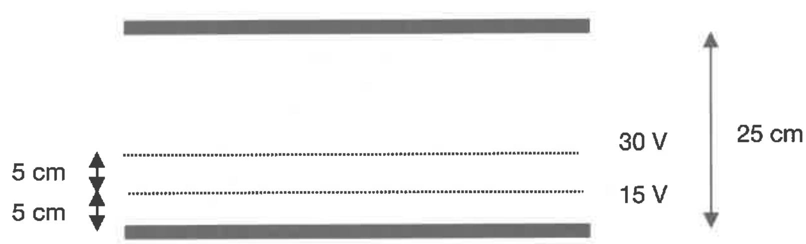
(b) Write an expression for the work done on the charge in terms of the charge and the potential through which it moves (V).

(c) Write an expression for the force applied to the charge to do this work in terms of the charge and the electric field strength.

(d) Combine your equations to derive an expression for the strength of the electric field in terms of the potential and distance through which the charge moves.

(e) State the units used to measure electric field.

6.3.1.2 The diagram shows two equipotential lines 5.0 cm apart between two charged parallel plates. The plates are 25 cm apart.



How much work would need to be done to move an electron from the 15 V line to the 30 V line?

(A) 8.0×10^{-19} J

(B) 2.4×10^{-18} J

(C) 3.6×10^{-18} J

(D) 4.8×10^{-18} J

6.3.1.3 A negative point charge at point X midway between two oppositely charged parallel plates moves at constant speed to point Y also midway between the plates. Which statement is correct?

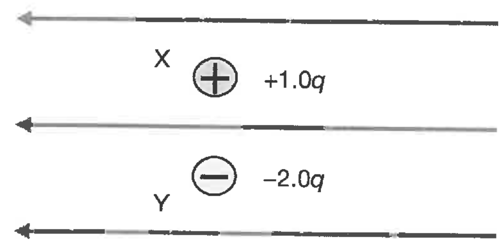
(A) The work done in moving X is zero.

(B) Work needs to be done on X to move it.

(C) The field does work on X when it moves.

(D) Work will have to be done on X by an external force.

6.3.1.4 The diagram shows two charges, X equal to 1.0q, and Y, equal to 2.0q, in an electric field which is directed from the right to the left.



(a) If left undisturbed, what will happen to each of these charges?

....

....

(b) Identify if work needs to be done, and by what, if X is moved to the left.

....

(c) Identify if work needs to be done, and by what, if X is moved to the right. ....

....

(d) Identify if work needs to be done, and by what, if Y is moved to the left. ....

....

(e) Identify if work needs to be done, and by what, if Y is moved to the right. ....

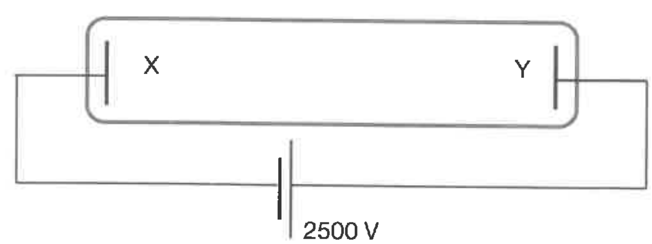
....

(f) In each case in (b) to (e) above, compare the amounts of work needed to be done on X compared to Y.

....

....

6.3.1.5 The diagram represents a cathode ray tube. Each second, 5×10^{18} electrons cross the evacuated gap between X and Y.



(a) What is the direction of the electric field inside the cathode ray tube? Justify your answer.

....

....

(b) What current flows through the circuit which includes the cathode ray tube? ....

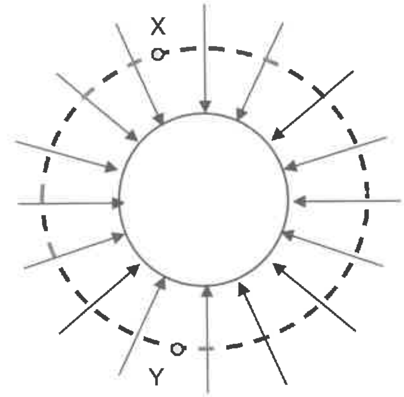
....

(c) How much work is done by the power supply each second? ....

....

....

6.3.1.6 The diagram shows the electric field around a charge, and an 'equipotential line' (the dotted circle) drawn around the charge. The electric potential at any point on an equipotential line is the same as the electric potential at any other point on the line.



A charge is moved along the equipotential line from point X to point Y on this equipotential line. Which of the following statements is true?

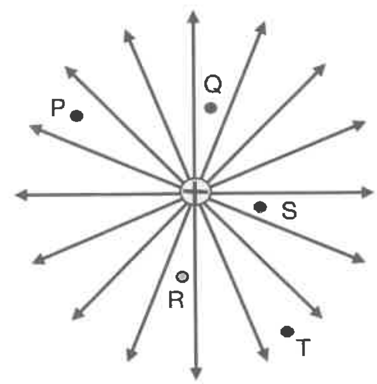
(A) Work is done whenever a charge is moved along an equipotential line.

(B) No work is required to move a charge along an equipotential line.

(C) Equipotential lines are parallel to field lines.

(D) Equipotential lines are at various angles to field lines depending on their position relative to the charge.

6.3.1.7 Consider the diagram which shows several points (P, Q, R, S and T) in the electric field around a positive point charge.



(a) At which point near the charge would the electric field be weakest?

....

....

(b) Compare the work needed to move identical positive charges from R to S and from R to T. Justify your answer.

....

....

....

....

....

(c) Imagine a positive test charge brought from infinity to each point near this charge. Which point would require the most work done on the test charge?

....

(d) In talking to students about this situation, a teacher said that no work needs to be done to move a positive test charge from R to S.

(i) Assess this statement. ....

....

....

(ii) Would the same statement hold if the test charge was negative? Justify your answer.

....

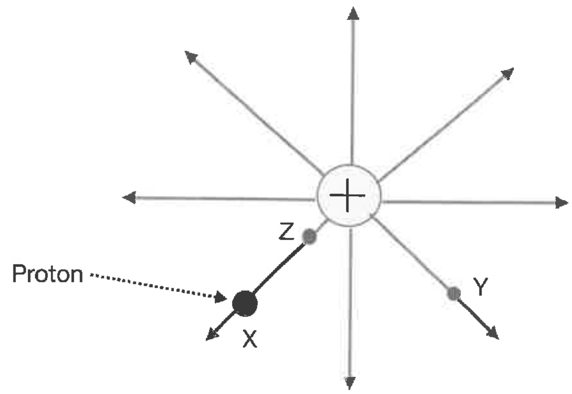
6.3.1.8 An electron is accelerated through a cathode ray tube device by a potential of 3500 V. Calculate the kinetic energy of the electron, in joules and electron volts, just before it hits the screen.

....

....

....

6.3.1.9 A proton is at point X in an electric field near a point positive charge as shown in the diagram. Points Y and Z are other points in the field. Y is the same distance from the charge as X, but Z is much closer to the charge. As the proton moves from X to Z, the field does 3.2×10^{-17} J of work on it.



(a) Calculate the potential difference between X and Z.

....

....

....

(b) Determine the potential difference between Y and Z.

....

(c) Determine the potential difference between X and Y. ....

6.3.1.10 During a storm a lightning strike transferred 200 C of charge from a cloud to the ground through a potential difference of 1.8×10^6 V.

(a) Determine the energy carried by the lightning strike. ....

....

....

(b) If this energy was input to a 5 tonne truck, what speed would it reach? ....

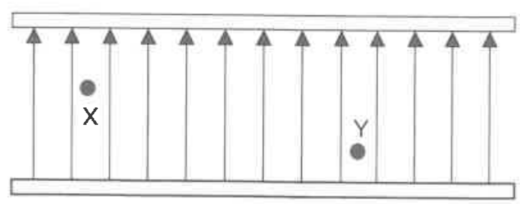
....

(c) Determine the mass of water at 20°C this amount of energy would boil. ....

....

....

6.3.1.11 The diagram shows the electric field between two parallel plates and two positions X and Y, between them. A charge of -8.0×10^{-18} C is placed at point X.



(a) Identify the positive plate. Justify your answer.

....

....

(b) Predict the direction of the force on the charge. Justify your answer. ....

....

(c) The charge is moved from X to Y. Identify any changes to the force on it. Justify your answer.

....

(d) In moving from X to Y, is any work done on the charge? If so, identify the source of the work.

....

....

(e) If a similar, but positive charge was moved from X to Y, identify the change in the force acting on it. Explain your answer.

....

....

6.3.1.12 The electric field plates of an oscilloscope are 5.0 mm apart and have a potential difference of 20 V across them.

(a) What is the strength of the electric field between the plates?

(b) Describe the motion of an electron released from the negative plate and travelling to the positive plate.

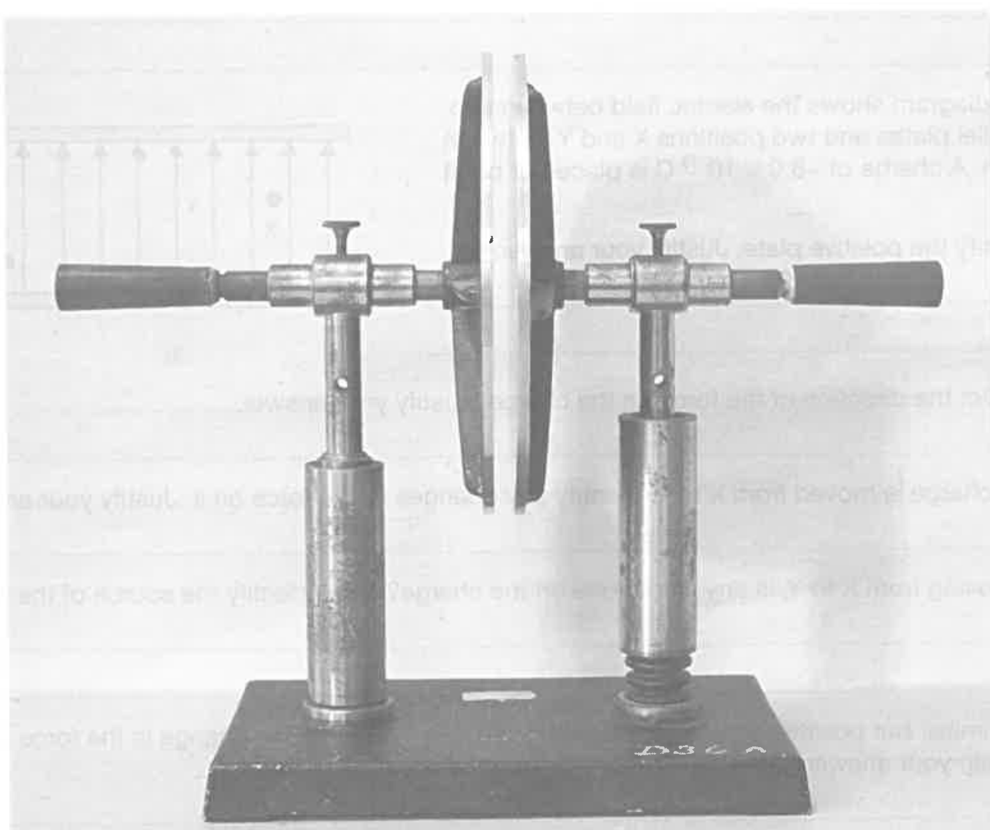
(c) What will be the force on this electron?

(d) What will be its acceleration?

(e) What work will the field do on this electron?

(f) With what speed will the electron reach the positive plate?

(g) How would your answers to (b) to (f) be different if the charge used was a proton rather than an electron?



6.4 Model qualitatively and quantitatively the trajectories of charged particles in electric fields and compare them with the trajectories of projectiles in a gravitational field.

INQUIRY QUESTION

Under what circumstances is a force produced on a current carrying conductor in a magnetic field?

6.4.1 Shapes of trajectories.

6.4.1.1

(a) Describe the shape of the path taken by a charged particle fired horizontally into an electric field between two parallel plates.

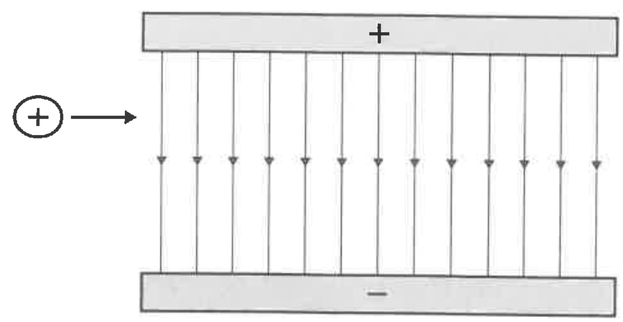
....

(b) Explain, in terms of the forces acting, why this path is this shape. ....

....

....

(c) Complete the diagram to show the shape of this path for a positively charged particle fired into the field shown.



6.4.1.2

(a) Describe the shape of the path taken by a projectile in a gravitational field. ....

....

(b) Explain, in terms of the forces acting, why this path is this shape. ....

....

....

(c) Complete the diagram to show the shape of this path for a projectile fired horizontally into the field shown below.

6.5 Analyse the interaction between charged particles and uniform magnetic fields, including the acceleration, perpendicular to the field, of charged particles.

6.5.1 Moving charges in a magnetic field 1.

6.5.1.1 Describe the motion of a charged particle in a magnetic field. ....

....

6.5.1.2 Justify the equality of these two equations: $F = Bqv \sin\theta = \frac{mv^2}{r}$. ....

....

....

....

6.5.1.3 Recall three ways the force on a charge moving through a magnetic field might be increased.

....

6.5.1.4

(a) Compare the force acting on a proton and an electron fired at equal speeds, in the same direction, into a magnetic field. Justify your answer.

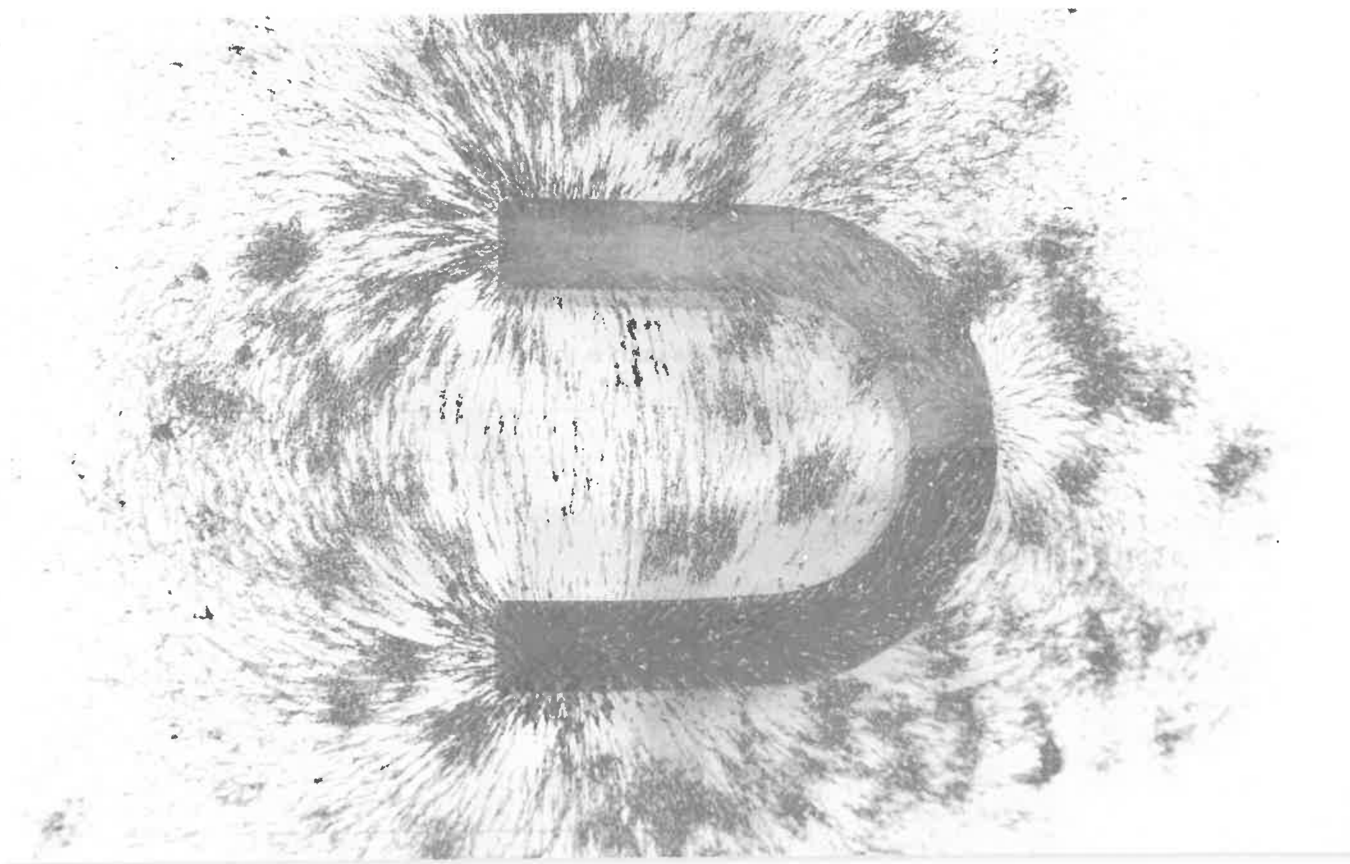
....

....

....

(b) Compare the forces if the direction of travel of the particles was opposite. Justify your answer.

....



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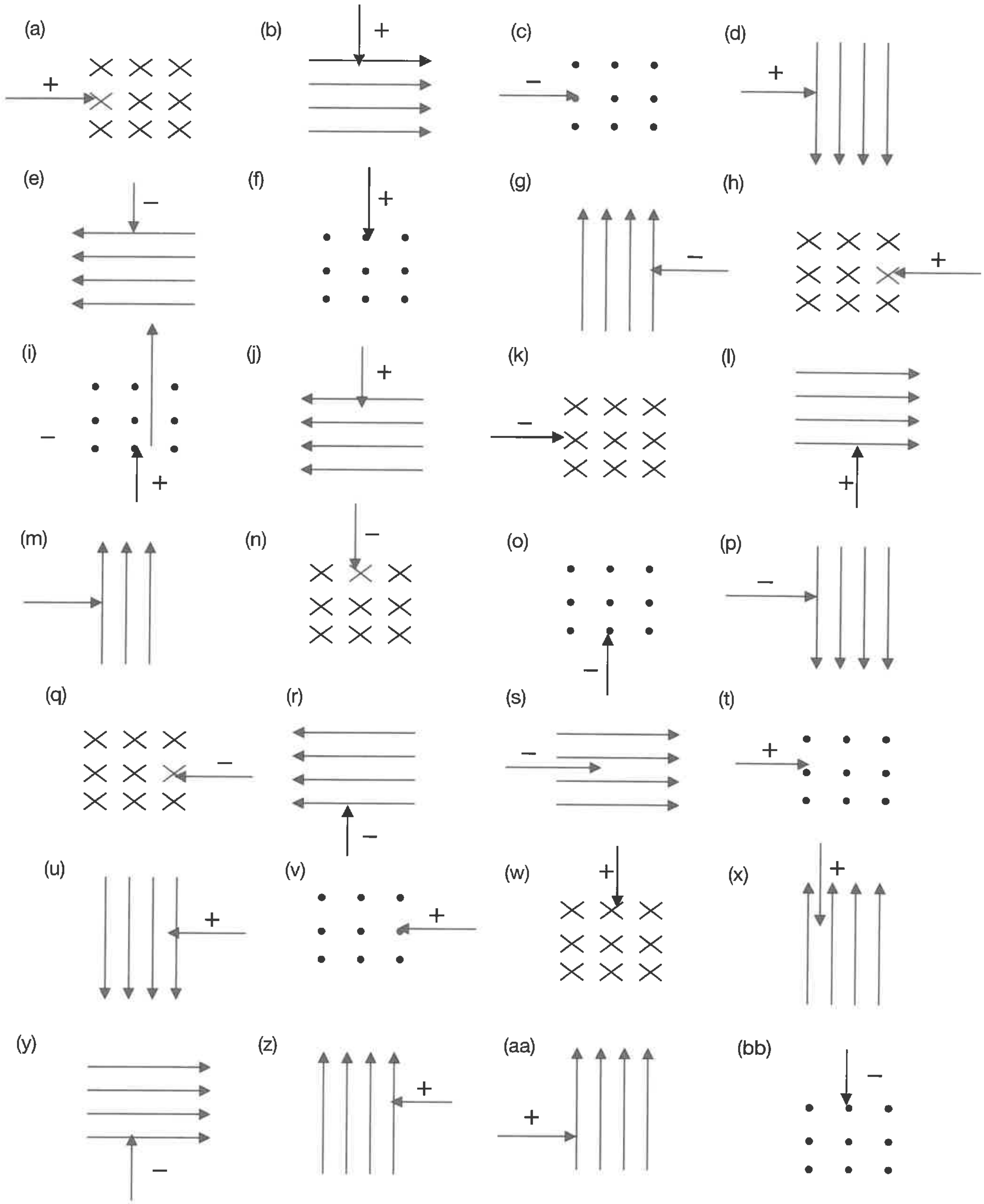
6.5.1.5 Use the right hand palm rule (or any other relevant rule you may have learnt) to determine the direction of the electromagnetic force on each of the charges moving into the magnetic fields shown below. The charges are represented by the arrows which are labelled (+) or (–).



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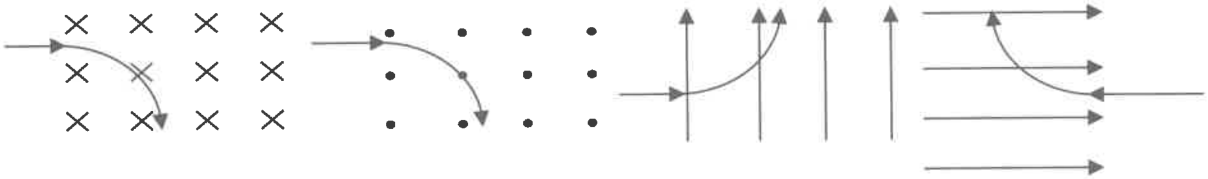
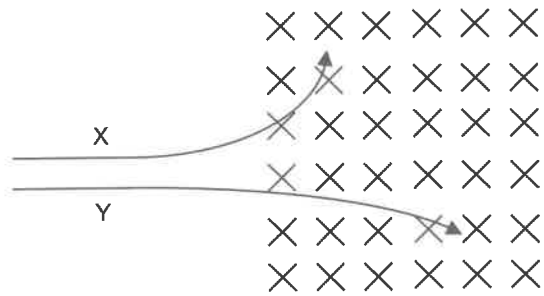
6.5.2 Moving charges in a magnetic field 2.

6.5.2.1 Which diagram correctly shows the path taken by a negatively charged particle in a magnetic field?

(A) (B) (C) (D)



6.5.2.2 The diagram shows two particles entering and travelling through a magnetic field.



(a) Predict the sign of each charge. Justify your answer.

....

....

....

....

(b) Give four possible reasons for the difference in the radius of curvature of each particle.

....

....

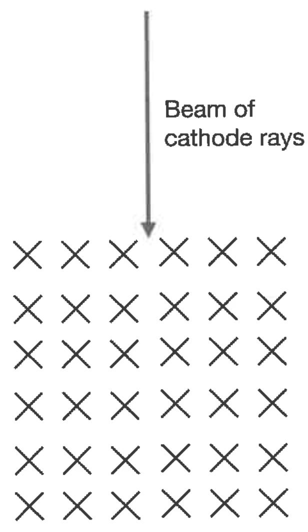
....

....

6.5.2.3 A negatively charged particle travelling from left to right enters a magnetic field and is deflected out of the page. What is the direction of the magnetic field?

(A) Out of the page.
(B) Into the page.
(C) Towards the top of the page.
(D) Towards the bottom of the page.

6.5.2.4 Consider a beam of negatively charged cathode rays entering a magnetic field directed vertically into the page as shown.

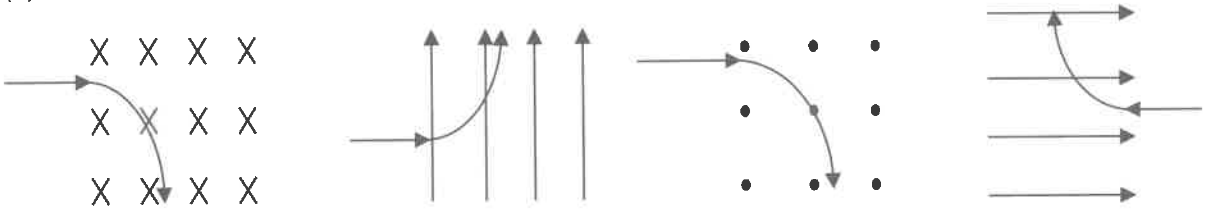


Which way will the cathode rays be deflected as they enter the magnetic field?

(A) To the left.
(B) To the right.
(C) Out of the page.
(D) Into the page.

6.5.2.5 Which diagram shows the path taken by a positively charged particle in a magnetic field?

(A) (B) (C) (D)



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6.6 Analyse the interaction between charged particles and uniform magnetic fields, including the force on the charge: $F = qvB \sin \theta$.

6.6.1 Moving charges in a magnetic field 3.

6.6.1.1 A single, positively charged particle of mass 2.0×10^{-26} kg enters a 0.4 T magnetic field into the page at 3.5×10^{5} m s^{-1}. The field covers an area of 0.3×0.3 m. The particle enters the field at 90°, 2.0 cm up from the bottom left hand corner. Determine (*Hint:* Draw a diagram of the data):

(a) The force on the particle as it enters the field. ....

....

....

(b) The radius of the path it takes in the field. ....

....

....

(c) The speed with which it exits the field. ....

....

....

(d) Where it exits the field. ....

....

....

6.6.1.2 A beam of electrons, accelerated by a 2.4 kV electron gun passes into a magnetic field of strength 9.7×10^{-3} T at 90° to the field.

(a) Find the speed of the electrons as they leave the electron gun. ....

....

....

(b) Find the force on each electron while it is in the magnetic field. ....

....

....

(c) Find the radius of curvature of the path taken by the electrons. ....

....

....

6.6.1.3 A charge of 4.8×10^{-19} C is travelling north at 2.5×10^{7} m s^{-1}, perpendicular to a magnetic field of 0.25 T directed vertically down.

(a) Calculate the force on the charge. ....

....

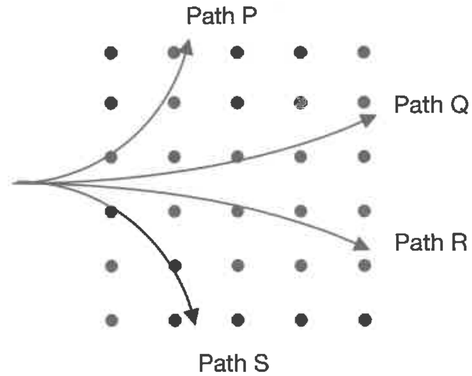
....

(b) Deduce the direction in which the charge will move while it is in the field. ....

....

6.6.1.4

(a) An alpha particle (helium nucleus) and an electron enter the same magnetic field at the same velocity. Four possible paths for these particles are shown on the diagram. Which choice best shows the paths they take while in the field?



	Path taken by alpha particle	Path taken by electron
(A)	P	Q
(B)	Q	S
(C)	R	P
(D)	S	Q

(b) A magnesium ion (Mg^{2+}) and an electron enter the same magnetic field at the same velocity. What is the ratio of the magnitude of the force on them due to the magnetic field?

(A) $Mg^{2+} : e^- = 1 : 1$

(B) $Mg^{2+} : e^- = 1 : 2$

(C) $Mg^{2+} : e^- = 2 : 1$

(D) Unable to calculate without relative masses.

(c) Compare the path taken by the magnesium ion to those shown in the diagram. ....

....

....

6.6.1.5 A 3.2×10^{-19} C charge travels south at 4.0×10^{7} m s^{-1}, at 90° to a magnetic field directed into the page. It experiences a force of 6.4×10^{-12} N.

(a) Find the strength of the magnetic field. ....

....

....

(b) Deduce the direction in which the charge will move while it is in the field. ....

....

Use the following information to answer the next TWO questions.

Two charged particles X and Y are fired into the same magnetic field. The charge on X is twice that of Y, but Y is moving twice as fast as X.

6.6.1.6 Which choice states the ratio of the force acting on X due to the magnetic field to that acting on Y?

(A) $F_X : F_Y = 4 : 1$

(B) $F_X : F_Y = 2 : 1$

(C) $F_X : F_Y = 1 : 1$

(D) $F_X : F_Y = 1 : 2$

6.6.1.7 How would the sign of the charge on X and Y affect this force?

(A) If the signs are both negative, the deflections would be in opposite directions.

(B) If the signs are both positive, the deflections would be in the same direction.

(C) If the signs are opposite, the deflections would be in the same direction.

(D) The sign of the charge will have no influence on the deflection.

6.6.1.8 A charge of 3.2×10^{-19} C is travelling south at 4.0×10^{7} m s^{-1}, perpendicular to a magnetic field directed vertically down. It experiences a force of 6.4×10^{-12} N.

(a) Calculate the strength of the magnetic field. ....

....

....

(b) Deduce the direction in which the charge will move while it is in the field. ....

....

6.6.1.9 Three electrons are fired at 2.5×10^{5} m s^{-1} from the east, west and south into a magnetic field of strength 0.02 T north.

(a) Calculate the magnitude of the force on each electron. ....

....

(b) Deduce the direction of the force on each electron. ....

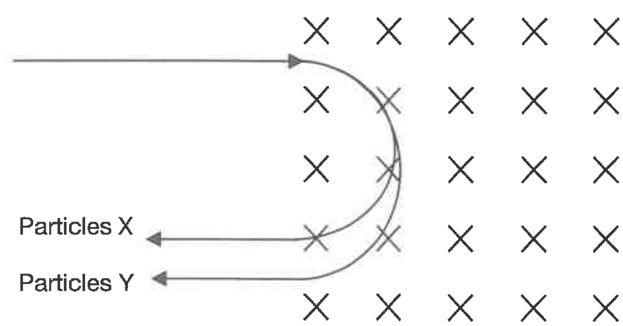
....

(c) Describe the path each electron will take while it is in the field. ....

....

Use the following information to answer the next TWO questions.

A beam of charged particles moves through a magnetic field directed into the page as shown.



6.6.1.10 Which statement about the particles is correct?

(A) Both are negatively charged and X has more mass than Y.
(B) Both are positively charged and X has more mass than Y.
(C) Both are negatively charged and Y has more mass than X.
(D) Both are positively charged and Y has more mass than X.

6.6.1.11 Which change would increase the radius of curvature of the beams through the field?

(A) Increase the strength of the magnetic field.
(B) Use a particle with a greater charge but the same mass.
(C) Use a particle with identical charge but less mass.
(D) Fire the particle into the field with a greater speed.

6.7 Compare the interaction of charged particles moving in magnetic fields to the interaction of charged particles with electric fields.

6.7.1 Comparing charges in electric and magnetic fields.

6.7.1.1

(a) Recall the formula we use to determine the force on a charged particle in an electric field between parallel plates.

(b) A charged particle enters an electric field at right angles to the field. Describe and account for the shape of its path in the field.

(c) Recall the formula we use to determine the force on a charged particle in a magnetic field.

(d) A charged particle enters a magnetic field at right angles to the field. Describe and account for the shape of its path in the field.

6.7.1.2 Two parallel plates are 2.0 cm apart, and have a potential difference across them of 200 V. They are in a magnetic field of strength 0.01 T such that a charge passed through them undeflected. What is the speed of the charge?

(A) 1×10^{4} m s^{-1}

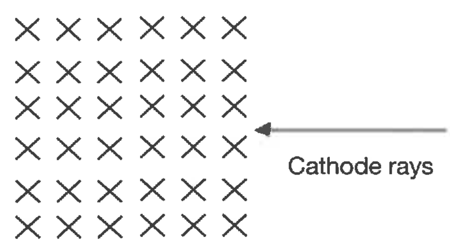
(B) 1×10^{6} m s^{-1}

(C) 2×10^{6} m s^{-1}

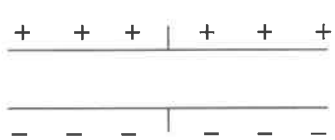
(D) Not enough information to decide.

6.7.1.3 A beam of cathode rays enters a magnetic field as shown.

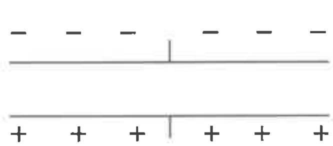
Which diagram shows the correct relative position of two parallel electric plates relative to the magnetic field so that the cathode rays pass through the magnetic field undeflected?



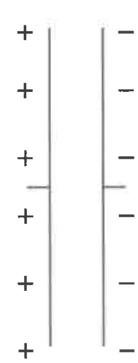
(A)



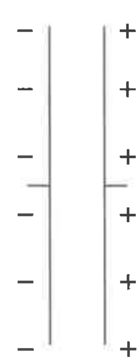
(B)



(C)



(D)



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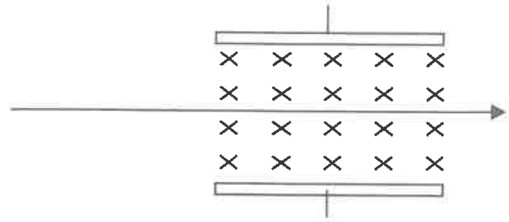
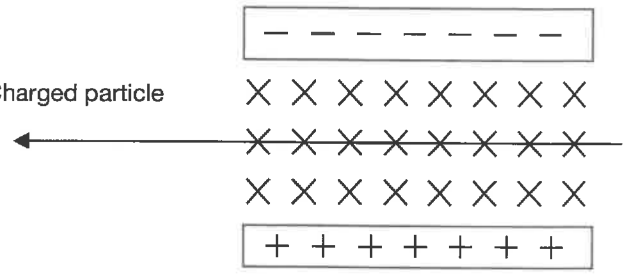
6.7.1.4 A beam of cathode rays moves straight through a region subject to a magnetic field directed into the page and an electric field as shown. Which statement about this situation is correct?



(A) The magnetic and electric fields are equal in strength.
(B) The top electric plate is positively charged.
(C) The electric field is acting up the page.
(D) The electric and magnetic fields cancel each other.

6.7.1.5 A charged particle travels straight through a pair of charged parallel plates and a magnetic field as shown in the diagram.



(a) What is the sign of the charge on the particle?
(A) Positive.
(B) Negative.
(C) Neutral.
(D) Not enough information to decide.

(b) Explain your answer.

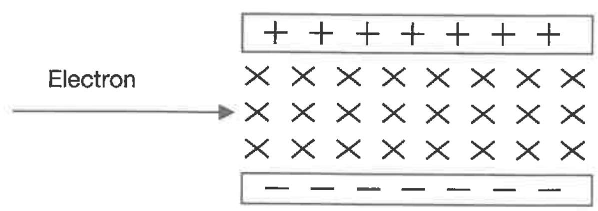
....

....

....

Use the following information to answer the next THREE questions.

An electron moves at 5.0×10^3 m s^{-1} between two charged, parallel plates 0.5 cm apart. A potential difference of 12.5 volts is applied across the plates. There is a magnetic field in this region of intensity 8.0×10^{-2} T directed into the page.



6.7.1.6 What force acts on the electron due to the electric field?
(A) 4×10^{-16} N down the page.
(B) 4×10^{-16} N up the page.
(C) 4×10^{-17} N down the page.
(D) 4×10^{-17} N up the page.

6.7.1.7 What force acts on the electron due to the magnetic field?
(A) 6.4×10^{-17} N down the page.
(B) 6.4×10^{-17} N up the page.
(C) 6.4×10^{-17} N to the left.
(D) 6.4×10^{-17} N to the right.

6.7.1.8 Which way does the electron move while it is in between the plates?
(A) Left.
(B) Right.
(C) Down the page.
(D) Up the page.

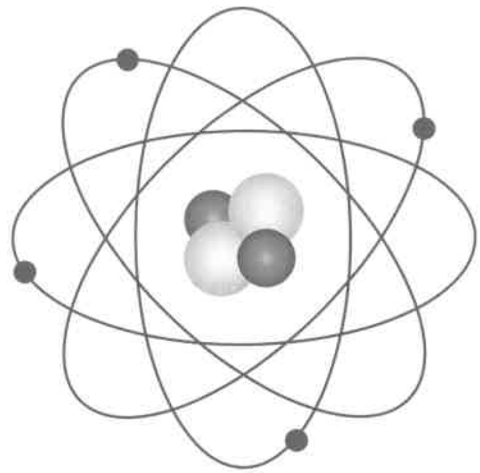
6.8 Compare the interaction of charged particles moving in magnetic fields to other examples of uniform circular motion.

6.8.1 Other examples of uniform circular motion.

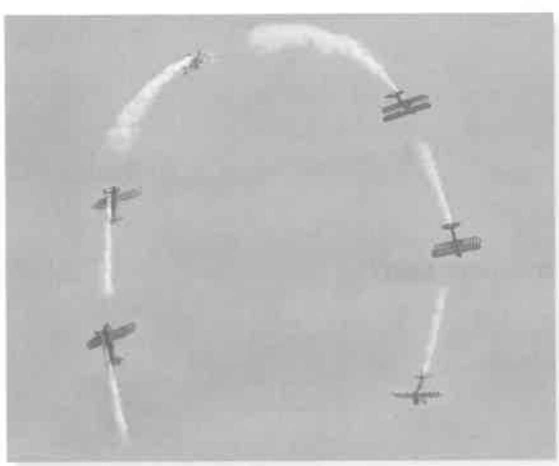
6.8.1.1 Each of the following pictures or diagrams show a situation involving circular motion, and for our purposes, assume it is uniform circular motion. For each situation, identify what is providing the centripetal force and in which direction it acts.

(a) Moon in orbit around the Earth.

(b) Electrons in orbit around atoms.



(c) Plane doing an aerial loop.



(d) Ice skaters skating in a circle.

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The Motor Effect

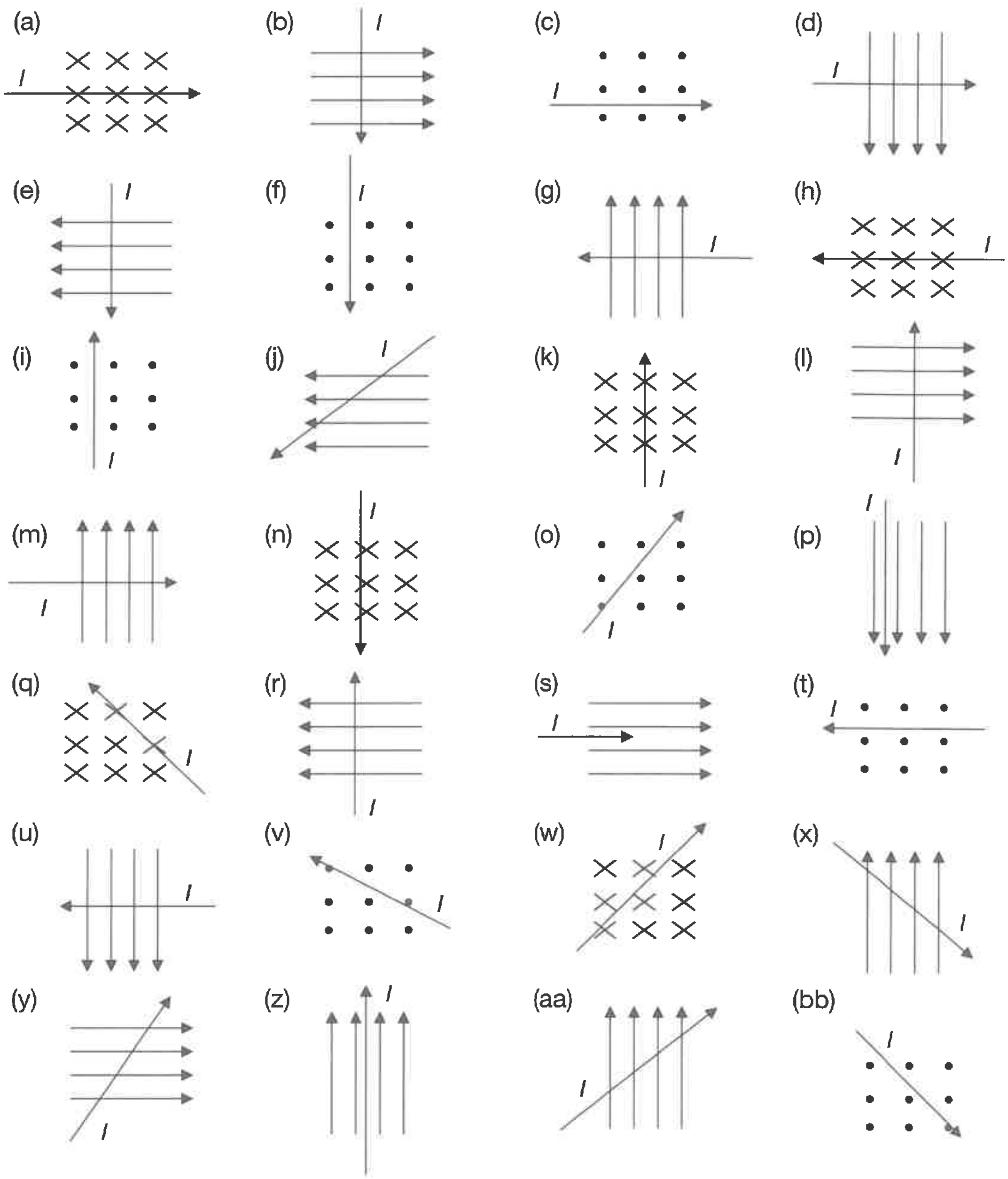
6.9 **Investigate qualitatively and quantitatively the interaction between a current carrying conductor and a uniform magnetic field ($F = BIL \sin \theta$) to establish conditions under which the maximum force is produced, the relationship between the directions of the force, magnetic field strength and current, and conditions under which no force is produced on the conductor.**

INQUIRY QUESTION

Under what circumstances is a force produced on a current carrying conductor in a magnetic field?

6.9.1 The motor effect 1.

6.9.1.1 Predict the direction of the force acting on each current carrying conductor in each magnetic field shown in the diagrams below.



6.9.2 The motor effect 2.

6.9.2.1

(a) Define the motor effect. ....

....

(b) What factors influence the magnitude of the motor effect? ....

....

....

(c) Express your answer to (b) above mathematically. ....

(d) What factors influence the direction of the motor effect? ....

....

(e) What causes the production of all electromagnetic forces? ....

....

6.9.2.2 Chose the correct option for the following by crossing out the incorrect word.

(a) Electric currents do/do not interact with each other.

(b) Electric currents do/do not interact with magnetic fields.

(c) Stationary charges do/do not interact with magnetic fields.

(d) Moving charges do/do not interact with magnetic fields.

(e) Magnetic fields do/do not interact with each other.

(f) A magnetic field is/is not induced around all current carrying conductors.

(g) A magnetic field is/is not induced around all moving charges.

6.9.2.3 A current carrying conductor in a magnetic field experiences a force of F newtons. Find the force on it if its length is halved and the current flowing in it is doubled?

(A) $0.5F$ (B) F (C) $2F$ (D) $4F$

6.9.2.4 A current carrying conductor in a magnetic field experiences a force of F newtons. Find the force on the conductor if the magnetic field is doubled in intensity?

(A) $0.5F$ (B) F (C) $2F$ (D) $4F$

6.9.2.5 A current carrying conductor makes an angle of θ with a magnetic field and experiences a force of F newtons. What be the effect on the force on the conductor if θ is increased?

(A) Force remains at F.
(B) Force will increase.
(C) Force will decrease.
(D) Unable to be answered unless values known.

6.9.2.6

(a) A current carrying conductor experiences a force when it is placed in a magnetic field. What is this known as?

(A) The motor effect.
(B) Electromagnetic induction.
(C) Electromagnetic force.
(D) The right hand palm rule.

(b) How do we find the direction of the force on a current carrying conductor in a magnetic field?

....

6.9.2.7

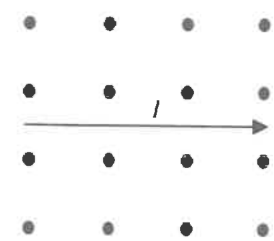
(a) Which choice correctly identifies the way we use the right hand palm rule?

	Fingers	Thumb	Direction palm faces
(A)	*F*	*B*	*I*
(B)	*B*	*F*	*I*
(C)	*B*	*I*	*F*
(D)	*I*	*B*	*F*

(b) Draw a diagram to show this.

6.9.2.8

(a) Consider the current carrying conductor in a magnetic field directed out of the page as shown. What is the direction of the force on the conductor?



(A) Up the page. (B) Down the page.

(C) Into the page. (D) Out of the page.

(b) What would be the force on the conductor if it was also oriented vertically into the page? Explain.

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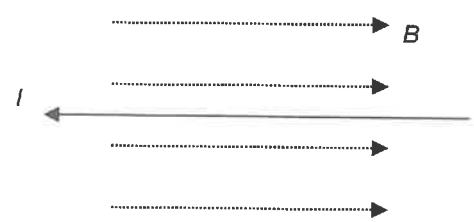
6.9.2.9 Consider the diagram which shows a conductor in a magnetic field. Which statement about the force on this conductor is correct?



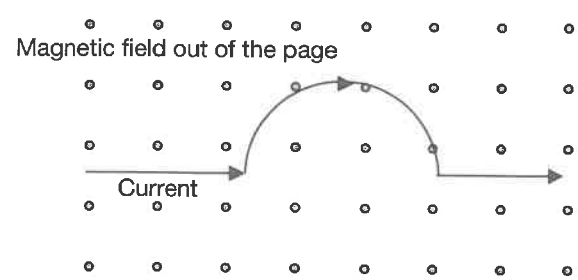
(A) Force is into the page.

(B) Force is out of the page.

(C) Force is up the page.

(D) There is no force on the conductor.

6.9.2.10 The diagram shows a current carrying coil in a magnetic field directed into the page.



(a) What is the direction of the resultant force on the semicircular section of the conductor?

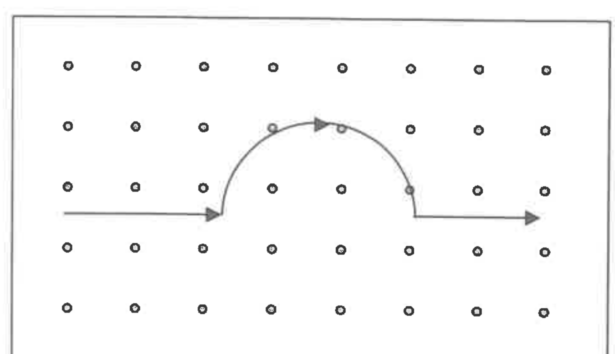
(A) Up the page.

(B) Out of the page.

(C) Down the page.

(D) There is zero resultant force.

(b) Justify your answer. Use the diagram to assist your justification.



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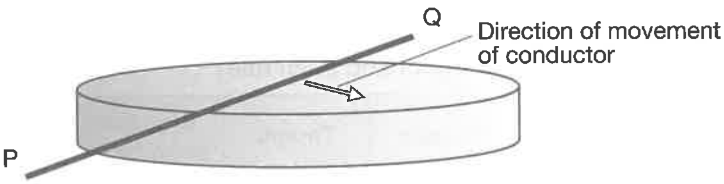
Science Press

6.9.2.11 In an experiment students placed a copper wire on top of a disc magnet which was lying on a horizontal surface as shown.



They noticed that when the wire was connected to a DC supply, it moved in the direction of the arrow.

Which choice correctly shows the direction of the current in the wire and the magnetic field?

(A) Current from P to Q and magnetic field vertically upwards.
(B) Current from P to Q and magnetic field vertically downwards.
(C) Current from P to Q and magnetic field out of the page.
(D) Current from Q to P and magnetic field vertically upwards.

6.9.3 Forces on straight conductors in magnetic fields 1.

6.9.3.1

(a) A current carrying conductor in a magnetic field experiences a force of F newtons. What will be the force on the conductor if its length and the current flowing in it are doubled?

(A) $0.5F$ (B) F
(C) $2F$ (D) $4F$

(b) Sketch a graph to show the relationship between the force on a conductor in a magnetic field and the current flowing through it.

6.9.3.2

(a) A current carrying conductor in a magnetic field experiences a force of F newtons. What will be the force on the conductor if the magnetic field in which it is placed is halved in intensity?

(A) $0.5F$ (B) F
(C) $2F$ (D) $4F$

(b) Sketch a graph to show the relationship between the force on a current carrying conductor in a field and the strength of the magnetic field.

6.9.3.3

(a) A current carrying conductor in a magnetic field experiences a force of F newtons. What will be the force on the conductor if the current flowing in it is tripled, its length in the magnetic field doubled and the magnetic field halved in intensity?

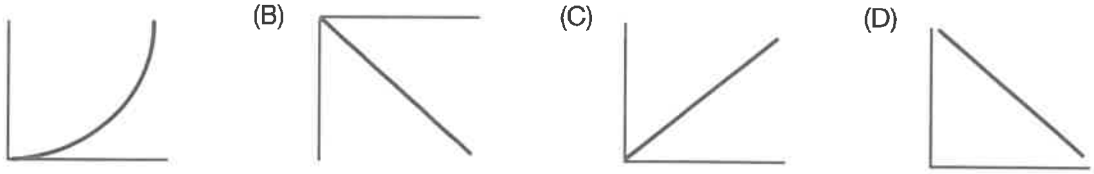
(A) $2F$ (B) $3F$
(C) $4F$ (D) $6F$

(b) Sketch a graph to show the relationship between the force on a current carrying conductor in a magnetic field and the length of the conductor in the magnetic field.

6.9.3.4

(a) Which graph correctly shows the relationship between the force on a conductor due to the motor effect and the current flowing in a coil? (Force on horizontal axis)

(A) (B) (C) (D)



(b) Sketch a graph to show the relationship between this force and the strength of the applied magnetic field.

6.9.3.5 A conductor experiences a force of *F* newtons when placed in a magnetic field. If the current in the wire is reduced to one third and reversed in direction and the intensity of the magnetic field is doubled, predict the new force on the wire.

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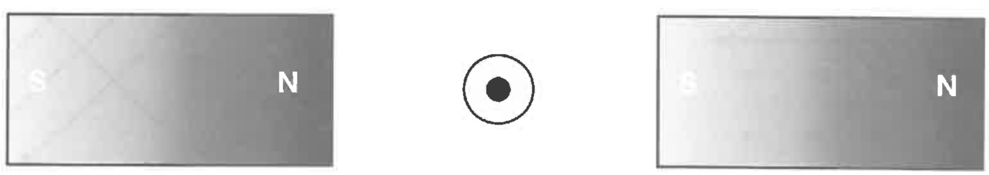
6.9.3.6 The diaram shows a cross-section of a current carrying wire (current out of page) and the poles of two magnets.



(a) If the field is 4.0 T, the current 0.5 A, and 5 cm of the conductor is between the poles, calculate the force on the wire.

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(b) In the space provided, draw a current carrying conductor between the poles so that the resultant force on it is out of the page.

6.9.3.7 A 1.2 m wire has a resistance of 0.6 Ω. The wire runs east-west in a uniform magnetic field of intensity 8×10^{-4} T directed vertically into the page. 12 V is applied across the ends of the wire.

(a) Calculate the magnitude of the force acting on the wire.

(b) If the force is down the page, predict the current direction.

6.9.3.8 A metal bar, mass 0.04 kg, resistance 4 Ω and length 0.5 m is placed on two frictionless conducting rails in a magnetic field of 0.3 T. The bar is connected to a 36 V power source.

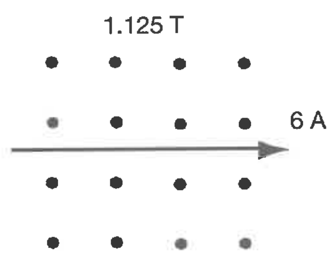
(a) Calculate the current in the bar.

(b) Calculate the magnitude of the force which acts on the bar.

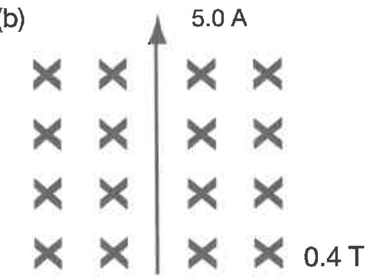
(c) If the bar is free to move, and the force is in the appropriate direction, calculate how far it will move along the rails in 0.25 s.

6.9.3.9 Each diagram below shows a 15 cm long current carrying conductor in a magnetic field. Calculate the force acting on each conductor due to the magnetic field.

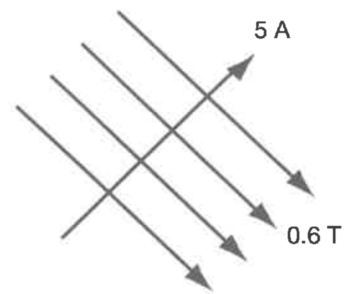
(a)



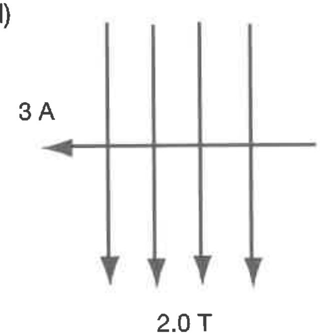
(b)



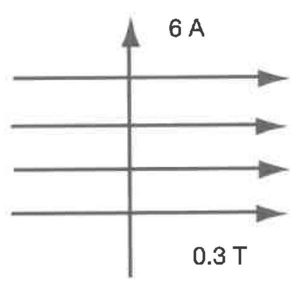
(c)



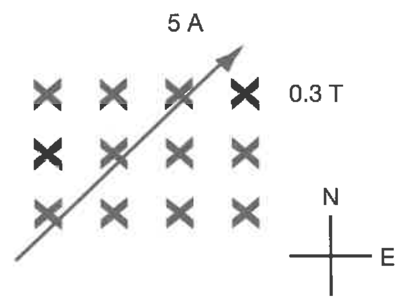
(d)



(e)



(f)



6.9.3.10

(a) A student was doing an experiment to calculate the strength of a magnetic field. She suspended a conducting wire by a string attached to a sensitive balance and measured the length of the wire in the field. She passed a current through the wire and recorded the reading on the balance. What other measurement(s) would she need to make?

(A) The force on the wire and the current flowing.

(B) The weight of the wire and the current flowing.

(C) The weight of the wire.

(D) The current flowing through the wire.

(b) Explain how she could calculate the strength of the magnetic field. ....

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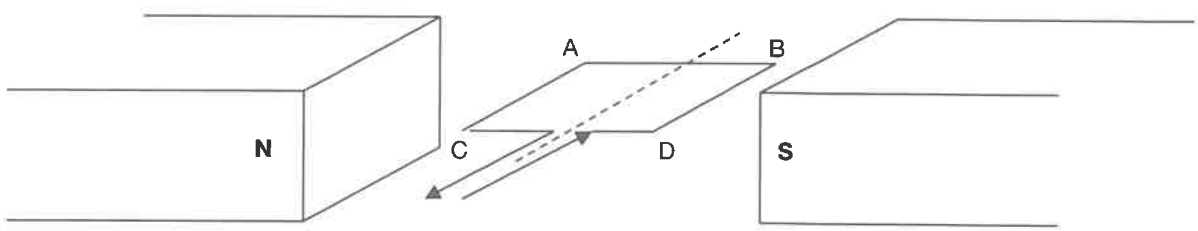
6.9.3.11 The diagram shows a horizontal, 10 cm square loop carrying 1.5 A in a magnetic field of strength 0.25 T.



(a) Describe and label (on the diagram) the force acting on each side of the coil. Justify each answer.

Side AB ....

Side BD ....

Side CD ....

Side AC ....

(b) If the coil was pivoted through the middle of sides AB/CD (about the dashed axle), predict what would happen to the forces on each side.

Side AB ....

Side BD ....

Side CD ....

Side AC ....

(c) Predict the force on side AC of the loop if it was made into a coil with 50 turns. ....

....

(d) Predict the force on side AC of the loop if the strength of the magnetic field was halved. ....

....

(e) Predict the force on side AC of the loop if the current flowing in it was doubled. ....

....

6.9.4 Forces on straight conductors in magnetic fields 2.

6.9.4.1 A current carrying conductor is at an angle of 30° to a magnetic field. It experiences a force of F newtons. Predict the new force on the conductor if:

(a) The magnetic field is doubled in strength. ....

(b) The current flowing in the conductor is halved. ....

(c) The length of the conductor in the field is halved. ....

(d) The angle the conductor makes with the field is increased to 60°. ....

....

(e) Find the force on the conductor if all four changes are made at the same time. ....

....

6.9.4.2 A conductor carrying 2.5 A experiences a force of 0.3 N when 0.4 m of its length is placed in a magnetic field of intensity 0.5 T.

(a) Calculate the angle the conductor makes with the field. ....

....

....

(b) Predict the angle where the conductor will experience maximum force. Justify your answer.

....

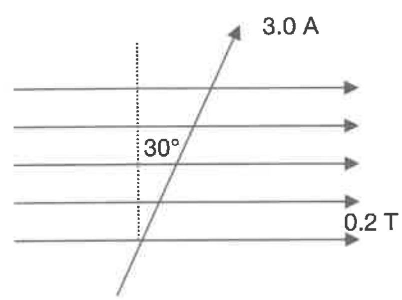
(c) Predict the angle where the conductor will experience zero force. Justify your answer.

....

(d) Predict the force on a new conductor with half the electrical resistance of the initial conductor placed in an identical position in the same field. Justify your answer.

....

6.9.4.3 Calculate the force on the conductor in a magnetic field of strength 0.2T shown in the diagram. It carries a current of 3.0 A and the length of the conductor in the magnetic field is 0.25 m. The conductor makes an angle of 30° with the field as shown.



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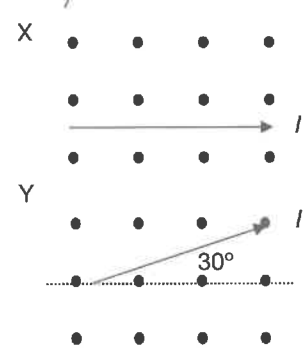
6.9.4.4 Consider the current carrying conductor in the magnetic field directed out of the page as shown in diagram X. The magnitude of the force acting on it is F.



What will be the magnitude of the new force acting on it if the conductor is moved to the position shown in diagram Y?

(A) Larger.

(B) Smaller

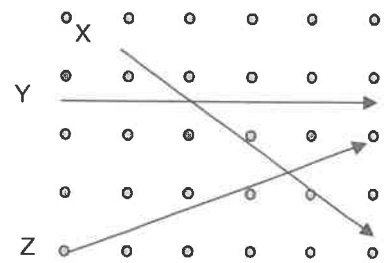
(C) The same.

(D) Halved.

6.9.4.5 The three conductors X, Y and Z in the diagram carry the same current. Which statement about the force these conductors experience due to the magnetic field is correct?

(A) $F_Y > F_Z > F_X$ (B) $F_X > F_Z > F_Y$

(C) $F_Y > F_X > F_Z$ (D) $F_X = F_Y = F_Z$



6.9.4.6

(a) A conductor of length 40 cm, and carrying 2.5 A is placed at 60° in a magnetic field directed into the page. The force acting on the conductor is 0.17 N. What is the strength of the magnetic field?

(A) 0.2 T (B) 0.15 T (C) 0.015 T (D) 0.020 T

(b) What additional information is required to determine the direction of the force? ....

....

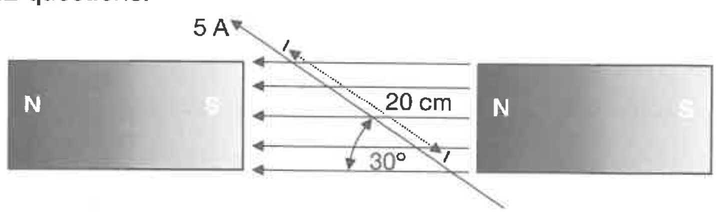
6.9.4.7 A current carrying conductor makes an angle of θ with a magnetic field and experiences a force of F newtons. What will be the effect on the force on the conductor if the size of θ is increased? Explain your answer.

....

....

Use the following information to answer the next THREE questions.

The diagram shows a current carrying conductor carrying 5 A of electricity between the poles of a pair of magnets which produce a magnetic field of intensity 0.4 T. As shown, the length of the conductor within the magnetic field is 20 cm.



6.9.4.8 What is the force on the conductor due to the magnetic field?

(A) 0.2 N out of the page. (B) 0.2 N into the page.

(C) 20 N out of the page. (D) 20 N into the page.

6.9.4.9

(a) The angle the conductor makes with the magnetic field is now changed to 50°. What is the force acting on the conductor due to the magnetic field now?

(A) 0.2 N out of the page. (B) 0.2 N into the page.

(C) 0.3 N out of the page. (D) 0.3 N into the page.

(b) Explain your answer. ....

....

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6.9.4.10

(a) The magnets are now rotated through 90° so that the magnetic field is directed down the page. How does this affect the direction of the force on the conductor?

(A) It is now towards the left. (B) It is now towards the right.

(C) It is now into the page. (D) It remains out of the page.

(b) Which two choices must be incorrect even before you apply the RHPR? ....

....

6.10 Conduct a quantitative investigation to demonstrate the interaction between two parallel current carrying wires.

6.10.1 Forces between parallel conductors 1.

6.10.1.1 Explain, in terms of interacting magnetic fields, and using diagrams to illustrate your answer, why current carrying conductors either repel or attract each other.

6.10.1.2 Explain, using the motor effect, and diagrams to illustrate your answer, the attraction of parallel current carrying conductors which carry currents in the same directions.

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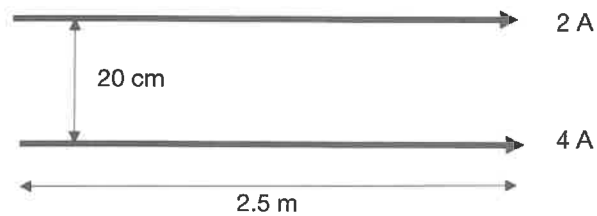
6.11 Analyse the interaction between two parallel current carrying wires $\left(\frac{F}{L} = \frac{\mu_0}{2\pi} \times \frac{I_1 I_2}{r}\right)$ and determine the relationship between the International System of Units (SI) definition of an ampere and Newton's third law of motion.

6.11.1 Forces between parallel conductors 2.

6.11.1.1 Consider the two parallel current carrying conductors shown. Each conductor is 2.5 m long.



(a) Calculate the force between the wires.

....

....

(b) Calculate the force per unit length between the wires.

....

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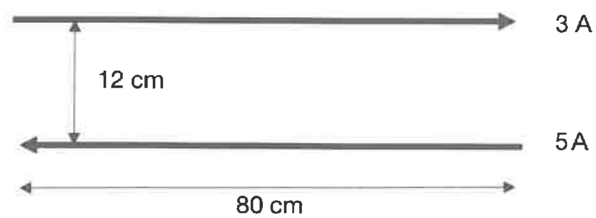
6.11.1.2 Consider the two parallel current carrying conductors shown. Each conductor is 80 cm long.



(a) Calculate the force between the wires.

....

....

(b) Calculate the force per unit length between the wires.

....

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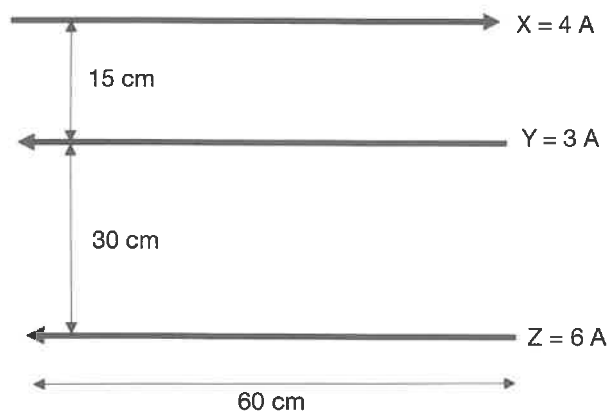
6.11.1.3 Consider the three parallel current carrying conductors X, Y and Z. Each conductor is 60 cm long. Calculate the net force on each wire.



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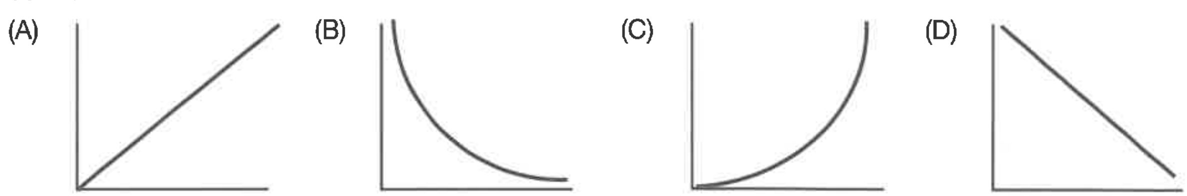
6.11.1.4

(a) Which graph best shows the relationship between the force between parallel current carrying conductors and the distance between them?



(b) Which graph would you get if you plotted F against $\frac{1}{d}$? ....

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6.11.1.5

(a) The force between two parallel current carrying conductors is F newtons. What would be the new force if one current was doubled, and the distance between them halved?

(A) $0.5F$ (B) F (C) $2F$ (D) $4F$

(b) How would this change the force per unit length between the wires? Explain your answer.

6.11.1.6

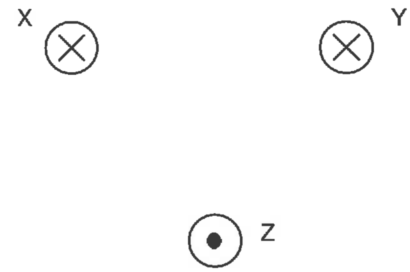
(a) Consider the two parallel current carrying conductors shown. The force on conductor X is F newtons down. What is the force on conductor Y?

(A) F newtons down. (B) F newtons up. (C) $2F$ newtons down. (D) $2F$ newtons up.

(b) Justify your answer with reference to appropriate principles in physics.

6.11.1.7 Consider the three current carrying conductors shown. X and Y carry currents into the page while Z carries a current out of the page. What is the direction of the net force on wire Y?

(A) ↘ (B) ↗ (C) ↖ (D) ↙



6.11.1.8

(a) The force per unit length between two 50 cm long parallel current carrying conductors is F N m^{-1}. What would be the force per unit length between them if their lengths were increased to 2.0 m?

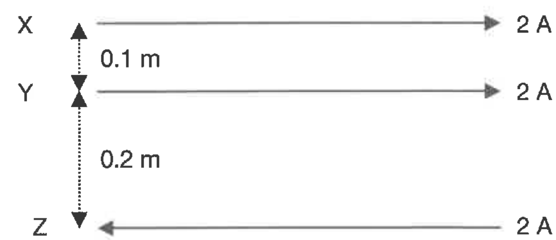
(A) $0.25F$ (B) $0.5F$ (C) F (D) $4F$

(b) How would this change in length change the force between the wires? Justify your answer.

Use the information in Question 6.11.1.9 to answer Questions 6.11.1.10 and 6.11.1.11.

6.11.1.9 Consider the three parallel, current carrying conductors, shown.

Which choice shows the correct directions of the forces on the wires?



	Force on X	Force on Y	Force on Z
(A)	↑	↑	↓
(B)	↑	↓	↑
(C)	↓	↓	↑
(D)	↓	↑	↓

6.11.1.10

(a) Referring again to the conductors in Question 6.11.1.9, which choice best shows the relationship between the magnitudes of the forces acting on X, Y and Z?

(A) $F_X > F_Y > F_Z$ (B) $F_Y > F_Z > F_X$ (C) $F_Z > F_Y > F_X$ (D) $F_Y > F_X > F_Z$

(b) How would this change if the current in Y was doubled? ....

6.11.1.11

(a) Referring again to the conductors in Question 6.11.1.9, if the current in conductor Y was doubled, which statement is correct?

(A) The force on conductor X would increase more than the forces on the other conductors.

(B) The force on conductors X and Y would increase equally.

(C) The force on conductor Y would increase more than the forces on the other conductors.

(D) The force on conductors Y and Z would increase equally.

(b) Explain your answer. ....

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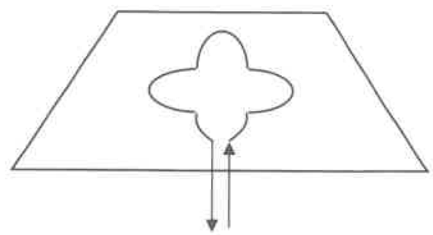
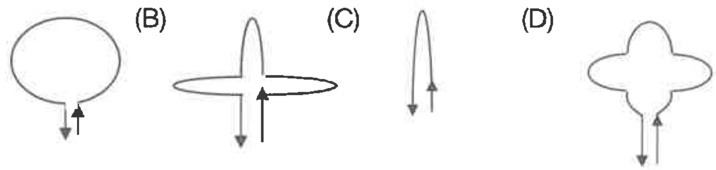
6.11.1.12



(a) A flexible loop of wire is lying on a horizontal surface as shown.
A current is passed through the loop in the direction shown.
Which choice best shows the final shape of the loop?



(b) Explain your answer. ....

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6.11.1.13

(a) The force per unit length between two parallel conductors is 0.2 N m^{-1}. The conductors are each 0.4 m long. What is the force between the conductors?

(A) 0.08 N (B) 0.2 N (C) 0.5 N (D) 1.0 N

(b) If the conductors are each 250 cm long, what is the force between them? ....

....

6.11.1.14

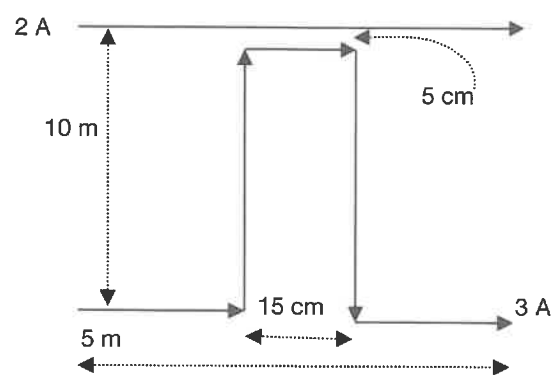
(a) Consider the diagram showing two current carrying conductors, each 5.0 m long.
What is the force between the two wires?

(A) 3.6×10^{-6} N attraction.

(B) 3.6×10^{-6} N repulsion.

(C) 6.0×10^{-8} N attraction.

(D) 6.0×10^{-7} N repulsion.



(b) Explain your answer. ....

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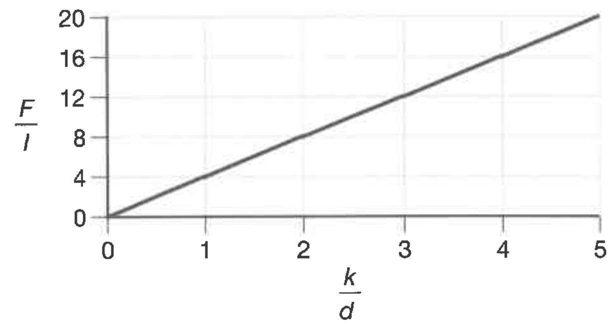
6.11.1.15 The graph shows the relationship between the force per unit length acting on two parallel current carrying conductors and $\frac{k}{d}$, where d is the distance between the wires and k is the magnetic force constant. All quantities are in their normal units.

If the same current flows in each wire, what is its magnitude?

(A) 1.0 A (B) 2.0 A

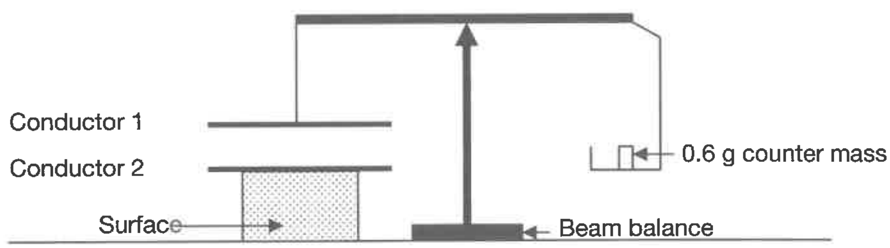
(C) 4.0 A (D) 4.47 A



Use the following information to answer the next THREE questions.

The diagram shows a beam balance which supports one current carrying conductor. A second current carrying conductor rests on a surface 0.5 cm below the first. The conductors have a common parallel length of 0.8 m. The balance is initially balanced.

When the same current flows though each of the wires, a 0.6 gram counter mass is needed to restore the balance.



6.11.1.16 What is the magnitude of the force between the two wires when the current is flowing?

(A) 4.70×10^{-2} N (B) 4.70×10^{-3} N (C) 5.88×10^{-3} N (D) 5.88×10^{-4} N

6.11.1.17 What is the current flowing in each wire?

(A) 12.1 A (B) 13.6 A (C) 147 A (D) 184 A

6.11.1.18

(a) Which statement about the directions of the current in the wires is correct?

(A) They both flow to the left. (B) They both flow to the right.

(C) They flow in opposite directions. (D) Need more data to answer this.

(b) Explain your answer. ....

....

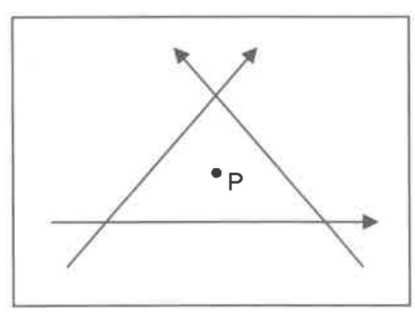
....

6.11.1.19 The diagram shows three straight, current carrying conductors. They each carry 6 A of current. The magnetic field at point P due to one of these wires is B. P is equidistant from each wire.

What is the magnetic field due to all three wires at point P?

(A) $3B$ into the page. (B) $3B$ out of the page.

(C) B out of the page. (D) B into the page.



6.11.1.20 Two parallel conductors are 12 cm apart. One carries 3 A from left to right, the other carries 4 A from right to left. The conductors are each 25 cm long. What is the force between them?

(A) 5×10^{-4} N attraction (B) 5×10^{-4} N repulsion

(C) 5×10^{-6} N attraction (D) 5×10^{-6} N repulsion

Electromagnetic Induction

6.12 Describe how magnetic flux can change, with reference to the relationship $\Phi = BA$.

INQUIRY QUESTION

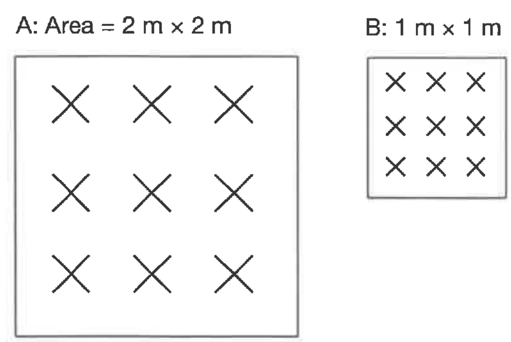
How are electric and magnetic fields related?

6.12.1 Magnetic flux and flux density.

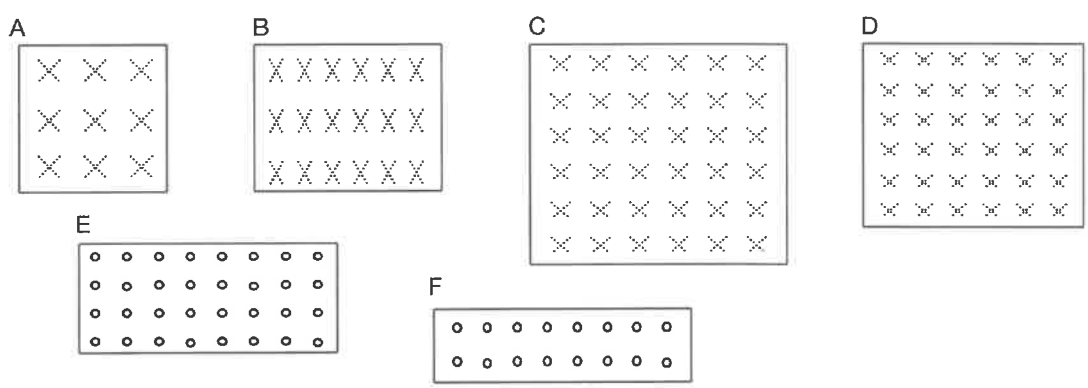
6.12.1.1 Define magnetic flux and state the units used to measure it.

6.12.1.2 Define magnetic flux density and state the units used to measure it.

6.12.1.3 Using the two diagrams distinguish between magnetic flux and magnetic flux density or magnetic field strength.



6.12.1.4 Consider the areas shown. Each has magnetic flux through it as represented by the dots and crosses. Each dot and cross represents the same amount of magnetic flux.



(a) Rank the magnetic flux through each of the areas from weakest to strongest.

(b) Rank the magnetic flux density through each of the areas from weakest to strongest.

6.12.1.5 A coil has a magnetic flux of *W* webers through it. This corresponds to a magnetic flux density of *B* teslas.

(a) Predict the magnetic flux through the coil if its area was halved.

(b) Predict the magnetic flux density through the coil if its area was halved.

(c) Predict the magnetic flux through the coil if its area was doubled.

(d) Predict the magnetic flux density through the coil if its area was doubled.

(e) Predict the magnetic flux through the coil if its area was tripled.

(f) Predict the magnetic flux density through the coil if its area was tripled.

6.12.1.6

(a) What is an alternate name for magnetic flux density?

(A) Magnetic field strength. (B) Magnetic field intensity.

(C) Magnetic induction field intensity. (D) All of the above.

(b) Clarify the idea of magnetic flux.

6.12.1.7

(a) An area is permeated by a magnetic flux of Φ which is equivalent to a flux density of B. Which choice shows the new flux and flux density through this area if the size of the area is halved?

	Magnetic flux	Flux density
(A)	Φ	B
(B)	Φ	$2B$
(C)	2Φ	B
(D)	2Φ	$2B$

(b) Draw diagrams to represent magnetic fields:

(i) Into the page. (ii) Out of the page.

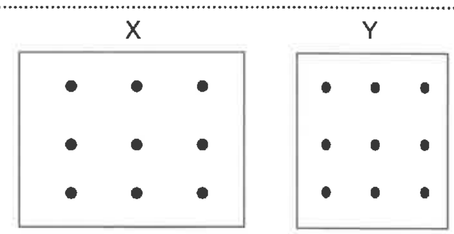
(iii) Down the page. (iv) From left to right.

6.12.1.8 Which statement gives the correct relationship between magnetic flux and magnetic flux density?

(A) $\Phi = B \times A$ (B) $\Phi = \dfrac{B}{A}$ (C) $\Phi = B \times A^2$ (D) $\Phi = \dfrac{B}{A^2}$

6.12.1.9 Recall the units we use for magnetic flux and magnetic flux density.

6.12.1.10 Consider the magnetic fields in areas X and Y.



Which statement about these magnetic fields is correct?

(A) $B_X = B_Y$ (B) $B_X > B_Y$

(C) $B_X < B_Y$ (D) $B_X = -B_Y$

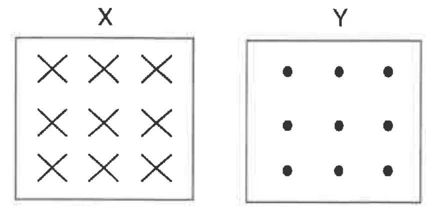
6.12.1.11

(a) A square has a magnetic flux of intensity *B* through it. What is the new intensity if the area of the square is doubled?

(A) $0.25B$ (B) $0.5B$ (C) $2B$ (D) $4B$

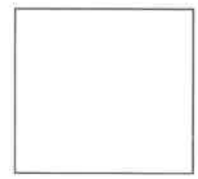
(b) How does the magnetic flux through the square change?

6.12.1.12

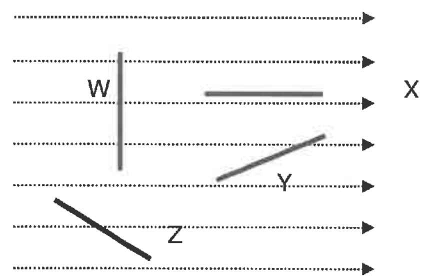


(a) Consider areas X and Y, both permeated by magnetic fields. Which statement about these magnetic fields is correct?
(A) Flux through X = flux through Y.
(B) Flux through X > flux through Y.
(C) Flux through X < flux through Y.
(D) Flux through X = –flux through Y.

(b) Complete the empty diagram to show a magnetic field with twice the intensity as that through X.



6.12.1.13 The diagram shows possible starting positions relative to the magnetic field for the coil.



Which diagram(s) best represents the correct starting position of the coil relative to the magnetic field? Justify your choice.

(A) W only.	(B) X only.
(C) W or X only.	(D) Y or Z only.

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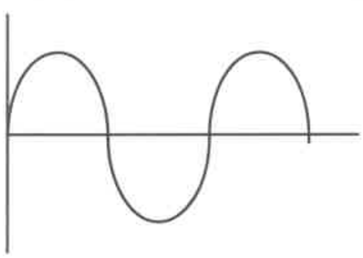
Use the following information to answer to next THREE questions.

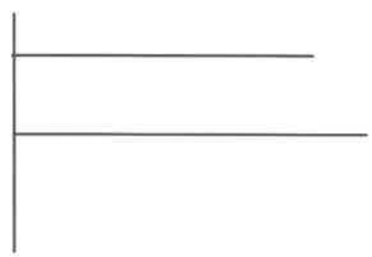
A coil is rotated in the space between two magnets which is permeated by field of constant flux density.

6.12.1.14 Which graph best shows the change in flux through the coil as it rotates?

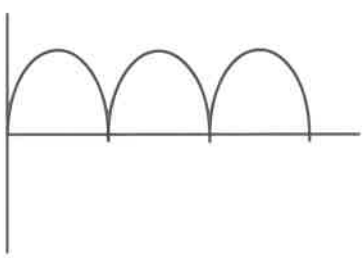
(A)



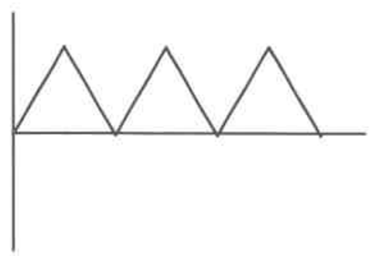
(B)



(C)



(D)



6.12.1.15 The three incorrect answers share at least one reason for being incorrect. What is this? ....

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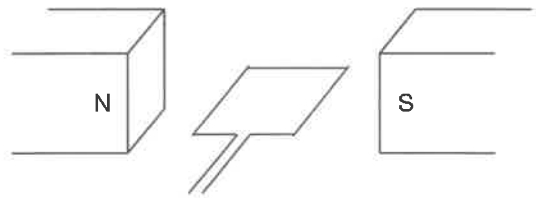
6.12.1.16 How many rotations does the coil do?

(A) 0.75	(B) 1	(C) 1.5	(D) 3

6.12.1.17 The diagram shows a coil between the poles of two magnets.



(a) Which action will increase the magnetic flux through this coil?

(A) Increase the strength of the magnets.
(B) Increase the area of the coil.
(C) Increase the number of turns in the coil.
(D) Rotate the coil through 20°.

(b) Would the other three actions ever increase the flux through the coil? Explain. ....

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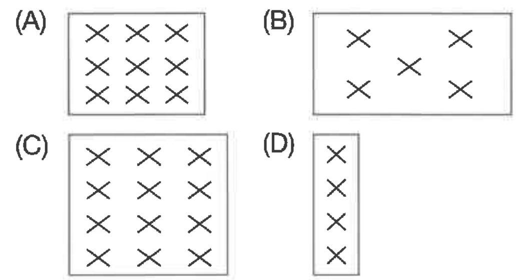
Use the following information to answer the next FOUR questions.

The diagrams show the magnetic flux through four areas.



6.12.1.18 Which area contains the largest magnetic flux?

(A) A
(B) B
(C) C
(D) D

6.12.1.19 Compare the magnetic flux in areas (A) and (D). ....

6.12.1.20 Referring to the diagrams, which area contains the smallest magnetic field intensity?

(A) A (B) B (C) C (D) D

6.12.1.21 Compare the magnetic field intensity in (A) and (D). ....

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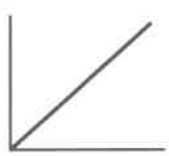
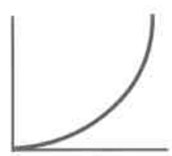
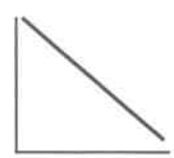
6.12.1.22

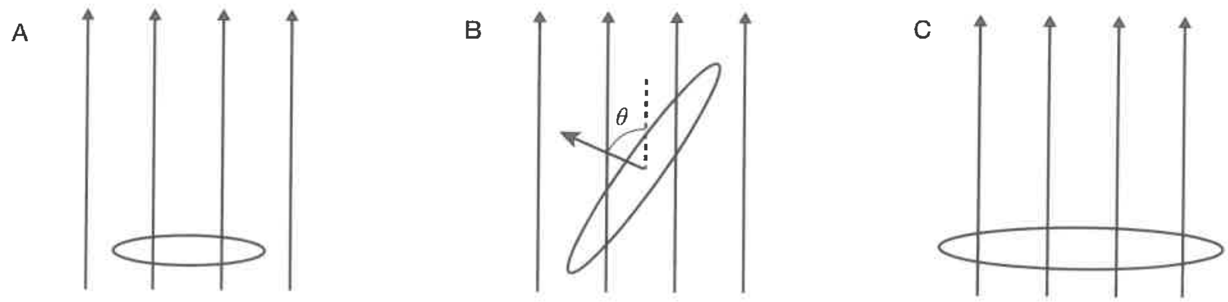
(a) Which graph best shows the relationship between magnetic flux density and area?

(A)  (B)  (C)  (D) 

(b) Sketch a graph to show the relationship between magnetic flux and flux density.

Science Press

6.12.1.23 The diagrams show three coils in identical magnetic fields.



What is the order of the magnetic flux through the four circles shown from least to most? Justify your answer.

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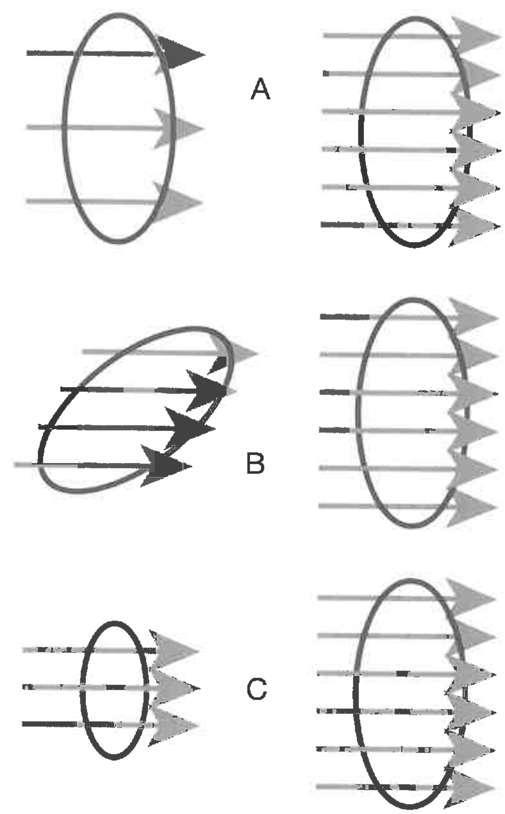
6.12.1.24 Consider the three pairs of coils A, B and C, and magnetic fields shown. A student drew these to represent the four variables which determine the amount of magnetic flux through coils.

Match each variable with the pair of coils which shows the effect of that variable. There may be more than one match for each variable.



	Variable	Coil pair(s)
(a)	The amount of flux through a coil depends on the area of the coil perpendicular to the magnetic field.	
(b)	The flux through the coil depends on the size of the coil.	
(c)	The flux through the coil depends on the orientation of the coil within the field.	
(d)	The flux through the coil depends on the strength of the magnetic field.	

6.13 **Analyse qualitatively and quantitatively, with reference to energy transfers and transformations, examples of Faraday's law and Lenz's law $\left(\varepsilon = -\frac{\Delta\Phi}{\Delta t}\right)$, including but not limited to the generation of an electromotive force (emf) and evidence for Lenz's law produced by the relative movement between a magnet, straight conductors, metal plates and solenoids or changes in current in one solenoid in the vicinity of another solenoid.**

6.13.1 **Faraday and induction.**

6.13.1.1 Define induced potential difference. ....

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6.13.1.2 Explain how an induced potential difference is produced. ....

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6.13.1.3 Recall the factors which affect the magnitude of an induced potential difference. ....

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6.13.1.4 Recall the factors which affect the direction of an induced potential difference. ....

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6.13.1.5 Outline Faraday's experiments with coils and magnets and the observations he made.

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6.13.1.6 Recall the two statements with which Faraday summarised his observations on electromagnetic induction.

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6.13.1.7 The north pole of a magnet is moved into a coil of wire which is connected to an ammeter. Predict the effect on the current indicated on the ammeter of:

(a) Moving the magnet into the coil faster.

(b) Moving the magnet out of the coil more slowly.

(c) Moving a south pole into the magnet at the same speed.

(d) Moving a south pole out of the coil at double the speed.

(e) Halving the number of turns in the coil.

(f) Moving two north poles into the coil at the same speed.

(g) Moving two south poles out of the coil faster.

6.13.1.8 Explain the idea of 'relative movement' between a conductor and a magnetic field.

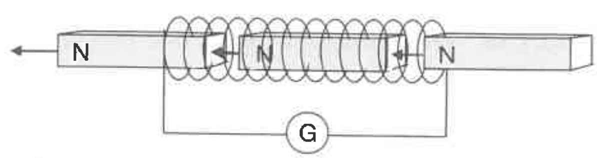
6.13.1.9

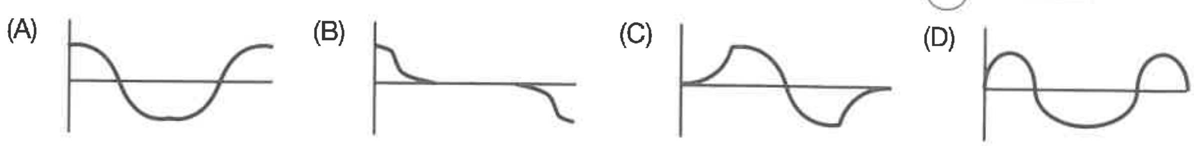
(a) Recall four factors which influenced the generation of an electric current in a coil.

(b) For each factor, explain why that factor influenced the current.

6.13.1.10

(a) In an experiment a student moved a magnet into, through and out of a coil as shown in the diagram. Which graph best shows the emf generated in the coil?

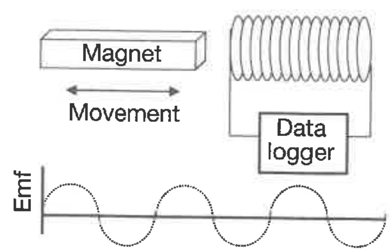


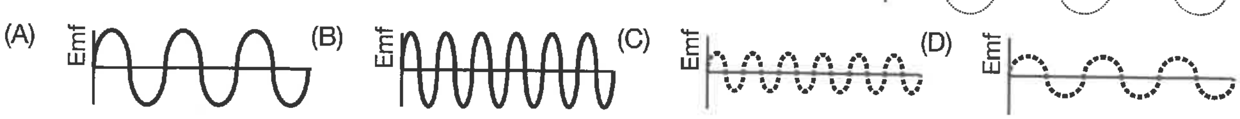


(b) Explain how you arrived at your answer.

6.13.1.11 A bar magnet is moved backwards and forwards near a coil which is connected to a data logger calibrated to plot the emf induced in the coil. The graph shows the plot obtained.

The magnet was then moved back and forth near the magnet at twice the original speed. Which graph shows the new graph produced by the data logger?



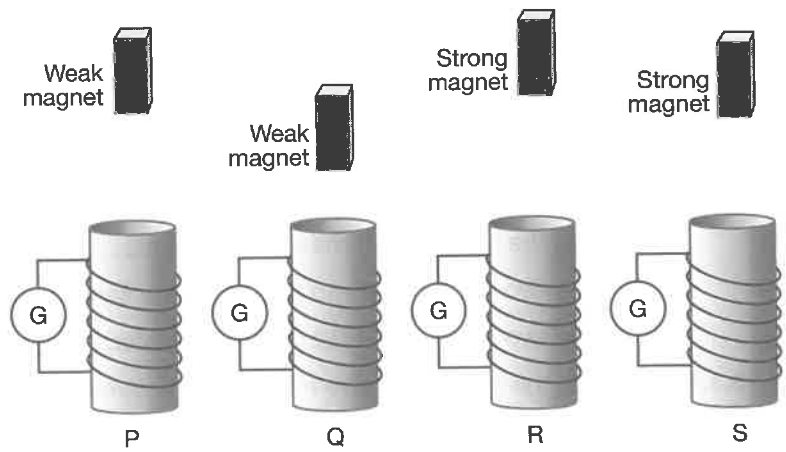


Use the following information to answer the next EIGHT questions.

The diagram shows how the equipment was set up for an experiment.

A coil of wire was wound on a thin cardboard tube and connected to a galvanometer.

In different runs, a weak and a strong magnet were dropped from different heights through the tube and the readings on the galvanometer noted.



6.13.1.12 Which choice shows the best purpose for this experiment?

(A) To determine if strong magnets induce larger currents in coils than weaker magnets.

(B) To determine the relationship between the height a magnet is dropped from and the size of the induced current it produces in a coil it passes through.

(C) To determine the relationship between the speed of a magnet falling through a coil and the size of the induced current it produces in the coil.

(D) To observe the effect of relative motion and magnetic strength on induced currents in a coil.

6.13.1.13 Which two coils could be used to determine the relationship between the size of the induced current and the strength of the magnet? Explain.

(A) P and Q. (B) P and R. (C) P and S. (D) R and S.

6.13.1.14 Which choice correctly shows the magnitude of the induced currents though the coil in runs P, Q, R and S in decreasing order?

(A) P > R > Q > S (B) R > P > S > Q (C) R > S > P > Q (D) Q > P > R > S

6.13.1.15 What would the result of P and Q alone show? Explain why.

(A) The effect of the rate of motion of the magnet through the coil on the size of the induced current.

(B) The effect of the height of the magnet on the size of the induced current.

(C) The effect of a weak magnet through the coil compared to a strong magnet on the size of the induced current.

(D) The effect of strength of the magnet through the coil on the size of the induced current.

6.13.1.16 Which factors have been controlled in this experiment?

(A) Number of turns and diameter of the coil. (B) Height and strength of the magnets.

(C) Height and number of turns in the coil. (D) Size of the coil and strength of the magnets.

6.13.1.17 Which of the following conclusions for this experiment is the best?

(A) Induced current is affected by the height from which the magnets are dropped and the strength of the magnets.

(B) Induced current is larger if the height from which the magnets are dropped and the strength of the magnets is greater.

(C) Induced current is affected more by stronger magnets dropped from greater heights.

(D) Induced current is larger if the height from which the magnets are dropped is increased.

6.13.1.18 Imagine that a strong magnet had been used in run Q. Which statement about the induced current it would have produced is correct?

(A) It would be larger than that in P. (B) It would be less than that in P.

(C) It would be less than that in R. (D) It would be equal to that in S.

6.13.1.19 Indicate five ways this experiment could have been improved. ....

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6.13.1.20 The diagrams show three activities done by a student during an experiment. In each, a conductor was moved in the directions shown relative to the magnetic fields. The conductors were each connected to an ammeter.

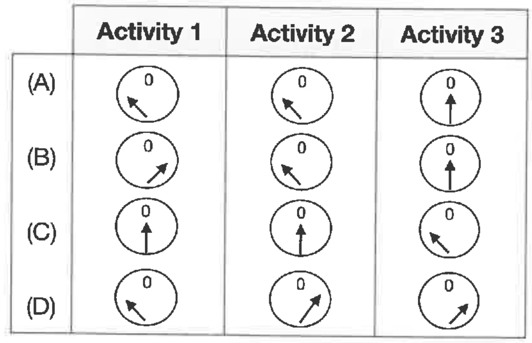
Activity 1: Conductor moved down

Activity 2: Conductor moved up

Activity 3: Conductor moved towards north pole

(a) Which choice best shows the readings on the ammeters?

(b) Explain the zero reading(s) in your answer.



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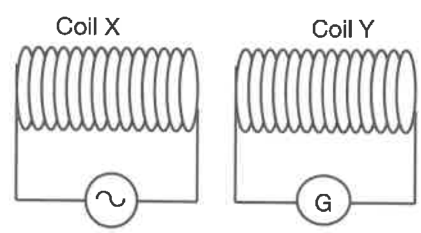
6.13.1.21 Which are the correct units for rate of change of flux?

(A) Webers (B) Weber seconds (C) Volts (D) Teslas

Use the following information to answer the next TWO questions.

A student set up two coils as shown. She noticed that when the AC supply to circuit X was turned on, the galvanometer in circuit Y showed a current flowing in coil Y.



6.13.1.22 Which statement best explains this observation?

(A) Whenever there is relative motion between a conductor and a magnetic field the conductor will experience a force.

(B) A changing current in a conductor will induce a changing magnetic field around the conductor.

(C) Whenever there is relative motion between a conductor and a magnetic field there will be an induced current in the conductor.

(D) A changing magnetic field around a conductor will induce a back emf in that conductor.

6.13.1.23 The student placed a soft iron core inside coil Y. Which statement best describes what she would have observed?

(A) The current in coil Y would increase.

(B) The current in coil Y would decrease.

(C) The current in coil Y would remain the same.

(D) The current in coil Y would vary with the temperature of the iron core.

6.13.2 Lenz's law and straight conductors.

6.13.2.1 State Lenz's law. ....

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6.13.2.2 Recall when Lenz's law applies. ....

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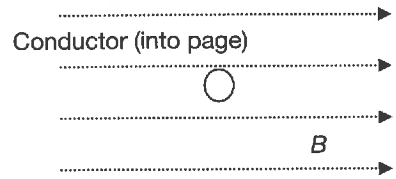
6.13.2.3 A vertical conductor is placed in a magnetic field as shown. In the diagram, in which direction would the conductor need to be moved to induce an emf in the conductor into the page?

(A) To the left. (B) To the right.

(C) Up the page. (D) Down the page.



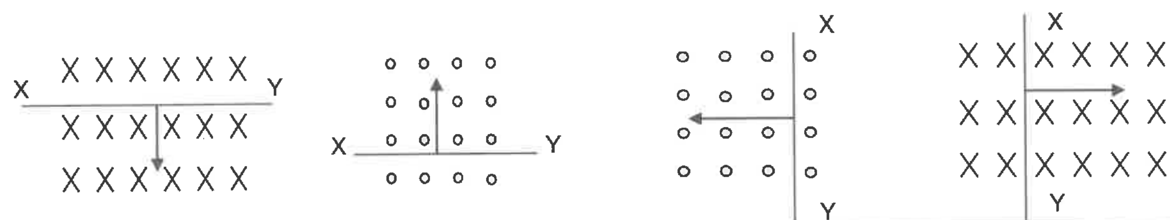
6.13.2.4 As a result of moving a vertical conductor to the left through a magnetic field, a current is induced in it out of the page as shown.

What is the direction of the magnetic field?

(A) Down the page. (B) Up the page.

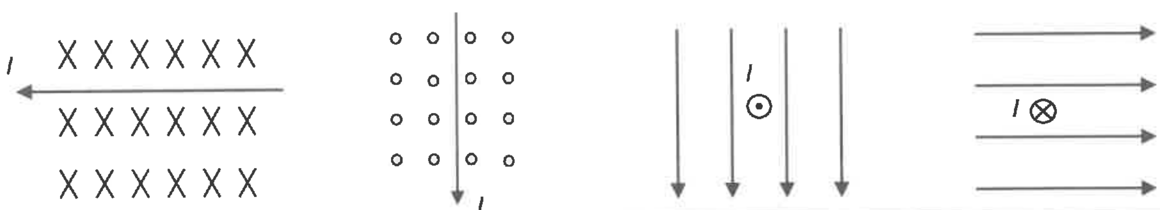
(C) Into the page. (D) Out of the page.

6.13.2.5 Use Lenz's law to determine the direction of the induced emf in each wire shown below (X to Y or Y to X). The wires are moving in the directions shown by the arrows (⟶).



(a)	(b)	(c)	(d)

6.13.2.6 Use Lenz's law to determine the direction in which the conductor must be moving in order to produce the induced emf shown in each wire.



(a)	(b)	(c)	(d)

6.13.2.7 Use Lenz's law to determine the direction in which the magnetic field must be directed in order to produce the induced emf shown in each wire.

(a)	(b)	(c)	(d)

6.13.2.8 In an experiment students took a long wire connected to a sensitive galvanometer into the playground, stood facing each other in a north-south direction, each holding one end of the wire, and swung it around in a large circle like a skipping rope. No reading was observed on the galvanometer.

Which of the following would *not* increase the induced current in the wire?

(A) Stand in an east-west direction.

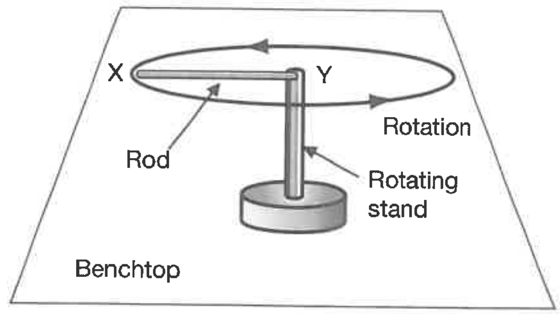
(B) Swing the wire faster.

(C) Use two strands of wire.

(D) Use a more sensitive galvanometer.

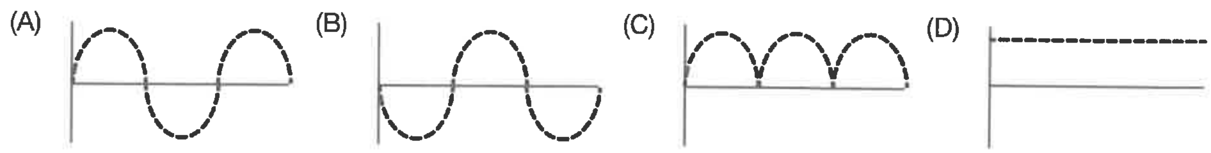
Use the following information to answer the next FOUR questions.

A rigid metal rod XY is mounted on rotating stand on a horizontal bench. A force is applied so that the rod rotates in a horizontal circle at constant speed. A magnetic field of uniform intensity is directed vertically upwards from the bench. At time = 0, the rod is in the position shown.



6.13.2.9

(a) Which graph best shows the emf generated in the rod XY as it rotates?



(b) Explain your answer, including a statement as to the direction of the induced emf.

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6.13.2.10 Which choice correctly describes the force acting on the rod due to the interaction between the magnetic field associated with the induced current and the magnetic field out of the bench?

(A) It varies in magnitude and opposes the motion of the rod.

(B) It has constant magnitude and opposes the rotation of the rod.

(C) It varies in magnitude and alternates in direction.

(D) It is constant in magnitude and alternates in direction.

6.13.2.11 Which choice best describes the change, if any, that would occur in the induced emf in the rod if the height of the supporting stand was halved?

(A) There would be no change as the field is uniform in intensity.

(B) It could be greater or smaller depending on whether the rod is closer to the north or south pole of the source of the field.

(C) Emf would increase as rod would cut a stronger magnetic field.

(D) Emf would decrease as rod would cut a weaker field.

6.13.2.12 What would happen to the emf if the rod was rotated faster?

(A) There would be no change as the field is uniform in intensity.

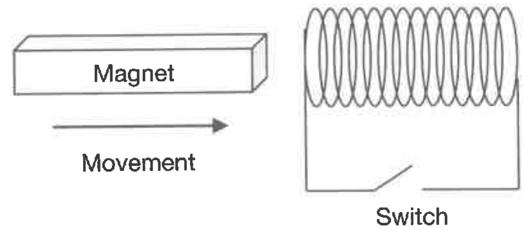
(B) Emf would decrease as rod would pass through magnetic field more quickly.

(C) The emf would increase because flux would be cut at a greater rate.

(D) Emf would increase as rod would cut a stronger field.

6.13.3 Lenz's law and coils.

6.13.3.1 A bar magnet is brought near and pushed into a coil which is connected into a circuit as shown.



(a) Which statement about the amount of energy needed to push the magnet into the coil at constant speed is correct?

(A) Zero whether the switch is open or closed.
(B) Less if the switch is closed.
(C) More if the switch is closed.
(D) Same if the switch is open or closed.

(b) Explain your answer. ....

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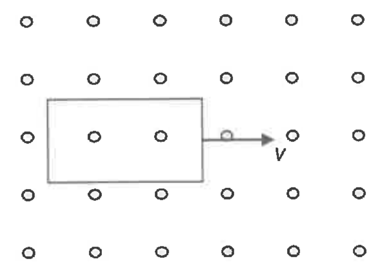
6.13.3.2 Consider a rectangular coil of wire totally within a magnetic field and moving to the right as shown.



(a) Which statement best accounts for the induced emf in the coil? There will be:

(A) No induced emf because it is totally enclosed within the field.
(B) No induced emf because there is no change in the flux through it.
(C) A clockwise emf induced because the coil is moving relative to the magnetic field.
(D) An anticlockwise emf induced because the coil is moving relative to the field.

(b) Suppose the coil is rotated clockwise within the field. What will be the direction of the induced emf in it now? Explain why.

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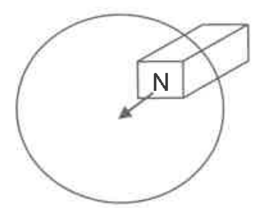
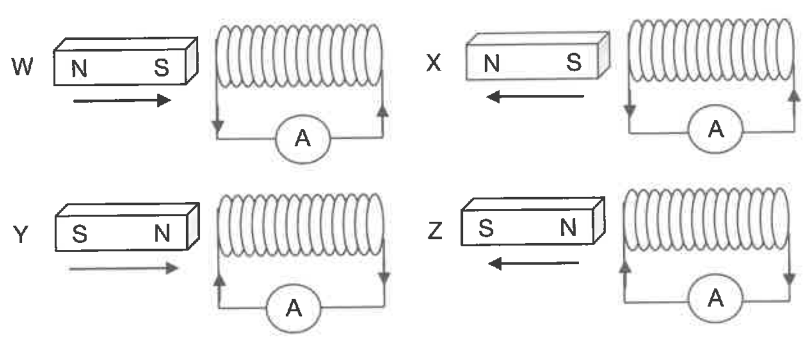
6.13.3.3 The diagram shows a magnet approaching a coil of wire from behind it. What would be the direction of the induced current in the coil as the magnet approached, passed through and moved away in front of the coil?



(A) Clockwise.
(B) Anticlockwise.
(C) Clockwise then anticlockwise.
(D) Anticlockwise then clockwise.

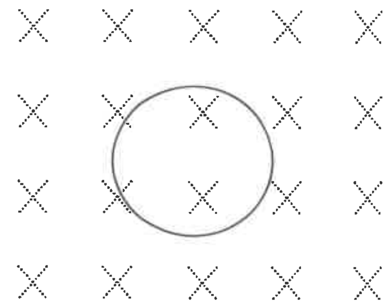
6.13.3.4 The diagrams show the directions of the induced currents formed by magnets moving towards or away from identical coils.



Which of the diagrams is correct?

(A) W and Y only. (B) X and Z only. (C) W, Y and X only. (D) X. Y and Z only.

6.13.3.5 Consider a conducting coil within a magnetic field directed into the page as shown. The strength of the magnetic field is increased gradually.



(a) Which statement best accounts for the induced emf in the coil?

(A) There will be no induced emf because it is totally enclosed within the field.

(B) There will be no induced emf because it is not moving relative to the field.

(C) There will be a clockwise emf induced because the flux through the coil is increasing.

(D) There will be an anticlockwise emf induced because the flux through the coil is increasing.

(b) Explain how you arrived at your answer. ....

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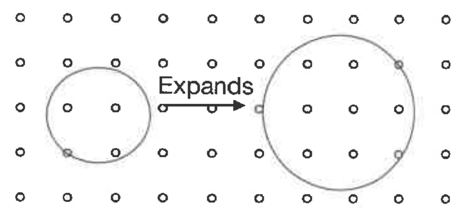
6.13.3.6 A coil is totally within a magnetic field as shown. Suddenly it expands and its area doubles.



(a) Which statement about the emf induced in the coil as it expands is correct?

(A) There will be no induced emf because it is totally enclosed within the field.

(B) There will be a clockwise emf induced because the magnetic field strength through it is increasing.

(C) There will be a clockwise emf induced because the magnetic flux through the coil is increasing.

(D) There will be an anticlockwise emf induced because the magnetic flux through the coil is increasing.

(b) Predict what would happen if the coil continually expanded and contracted within the field.

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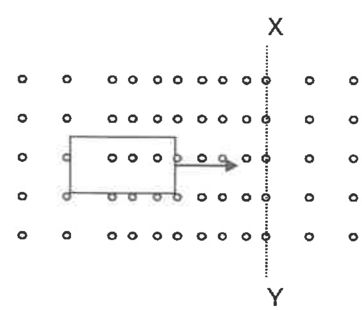
6.13.3.7 Consider a rectangular coil of wire totally within a magnetic field and moving to the right as shown.



(a) Which statement about the emf induced in the coil is correct?

(A) There will be no induced emf because it is totally enclosed within the field.

(B) There will be no induced emf because there is no change in the flux through it.

(C) There will be a clockwise emf induced because the flux through the coil is increasing.

(D) There will be an anticlockwise emf induced because the flux through the coil is increasing.

(b) Explain what happens as the coil moves through the magnetic field and crosses the line XY.

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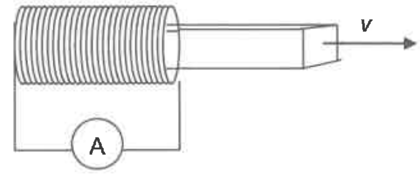
6.13.3.8 A magnet is moved out of a coil at speed v as shown.



(a) What would happen if the speed of the magnet was increased?

(A) There would be less induced current because the rate at which magnetic flux is cut is increasing.

(B) There would be more induced current because the rate at which magnetic flux is cut is increasing.

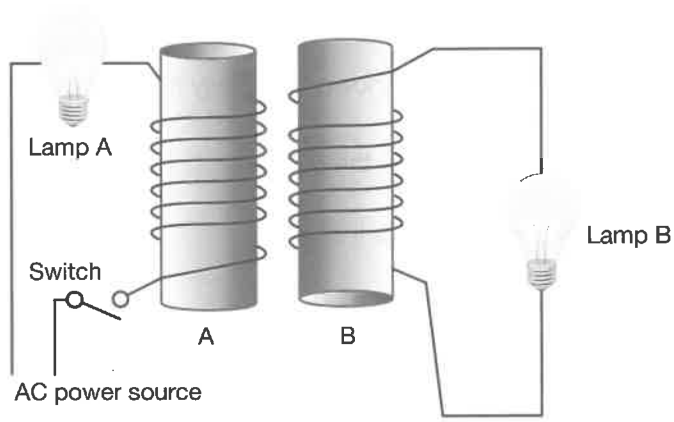
(C) There would be less induced current because the rate at which magnetic flux is cut is decreasing.

(D) There would be more induced current because the rate at which magnetic flux is cut is decreasing.

(b) What would be the effect of using a stronger magnet? ....

....

6.13.3.9 Explain why, when the AC power is turned on, both lamps light up but if a DC power source is used, only lamp A lights up, and lamp B does not light up.



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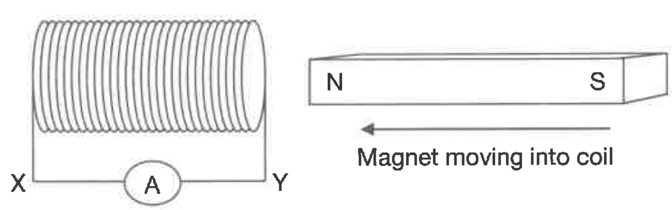
6.13.3.10 Predict the direction of the induced current in the circuits below (X to Y or Y to X).

(a)



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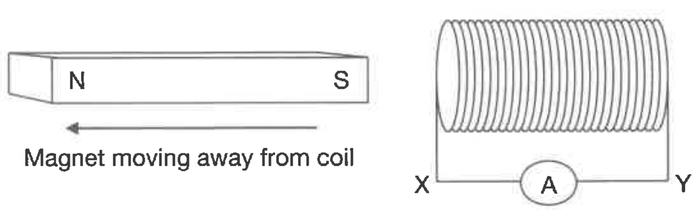
(b)



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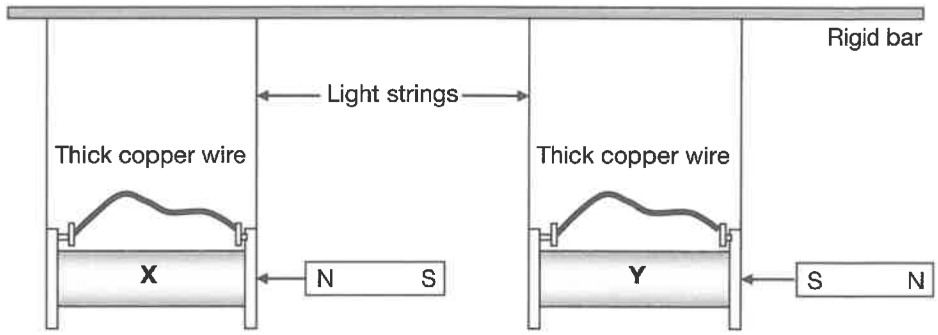
Use the following information to answer the next TWO questions.

Two light solenoids are suspended by light strings from a rigid bar so that they can swing like pendulums. The two ends of the wire making the coils are joined by thick copper wires. A magnetic north pole is moved towards solenoid X. A magnetic south pole is moved towards solenoid Y. The magnets are stopped just as they enter the solenoid.



6.13.3.11

(a) Which statement describing what happens as the magnets approach the solenoids is correct?

(A) Both solenoids will swing to the left.
(B) Both solenoids will swing to the right.
(C) Solenoid X will swing to the left and solenoid Y will swing to the right.
(D) Solenoid X will swing to the right and solenoid Y will swing to the left.

(b) Explain your answer. ....

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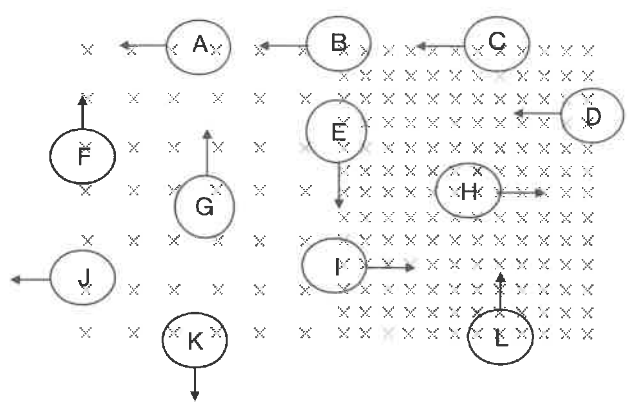
6.13.3.12 Which statement about the current induced in each solenoid (as viewed from the end closest to the magnets) is correct?

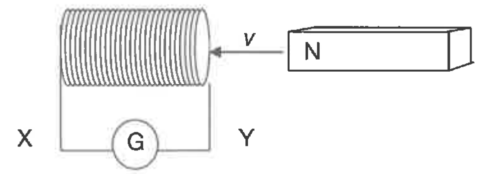
	Current in solenoid X	Current in solenoid Y
(A)	Clockwise	Anticlockwise
(B)	Clockwise	Clockwise
(C)	Anticlockwise	Anticlockwise
(D)	Anticlockwise	Clockwise

6.13.3.13 Use Lenz's law to determine the direction of the induced current in each of the coils of wire (clockwise or anticlockwise). Each coil is moving in the direction of the arrow.



A	E	I
B	F	J
C	G	K
D	H	L

6.13.3.14 The north pole of a magnet is brought near a coil which is connected into a circuit as shown.



(a) Which statement about the emf induced in the circuit is correct?

(A) There will be an induced emf in the circuit directed XGY because the magnetic flux in the coil is increasing.

(B) There will be an induced emf in the circuit directed YGX because the magnetic flux in the coil is increasing.

(C) There will be an induced emf in the circuit directed XGY because the magnetic flux in the coil is decreasing.

(D) There will be an induced emf in the circuit directed YGX because the magnetic flux in the coil is decreasing.

(b) What would be the situation if the coil was not connected into a closed circuit? ....

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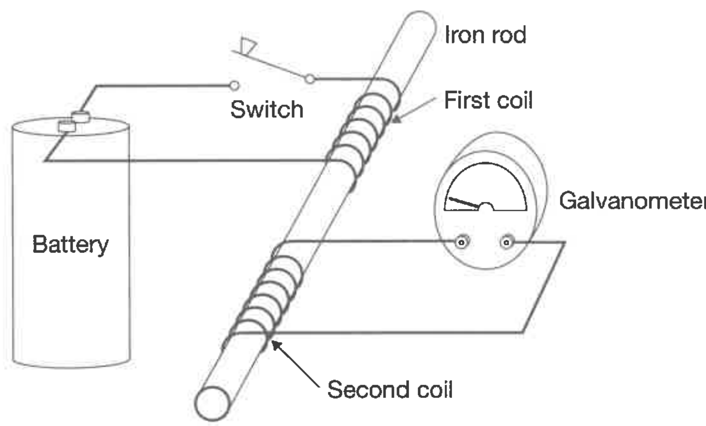
6.13.3.15 Consider the circuit shown in the diagram. Describe and explain what happens to the reading on the galvanometer when:



(a) The switch is closed. ....

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(b) The switch remains on. ....

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....

(c) The switch is turned off. ....

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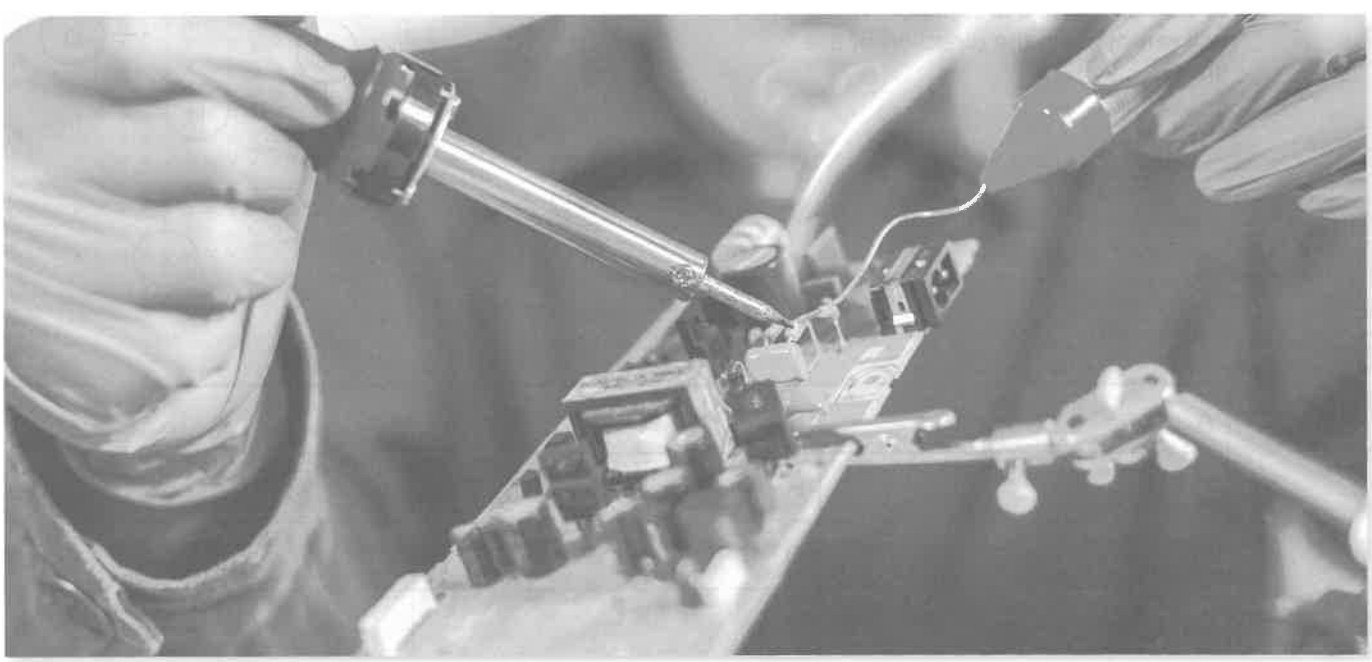


Science Press

6.14 Analyse quantitatively the operation of ideal transformers through the application of $\frac{V_p}{V_s} = \frac{N_p}{N_s}$ and $V_pI_p = V_sI_s$.

6.14.1 Transformers.

6.14.1.1 State the types and purposes of transformers in electrical circuits.

6.14.1.2 Compare step-up and step-down transformers in terms of their roles in a circuit and their structures.

6.14.1.3 A battery charger is used to recharge 1.5 V batteries through a 12 V transformer. The transformer has 2400 turns in the primary coil. Assuming 100% efficiency, calculate:

(a) The number of turns in the secondary coil.

(b) The output current if the input current is 10 mA.

6.14.1.4 A transformer changes 240 V to 24 000 V.

(a) Identify this as either a step-up or step-down transformer.

(b) Calculate the ratio of the number of turns in the primary to the secondary coils.

(c) Predict where this transformer might be used in your home.

6.14.1.5 A transformer changes 11 000 V to 240 V.

(a) Calculate the ratio of the number of turns in its coils.

(b) Identify the type of transformer this is.

(c) If the primary current is 5 A, calculate the theoretical secondary current.

(d) The output current is actually 10 A. Account for the difference between the theoretical output current and the actual output current.

(e) If the input coil had 2000 turns, calculate the number of turns there would be in the output coil.

6.14.1.6 Explain how a transformer works.

6.14.1.7 A transformer will not work with DC current. Explain why.

6.14.1.8 A commercial transformer (which has other circuit components to do other electrical 'jobs' built into it) has these characteristics printed on it: # Input AC 240 V, 50 Hz, 15 A

Output DC 12 V, 1.0 A

(a) Explain each of these characteristics.

(b) Identify this as a step-up or step-down transformer.

(c) State what else this transformer's other components are doing.

(d) If the input coil has 2000 turns, deduce the number in the output coil.

(e) Calculate what the output current should be, based on the voltage figures.

(f) Explain why the output current is rated at only 1 A.

(g) What observation of step-down transformers that you have used in your home supports your answer to (f). Explain your answer.

6.14.1.9 Who discovered the principle which means that the output voltage in a transformer depends on the ratio of the number of coils in the primary and secondary coils?

(A) Faraday. (B) Lenz. (C) Oersted. (D) Tesla.

6.14.1.10

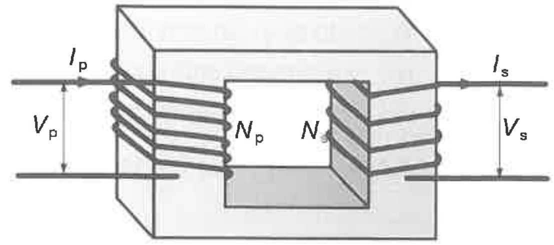
(a) Which statement about a step-up transformer is correct?

(A) Output current will always be larger than input current.
(B) Output current will always be smaller than input current.
(C) The relative sizes of the output and input currents will depend on the specifics of the coils used.
(D) The output current will only be smaller than the input current if the number of coils in the secondary coil is greater than the number in the primary coil.

(b) Justify your answer.

Science Press

6.14.1.11 The diagram shows a transformer.



(a) Identify this as a step-up or step-down transformer.

....

(b) Justify your answer. ....

....

....

(c) The transformer has 250 and 50 turns in its coils. Identify each coil. ....

....

(d) If the input voltage was 220 V, calculate the output voltage. ....

....

....

6.14.1.12

(a) Which choice correctly describes the power input and output of ideal transformers?

(b) What would be the answer if we were talking about 'real' transformers? Explain.

	Step-up transformer		Step-down transformer	
	Input power	Output power	Input power	Output power
(A)	*P*	*P*	*P*	*P*
(B)	*P*	< *P*	*P*	> *P*
(C)	*P*	> *P*	*P*	< *P*
(D)	*P*	< *P*	*P*	< *P*

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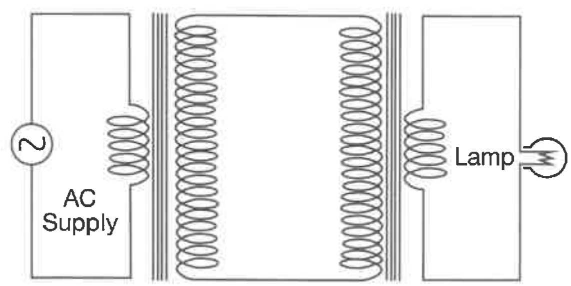
6.14.1.13 The diagram shows two transformers connected into a circuit.



(a) Assuming the coils are drawn to scale, compare the input AC current with the current in the lamp.

....

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(b) Compare the input AC voltage with the voltage across the lamp.

....

....

(c) State whether the power loss in transmission lines depends on the voltage across them or the current in them.

....

(d) Assess the value of having a transformer like this connected into a circuit. ....

....

(e) What type of transformer is needed at a substation which distributes electrical power to suburban homes. Justify your answer.

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6.14.1.14

(a) What do step-up and step-down transformers have in common?

(A) Laminated soft iron core.
(B) More turns in the secondary coil.
(C) Primary to secondary coil ratio.
(D) Voltage input size.

(b) Why do they have this feature in common? ....

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6.14.1.15 Complete the table by listing ten appliances in your home that use transformers and state whether they are step-up or step-down transformers.

	Appliance containing transformer	**Step up or down?**
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

6.14.1.16

(a) Four students made statements about transformers.

Jodie: The voltage produced by a transformer coil is directly proportional to the number of turns in the coil.

Toula: The voltage produced by a transformer coil is indirectly proportional to the number of turns in the coil.

Xaiou: The current produced by a transformer coil is directly proportional to the number of turns in the coil.

Burak: The current produced by a transformer coil is indirectly proportional to the number of turns in the coil.

Who is correct?

(A) Only Jodie.
(B) Jodie and Xaiou.
(C) Jodie and Burak.
(D) Toula and Xaiou.

(b) Justify your answer. ....

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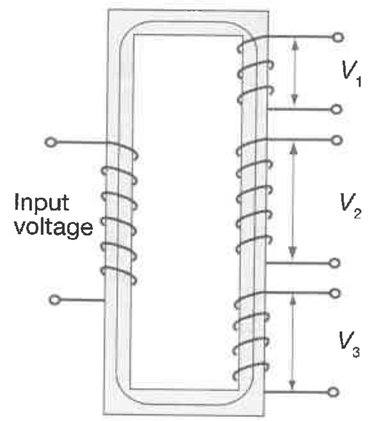
6.14.1.17 The diagram shows a transformer combination. If V_2 reads 720 V and feeds 18 A to its output circuit, calculate the voltage and current input and output from the other coils.



(a) From input. ....

....

....

(b) From V_2. ....

....

....

(c) From V_3. ....

....

....

6.14.1.18

(a) The ratio of the turns in the primary coil to those in the secondary coil of a transformer is 3 : 16. If the input voltage is 48 V, what will be the output voltage?

(A) 9 V
(B) 144 V
(C) 256 V
(D) 768 V

(b) What will be the ratio of the input current to the output current? ....

....

6.14.1.19

(a) A Christmas tree contains a string of 24 1.5 volt lights in series with each other. They are connected through a transformer to a 240 V supply. The transformer has 640 turns in its primary coil. How many turns does it have in its secondary coil?

(A) 4
(B) 48
(C) 96
(D) 4267

(b) Which choice *must* be incorrect? Explain. ....

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6.14.1.20 Explain how the law of conservation of energy applies to transformers. ....

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6.14.1.21

(a) Does the diagram show a step-up or a step-down transformer?

....

....

(b) If the input is 240 V, 10 A, what is the output?

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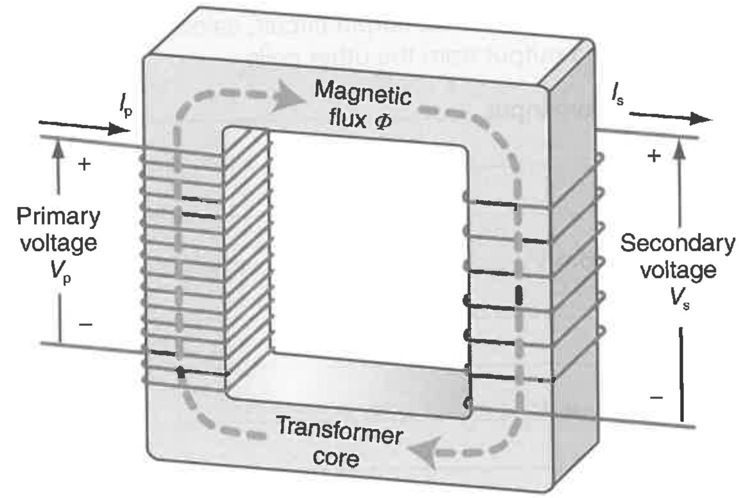

Use the following information to answer the next TWO questions.

A neon shop sign operates at maximum efficiency if a voltage of 6000 V is applied.

6.14.1.22 What would be the ratio of the number of coils in the secondary coil to the number in the primary coil of the transformer needed to run it efficiently from a 240 V supply line?

(A) 1 : 25
(B) 1 : 40
(C) 25 : 1
(D) 40 : 1

6.14.1.23 Why is such a high voltage needed?

(A) Gases are not good conductors of electricity so to get the electrical discharges needed to light up the tube a high voltage is needed.
(B) Gases are not good conductors of electricity so to get the electrical discharges a very low gas pressure is required inside the tubes.
(C) Neon signs are large and a large voltage is required to enable electrons to travel the length.
(D) Neon signs use a lot of energy so a large input of energy is required.

6.14.1.24 A transformer is to be used to run a 45 V system from a 240 V supply line. Which choice shows a possible number of turns in each of its primary and secondary coils?

	Primary coil	Secondary coil
(A)	500	94
(B)	7500	1250
(C)	40 000	7500
(D)	10 000 000	1 500 000

6.14.1.25 Some students built a transformer and connected it to the DC terminals of a power supply. It failed to work. Which choice best accounts for this?

(A) Electromagnetic induction only occurs in the presence of changing magnetic fields.
(B) The DC current was probably not large enough to cause induction of strong magnetic fields.
(C) Alternating current is needed for the electrons in the transformer coils to oscillate back and forth.
(D) They probably connected the transformer coils into the circuit with reverse polarities.

6.15 Evaluate qualitatively the limitations of the ideal transformer model and the strategies used to improve transformer efficiency, including but not limited to incomplete flux linkage and resistive heat production and eddy currents.

6.15.1 **Transformers and electricity transmission.**

6.15.1.1

(a) What is flux linkage? ....

....

(b) Explain how the number of turns in a solenoid coil affects its flux linkage. ....

....

(c) What is meant by incomplete flux linkage? ....

....

(d) How does incomplete flux linkage affect the efficiency of a transformer? ....

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6.15.1.2 Without transformers, electricity in our homes would be costly. It would certainly be very differently supplied. Explain why.

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6.15.1.3 Describe the purpose of transformers in electrical transmission circuits. ....

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6.15.1.4 Electricity is transmitted from power stations at 500 kV. This is transformed at substations to 132 kV for distribution to regional suppliers where it is further transformed to 33 kV and then to 11 kV for distribution to street networks. Pole mounted transformers change this to 415 V for use in factories. Before entering homes, it is further transformed to 240 V.

(a) Assuming the last transformer in this chain has an output coil with 1000 turns, calculate the sizes of the other coils in the system. Put your answers in the table provided.

(b) If the current entering your home is 15 A, calculate the current flowing in all the other transmission lines. (Assume power transmission is the same in all lines.) Put these answers in the table also.

Where	Homes	Factories	Street networks	Suburban substation	City substation	Power stations
Voltage	240					
Coils						
Current						

(c) From your answers, propose a reason why electricity is transmitted over long distances at very high voltages.

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6.15.1.5 Power throughout Australia is transmitted over long distances at between 300 000 and 500 000 V. A typical power station transmits 40 MW of power through 4 ohm km^{-1} lines.

(a) What would be the current in the 500 000 V lines? ....

....

....

(b) How much power would be lost in this line per km? ....

....

(c) What percentage of the power would be lost over 50 km? ....

....

....

6.15.1.6 How are energy losses in transmission lines minimised?

(A) By transmitting at high voltage and high current.

(B) By transmitting at high voltage and low current.

(C) By transmitting at low voltage and high current.

(D) By transmitting at low voltage and low current.

6.15.1.7

(a) Complete the table to calculate possible energy losses during electricity transmission. Assume the power station is producing 4.0 MW of power, and needs to transmit it 50 km through 4 ohm km^{-1} lines.

Transmission voltage (V)	30 000	50 000	250 000	500 000
Power generated	4 MW	4 MW	4 MW	4 MW
Current in lines $I = \frac{P}{V}$				
Power loss in lines ($P = I^2R$)				
Power left after losses				
Power lost (%)				

(b) What are the implications in your calculations above for the transmission of power over significant distances?

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6.15.1.8

(a) What is the main cause of energy losses in transmission lines?

(A) Interaction of the current with resistance in the lines.

(B) The high current in the lines.

(C) The distance the electricity needs to be transmitted.

(D) The high voltage needed to transmit the electricity efficiently.

(b) Explain how this energy loss occurs. ....

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6.15.1.9

(a) Why don't we use direct current to supply electricity to communities?

(A) DC production causes more pollution than AC.

(B) DC cannot be transformed.

(C) DC cannot be produced at high enough voltages.

(D) Sufficiently large currents cannot be produced.

(b) Explain your answer. ....

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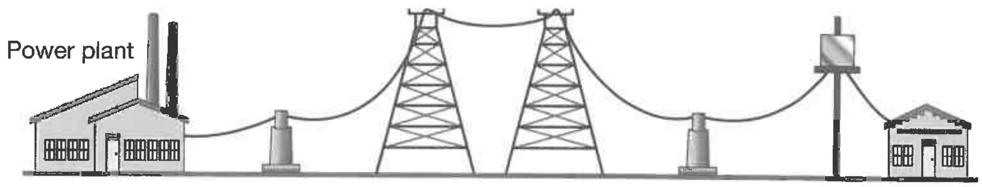
6.15.1.10

(a) Consider the following diagram which shows an electrical transmission system.



At which position in this system would you find a step-up transformer?

(A) A (B) B (C) C (D) D

(b) What is the voltage in the transmission lines between A and C? ....

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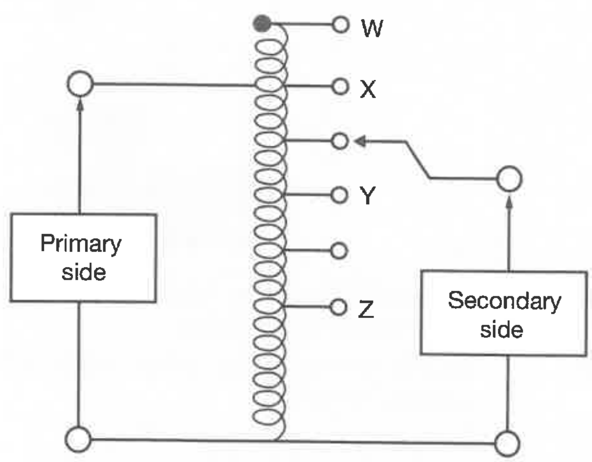
6.15.1.11 The diagram shows a variable output transformer. Depending on the output connections chosen, the output voltage can be varied.



(a) How many different output voltages are possible?

....

....

(b) Suppose the input voltage is 300 V. Estimate the output voltage (round off to the nearest 5 V) when the connection used is:

(i) W ....

(ii) X ....

(iii) Y ....

(iv) Z ....

(c) What is the output voltage (to the nearest 5 V) at the connection shown in the circuit? ....

....

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6.16 Analyse applications of step-up and step-down transformers, including but not limited to the distribution of energy using high voltage transmission lines.

6.16.1 **Applications and impacts of transformers.**

6.16.1.1 Imagine this question to be worth, say, 4 marks which means you should write at least 8 lines if good, solid non loopy writing physics.

Summarise three major impacts of the generation and transmission of electricity on people (society). Make sure your answer states generalities then goes deeper to analyse the 'chain reaction' impacts – the 'flow-on' effects of each generality.

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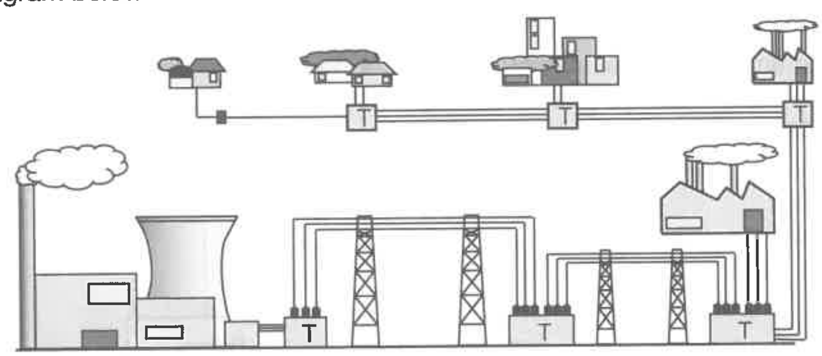
6.16.1.2 Consider the diagram below.



(a) On each transformer (labelled T) in the diagram, place a 'U' if it is a step-up transformer and a 'D' if it is a step-down transformer.

(b) Explain the reasoning behind having different transformers at different positions along this type of distribution line.

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6.16.1.3 When you charge your mobile phone or iPad or whatever, the transformer included in the charging lead gets hot. Explain why.

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Applications Of the Motor Effect

6.17 Investigate the operation of a simple DC motor to analyse the functions of its components and the production of a torque ($\tau = nBA\cos\theta$) and the effects of back emf.

INQUIRY QUESTION

How has knowledge about the motor effect been applied to technological advances?

6.17.1 **Torque on a coil 1.**

6.17.1.1 Define torque. ....

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6.17.1.2 Write the equation we use to find the torque on a current carrying coil in a magnetic field and identify each of the symbols in the equation and the units used to measure them.

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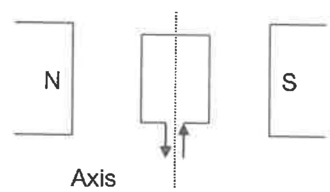
6.17.1.3 The diagram shows a 250 turn 5 × 8 cm coil carrying 4.0 A of current in a magnetic field of strength 0.2 T. The coil is free to turn around the axis shown.



(a) What is the magnitude of the force, F, acting on the two sides of the coil which are perpendicular to the magnetic field?

(A) 10 N (B) 16 N (C) 100 N (D) 1600 N

(b) To determine the maximum torque on this coil, this force needs to be multiplied by what?

(A) 0.025 (B) 0.04 (C) 0.05 (D) 0.08

(c) The coil is now rotated through some angle θ. How do we calculate the new torque on it?

(A) $F \times 0.04 \times \cos\theta$ (B) $F \times 0.05$ (C) $F \times 0.08$ (D) $F \times 0.05 \times \cos\theta$

6.17.1.4 Which statement is correct if a coil is perpendicular to a magnetic field?

(A) The torque is maximum because $\cos\theta = 1$.

(B) The torque is maximum because the perpendicular distance between the forces on opposite sides of the coil is maximum.

(C) The torque is minimum because the forces on the opposite sides of the coil are zero.

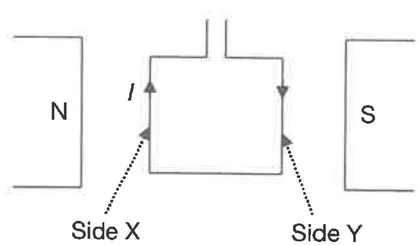
(D) The torque is minimum because the perpendicular distance between the forces on opposite sides of the coil is zero.

Use the following information to answer the next FOUR questions.

A current carrying coil lies in a magnetic field as shown. It also hangs on fine wires and is able to rotate.

6.17.1.5 Which choice correctly describes the forces on the two vertical sides X and Y of the coil?

	Side X	Side Y
(A)	Out of the page	Into the page
(B)	Into the page	Out of the page
(C)	To the left	To the right
(D)	To the right	To the left



6.17.1.6 What are the directions of the forces on the top and bottom wire of the coil? Explain. ....

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6.17.1.7

(a) What will the coil do as a result of these forces?

(A) Rotate clockwise. (B) Rotate anticlockwise. (C) Become circular. (D) Remain stationary.

(b) Explain your answer. ....

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6.17.1.8

(a) How far will it rotate?

(A) 90° then stop. (B) 180° then stop. (C) Continuously. (D) It does not rotate.

(b) Explain your answer.

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6.17.1.9 A square coil experiences a torque of X N m. What is the new torque if both the current flowing through it and the number of turns in the coil are doubled and the lengths of the sides of the coil are halved?

(A) $0.5X$ (B) X (C) $2X$ (D) $8X$

6.17.1.10 Consider a coil in a magnetic field and carrying a current as shown in the diagram.

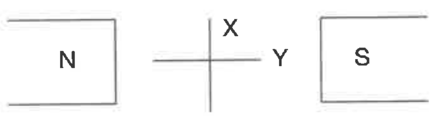
What will happen to the torque on the coil if both the magnetic field and the current are reversed?

(A) The magnitude will be unchanged but the direction will be reversed.
(B) The magnitude will double but the direction will be unaffected.
(C) The magnitude will be doubled but the direction will be unaffected.
(D) The magnitude and direction will be unchanged.

6.17.1.11 A 10 cm square coil with 25 turns is suspended in a magnetic field. It experiences a maximum torque of 0.35 N m when a current of 0.4 A flows through it. What is the strength of the magnetic field it is in?

(A) 3.5×10^{-3} T (B) 0.035 T (C) 3.5 T (D) 8.75 T

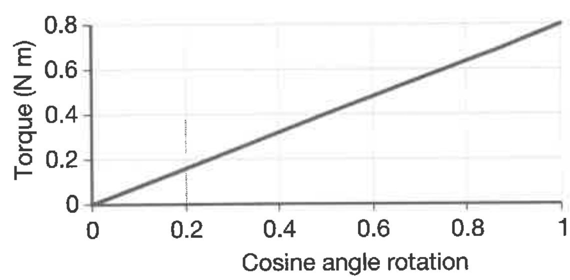
6.17.1.12 Consider a current carrying coil in a magnetic field in two positions X and Y as shown.



Which choice correctly describes the force on each side of the coil and the torque on the coil in each position?

	Coil at position X		Coil at position Y	
	Force on side	Torque on coil	Force on side	Torque on coil
(A)	0	0	Maximum	Maximum
(B)	Maximum	Maximum	Maximum	0
(C)	Maximum	0	Maximum	Maximum
(D)	0	Maximum	0	Maximum

6.17.1.13 A 250 turn coil with an area of 16 cm² has a current of 4 A flowing through it. A student measured the torque on the coil as it rotated and plotted his results to obtain the graph shown.



(a) What was the strength of the magnetic field in which the coil was turning?

(A) 5×10^{-5} T (B) 7.8×10^{-5} T
(C) 0.5 T (D) 0.78 N m

(b) What would be the effect on the torque of doubling the number of turns in the coil?

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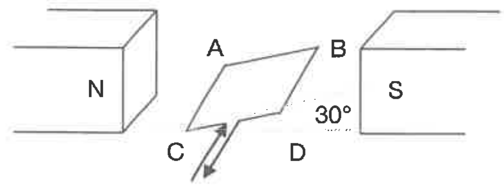
Science Press

6.17.2 Torque on a coil 2.



6.17.2.1 A 5.0 cm square coil with 150 turns of wire is in a magnetic field of intensity 0.25 T. The plane of the coil makes an angle of 30° with the field as shown in the diagram. The coil carries a current of 3.0 A.

(a) Calculate the magnitude of the force acting on each side of the coil.

AB = ...

....

BC = ...

....

CD = ...

....

CA = ...

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(b) Calculate the torque on the coil. ....

....

(c) Predict the position of the coil relative to the magnetic field when the torque on it is maximum.

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(d) Predict the position of the coil relative to the magnetic field when the torque on it is minimum.

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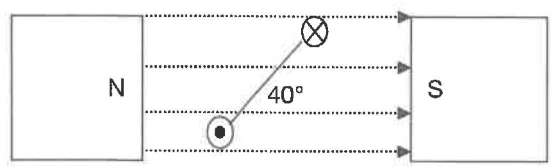
6.17.2.2



(a) The diagram shows the end of a rectangular coil with 50 turns in a 0.03 T magnetic field. The coil has an area of 25 cm^2 and makes an angle of 40° with the field. The current in the coil is 1.25 A.

What is the torque on the coil?

(A) 3.6×10^{-3} N m clockwise.
(B) 3.6×10^{-3} N m anticlockwise.
(C) 35.9 N m clockwise.
(D) 35.9 N m anticlockwise.

(b) How would the answer differ if the coil was a '25 cm square' coil? ....

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6.17.2.3 In the space below, describe and draw an appropriate diagram to describe how the torque on a current carrying coil in a magnetic field changes as the coil rotates through 360°. Assume that the coil starts parallel to the field.

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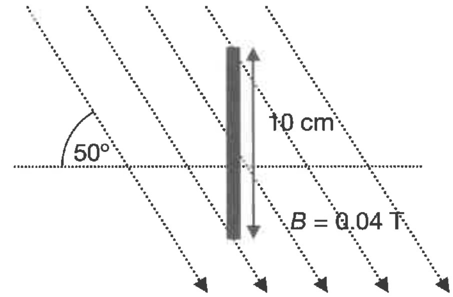
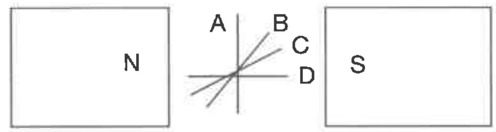
6.17.2.4 A 250 turn, 10 cm square coil carrying 3.2 A of current is placed in a magnetic field of strength 0.04 T as shown.



What is the magnitude of the torque on the coil?

(A) 0.21 N m
(B) 0.25 N m
(C) 1.6 N m
(D) 3.2 N m

6.17.2.5 The diagram shows four positions of a coil in a magnetic field.

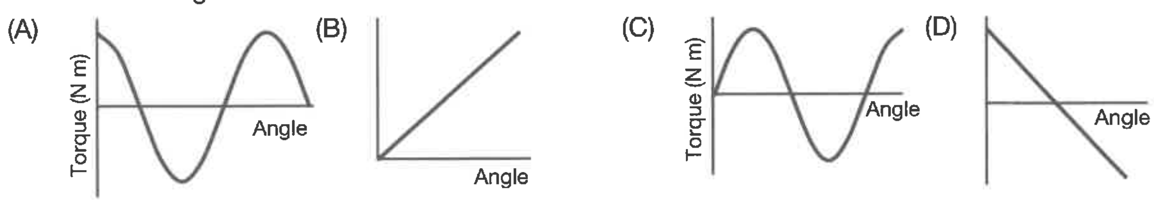


In which position would the torque on the coil be maximum?

(A) A (B) B (C) C (D) D

6.17.2.6

(a) Which graph best shows the relationship between the torque on a current carrying coil in a magnetic field and the angle the coil makes with the field.



(b) Explain how you arrived at your answer. ....

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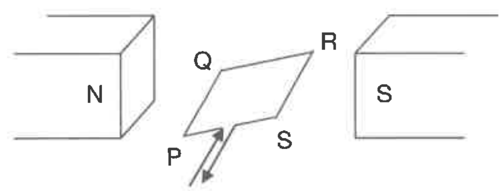
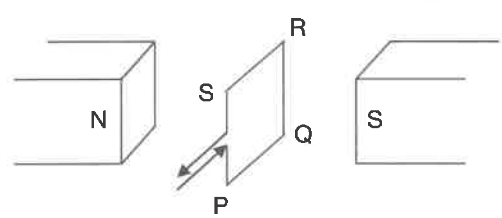
6.17.2.7 A 200 turn coil in a 0.02 T magnetic field is carrying a current of 6 A as shown. The length of side PQ is 10 cm and QR is 6 cm. This coil is rotated so that it makes an angle of 30° with the magnetic field.



(a) What is the magnitude of the torque on the coil in this new position?

(A) 0 N m (B) 0.125 N m
(C) 12.5 N m (D) 125 N m

(b) The coil is rotated so that it is perpendicular to the magnetic field. What is the magnitude of the torque on the coil in this new position?



(A) 0 N m (B) 0.144 N m
(C) 14.4 N m (D) 144 N m

6.17.3 **Simple DC motors.**

6.17.3.1 Outline the principles by which a simple DC motor operates. ....

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6.17.3.2

(a) A DC motor has a square coil with 2500 turns. Which statement about this motor is correct?

(A) The slip rings reverse the direction of current flow every half rotation.

(B) The torque on the coil is maximum when it is parallel to the magnetic field.

(C) When it is running, the back emf reduces the net torque to zero.

(D) Carbon brushes allow produced current to flow into the external circuit.

(b) A similar motor has 5000 turns in its coil. Compare the torques these motors will develop.

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6.17.3.3

(a) Which statement best describes the role of the split rings in a DC motor?

(A) To ensure that the direction of the current in the coil stays constant relative to the magnetic field.

(B) To ensure that the direction of the current in the coil relative to the magnetic field changes every 180° of rotation.

(C) To ensure that the direction of the current in the coil always flows in the same direction.

(D) To ensure that the direction of the current in the coil changes with its position.

(b) Explain your answer. ....

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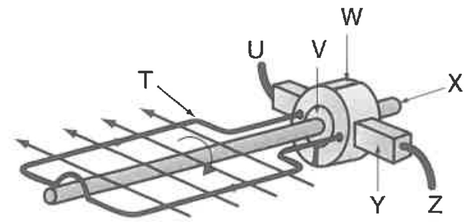
6.17.3.4 The diagram shows a simple DC motor. The directions of the magnetic field and current are shown.



Magnetic field

(a) Which choice correctly identifies each labelled component of this motor?

	T	W	X	Y
(A)	Current	Split ring	Armature	Brush
(B)	Coil	Rotor	Axle	Split ring
(C)	Coil	Armature	Soft iron core	Split ring
(D)	Coil	Split ring	Axle	Brush

(b) If this motor rotates anticlockwise, determine the direction of the current flowing through the coil.

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(c) Which choice correctly identifies the component labelled V in the motor and its function?

(A) Conducting ring to join the two halves of the commutator.

(B) Insulating disc to prevent short circuiting the split rings.

(C) Conducting ring to connect the coil to the split rings.

(D) Insulating disc to stop the coil from touching the split rings.

(d) Explain your answer. ....

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(e) What is the function of the split rings in a simple DC motor?

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6.17.3.5 Electric motors often have the following:

1. Electromagnets.
2. More than one coil.
3. A laminated soft iron core.

(a) Which of these helps increase the output power of the motor?

(A) 1 only. (B) 1 and 2 only.
(C) 3 only. (D) 1, 2 and 3.

(b) Justify your answer. ....

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6.17.3.6

(a) Why do we use electromagnets instead of permanent magnets in motors?

(A) The field produced by permanent magnets is not as uniform.
(B) It is difficult to produce radial fields with permanent magnets.
(C) Electromagnets can produce stronger magnetic fields.
(D) Electromagnets are much lighter than permanent magnets.

(b) How could we increase the strength of a set of electromagnets?

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6.17.3.7

(a) Which of the following is an advantage of using electromagnets in a motor rather than permanent magnets?

(A) The have fewer moving parts and so the motor is more reliable.
(B) Their strength can be easily changed to vary the motor's torque.
(C) They are stronger and so the motor will be more efficient.
(D) They simplify its structure and make them cheaper.

(b) Justify your answer. ....

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6.17.4 Back emf in motors.

6.17.4.1 Clarify the term 'back emf'. ....

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6.17.4.2 Explain how a back emf is produced in a motor.

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6.17.4.3 Explain the consequences of back emf for the design of an electric motor and the supply voltage.

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6.17.4.4 A motor is connected in series with an ammeter and a 12 V power supply. The internal resistance of the motor is 1.5 Ω. When the motor is running at full speed, the ammeter reads 3.0 A. Account for this.

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6.17.4.5 Recall Lenz's law. ....

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6.17.4.6 When we apply Lenz's law to a situation, which principle in physics is being utilised?

(A) Newton's third law.

(B) The motor effect.

(C) The law of conservation of momentum.

(D) The law of conservation of energy.

6.17.4.7 Consider these two statements:

1. Motors are used to convert electrical energy into mechanical energy.
2. As a motor is used, some reverse energy conversion must occur.

(a) Which choice best evaluates statement 2?

(A) The statement is correct because motors can be connected in reverse and used as generators.

(B) The statement is correct because the induction of a back emf occurs in all coil motors.

(C) The statement is incorrect as this would violate the law of conservation of energy.

(D) The statement is correct only if the motor is inefficient. If the motor is operating efficiently, all energy input is converted to mechanical energy output.

(b) Identify the principles in physics involved in this concept and state where they are involved in the operation of the motor.

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6.17.4.8

(a) When the load on a DC motor is increased, its speed decreases. What other quantity decreases?

(A) The input voltage.

(B) The input current.

(C) The back emf.

(D) Its internal resistance.

(b) Explain why this happens. ....

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6.17.4.9 Several students were debating the consequences if the 'Lenz's law of force' on the coil of a motor was in the same direction as the rotation of the coil. Their statements included:

John: The motor would run more efficiently.

Azzi: The motor armature would rotate faster.

Chahin: The law of conservation of energy would be violated.

Thao: There would no longer be need for a continuous supply energy input.

(a) Who is correct?

(A) Chahin only.

(B) Azzi, and Chahin only.

(C) John, Azzi and Thao only.

(D) John, Azzi, Chahin and Thao.

(b) Evaluate John's statement. ....

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6.17.4.10

(a) An electric motor often has a variable resistor in series with its coil. What is the purpose of this variable resistor?

(A) To reduce initial input current to protect the coil windings.

(B) To increase the input current and improve the efficiency of the motor.

(C) To reduce both the input current and the operating current.

(D) To increase the operating current and protect the coil windings.

(b) Explain why this resistor is used. ....

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6.17.4.11

(a) Why is a motor more likely to burn out when it jams rather than when it is running normally?

(A) The large back emf when it jams produces an increase in current.

(B) The motor coil has more resistance when it jams.

(C) Eddy currents in the coil when it jams cause the coil to overheat.

(D) The net voltage across the coil increases when it jams.

(b) How is a motor protected against this possibility?

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6.17.4.12

(a) How do we reduce the back emf in a motor so that it works more efficiently?

(A) By using non-magnetic substances to make the core.

(B) By using radial field magnets.

(C) By laminating the soft iron core.

(D) We can't.

(b) Explain your answer. ....

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6.17.4.13

	Current in coils	Back emf
(A)	Increases	Increases
(B)	Increases	Decreases
(C)	Decreases	Increases
(D)	Decreases	Decreases

(a) As a builder drills a hole into a brick wall, the friction on the drill bit causes the armature of the drill to slow down. Which choice describes what happens to the current in the drill's coils and the back emf in these coils as the drill slows down?

(b) Explain your answer. ....

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6.17.4.14

(a) A car mechanic noticed that when his 240 V DC motor was operating at maximum speed, the voltage across its coil was significantly less than 240 V. Why?

(A) The coil in the motor has a high resistance.

(B) The motor is starting to wear out and is becoming less efficient.

(C) The coil in the motor has a back emf induced in it.

(D) There is a short circuit somewhere inside the motor.

(b) Explain, mentioning the principles in physics involved, your answer.

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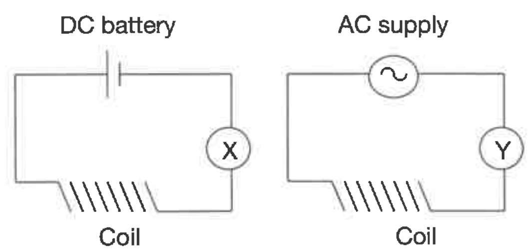
6.17.4.15 Identical globes, X and Y, are connected into two circuits as shown. They have an identical glow.



	Globe X	Globe Y
(A)	Same	Same
(B)	Same	Duller
(C)	Duller	Duller
(D)	Brighter	Brighter

(a) Which choice correctly describes what happens when a soft iron core is inserted into each coil?

(b) Explain your answer. ....

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6.18 Analyse the operation of simple DC and AC generators and AC induction motors.

6.18.1 Simple AC motors.

6.18.1.1 Compare the structure of a simple AC motor and a simple DC motor. ....

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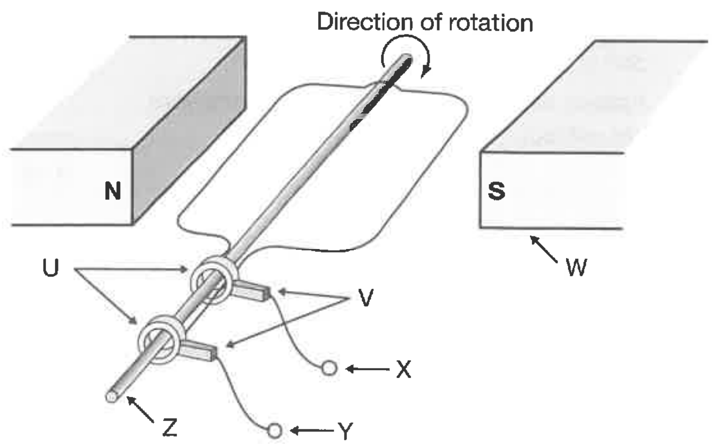
Use the following information to answer the next TWO questions.

The diagram shows a simple AC motor.



6.18.1.2 Identify each labelled part of the simple AC motor and state its function.

Part	Name of part	Function(s) of part
U		
V		
W		
X		
Y		
Z		

6.18.1.3 Which choice correctly identifies the way current flows through the generator coil (as you look at it) and part X and Z?

	Direction of current	X	Y
(A)	Anticlockwise	Negative terminal	Positive terminal
(B)	Anticlockwise	Positive terminal	Negative terminal
(C)	Clockwise	Negative terminal	Positive terminal
(D)	Clockwise	Positive terminal	Negative terminal

6.18.1.4 Two students gave the answers to a question which asked the function of the slip rings in a simple AC motor.

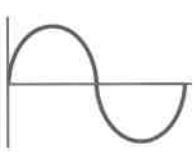
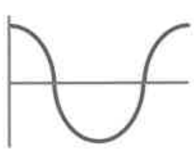
Student A: The function of the slip rings in a simple AC motor is to change the direction of the flow of current through the coil every 180° of rotation so that the torque on the coil is always in the same direction.

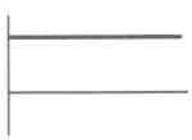
Student B: The function of the slip rings in a simple AC motor is to ensure that the direction of the current flow through the coil is in the same direction relative to the magnetic field so that the torque on the coil is always in the same direction.

(a) Assess whether or not these two answers are correct.

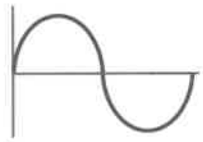
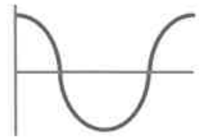
(b) Which of the two answers is the better answer? Explain your reasoning.

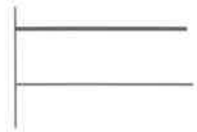
6.18.1.5 A simple AC motor coil rotates within a magnetic field. Initially the plane of the coil is parallel to the magnetic field. Which graph correctly shows the torque acting on the coil? Justify your choice.

(A)

(B)

(C)

(D)


6.18.1.6 An AC motor has radial magnets. Which graph correctly shows how the torque on the motor coil changes as it rotates? Justify your choice.

(A)

(B)

(C)

(D)


6.18.1.7 Which statement about an AC motor is correct?

(A) It has slip rings and carbon brushes.
(B) It has slip rings but no carbon brushes.
(C) It has a split ring commutator and carbon brushes.
(D) It has a split ring commutator but no carbon brushes.

6.18.1.8 Which statement about split rings and slip rings is correct?

(A) Neither are commutators.
(B) Only split rings are commutators.
(C) Only slip rings are commutators.
(D) Both are commutators.

6.18.1.9 What is the function of the slip rings on an AC motor?

(A) To change the direction of the supply current flowing into the coil.
(B) To provide electrical contact between the coil and the external circuit.
(C) To provide a constant magnitude torque on the coil.
(D) To change the direction of the torque on the coil every 180° of rotation.

6.18.1.10 Which statement about the flux through a simple AC motor coil is correct?

(A) It is constant in magnitude.
(B) It is maximum when the coil is parallel to the field.
(C) It is maximum when the coil is perpendicular to the field.
(D) Its magnitude changes every 180° of rotation.

6.18.1.11 Which statement about the flux through an AC motor coil is correct if the motor has a radial magnetic stator field?

(A) It is constant in magnitude.

(B) It is maximum when the coil is parallel to the field.

(C) It is maximum when the coil is perpendicular to the field.

(D) Its magnitude changes every 180° of rotation.

6.18.1.12 How could the operating power of an AC motor be increased?

(A) Use a thinner copper wire in the coil windings.

(B) Increase the frequency of the applied voltage.

(C) Increase the diameter of the coil.

(D) Increase the number of turns in the coil.

6.18.1.13 What would happen to the torque on the coil of a simple AC motor if the current flowing through it was doubled?

(A) It would also double.

(B) It would increase according to cos θ.

(C) It would increase but not double.

(D) It would stay the same.

6.18.1.14 What effect would increasing the frequency of the supply voltage have on an AC motor?

(A) The coil would rotate more slowly.

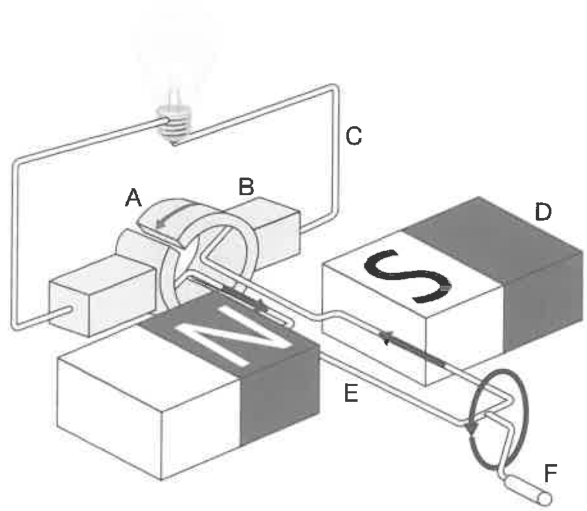
(B) The coil would rotate faster.

(C) There would be no effect on the coil.

(D) The torque on the coil would double.

6.18.2 DC generators.

6.18.2.1 The diagram shows a simple DC generator.



Identify the labelled parts of this generator and state the function of each part.

Part	Name of part	Function of part
A		
B		
C		
D		
E		
F		

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6.18.2.2 What would be the effect of each of the changes below on the current produced by a generator?

(a) Decreasing the number turns in the coil.

(b) Rotating the coil faster.

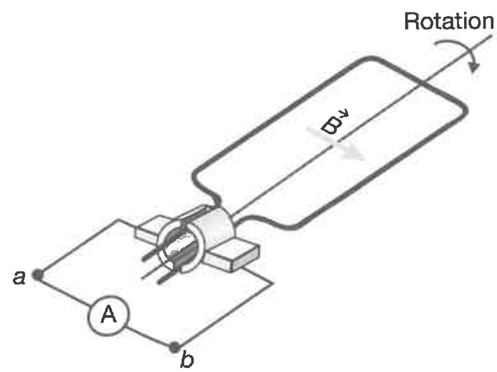
(c) Increasing the strength of the magnetic field.

(d) Winding the coil on a soft iron coil rather than an air coil.

(e) Having two coils at 90° to each other.

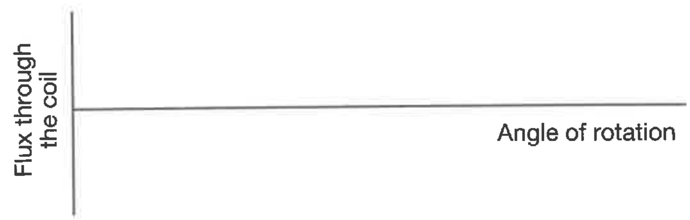
6.18.2.3

(a) The diagram shows a simple DC generator and several positions of the coil as it rotates within the magnetic field. Draw graphs on the axes provided to show the various relationships indicated. (*Note:* The starting position of the coil for the graphs does not match the position in the circuit.)

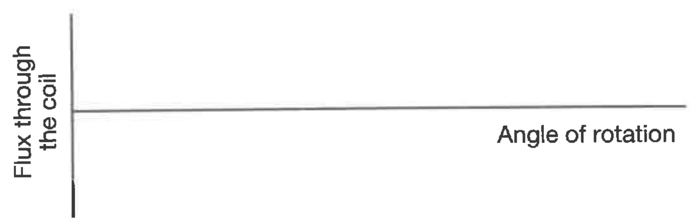


(b) Predict which way the current delivered to the external circuit will flow through the ammeter.

(c) Imagine that the rate at which the coil is turned by the external source is halved. What effect would this have on the output emf?



(d) Imagine that the number of turns in the coil is doubled. What effect would this have on the output emf?



(e) Imagine that the magnetic field strength containing the coil is tripled in strength. What effect would this have on the output emf?

(f) Imagine that the number of turns in the coil is halved, the magnetic field strength is doubled and the rate of rotation of the coil is increased by a factor of four. What effect would this have on the output emf?

6.18.2.4 Explain why the graph of the emf produced by a simple generator is a sinusoidal curve.

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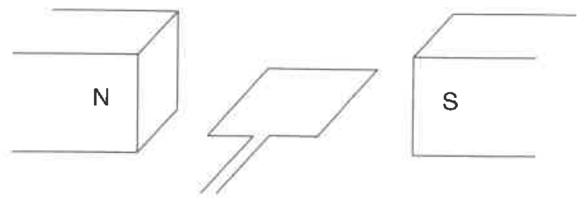
6.18.2.5 The diagram represents a DC generator which produces an output voltage as the coil rotates in the magnetic field.



(a) If the voltage produced as it passes the position shown is 5 V, what will it be as it rotates, at the same speed, at 90° to this position?

(A) 0 V (B) Less than 5 V but greater than 0 V.

(C) 5 V (D) Unable to determine with this data.

(b) Explain your answer. ....

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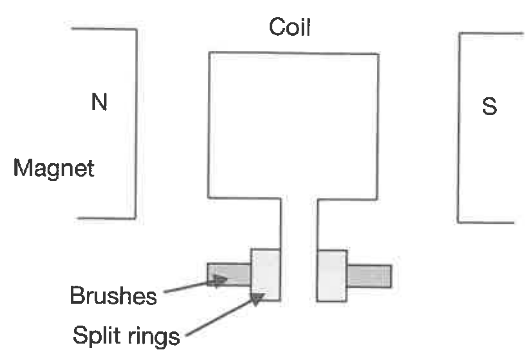
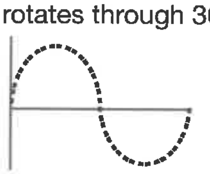
6.18.2.6 The diagram shows equipment used to generate a current.

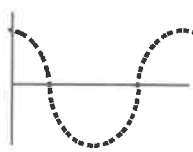


(a) Assuming that the coil starts from the position shown, which graph best shows the current delivered to the external circuit by this device as it rotates through 360°?

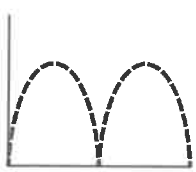
(A)



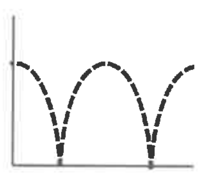
(B)



(C)



(D)



(b) Justify your answer. ....

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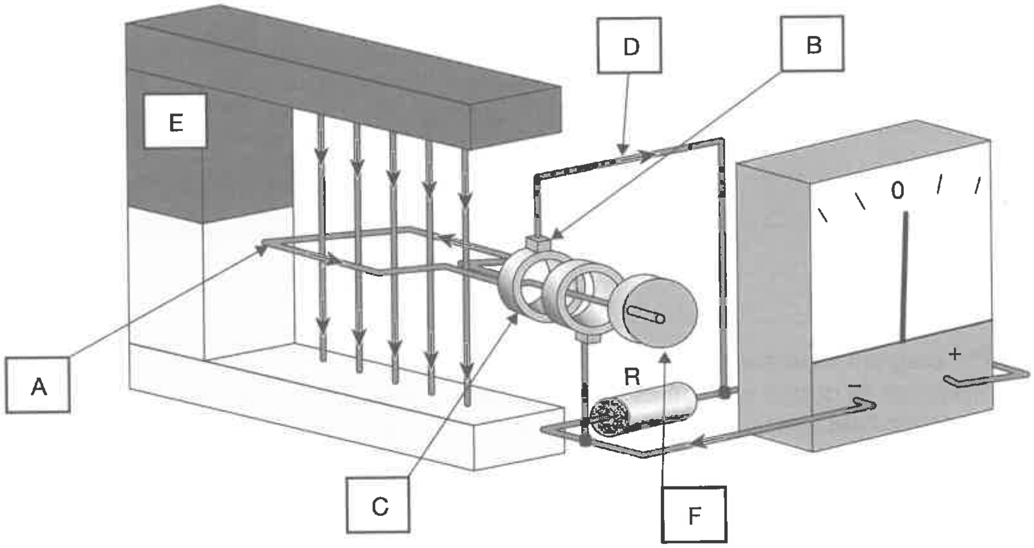
6.18.3 AC generators.

6.18.3.1 Identify the labelled parts of the generator shown and state their function.



Part	Name of part	Function of part
A		
B		
C		
D		
E		
F		

6.18.3.2 A generator produces a current of *I* A. Predict the current if all other factors remain constant but:

(a) The number of coils is doubled. ....

(b) The original coil is rotated at twice the speed. ....

(c) The magnetic field is halved. ....

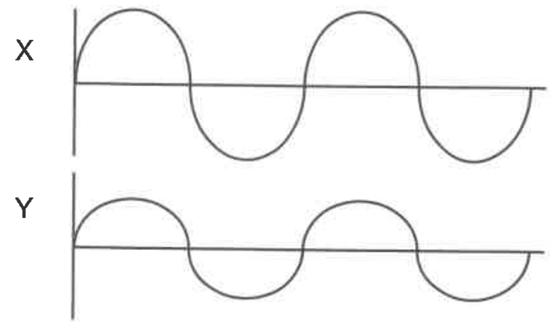
(d) Radial magnets are used. ....

6.18.3.3

(a) Sketch a graph to illustrate the emf produced by a simple AC alternator (generator) for two complete revolutions of its coil if the starting position of the coil is perpendicular to the magnetic field.

(b) Sketch a graph to illustrate the emf delivered to the external circuit by a simple AC alternator (generator) for two complete revolutions of its coil if the starting position of the coil is perpendicular to the magnetic field.

6.18.3.4 Consider the output from two AC generators X and Y over the same time period.



(a) If the generators have the same number of turns in their coils, what must be different about their structures to account for a difference in these graphs?

(A) X has a stronger set of field magnets.
(B) X has a larger supply current than Y.
(C) X has two sets of coils while Y has only one coil.
(D) X is rotating faster than Y.

(b) Explain your answer. ....

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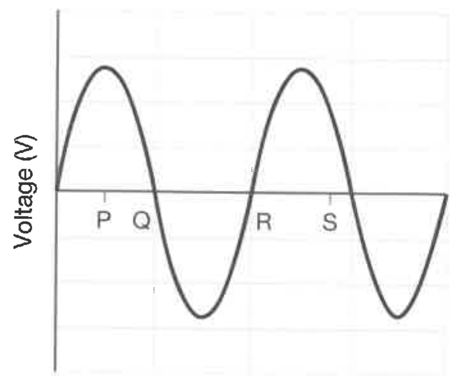
6.18.3.5 The graph shows how the voltage output from a generator varied with time.



(a) When does the coil of the generator cut flux at the greatest rate?

(A) At time P. (B) At time Q.
(C) At time R. (D) At time S.

(b) Justify your answer. ....

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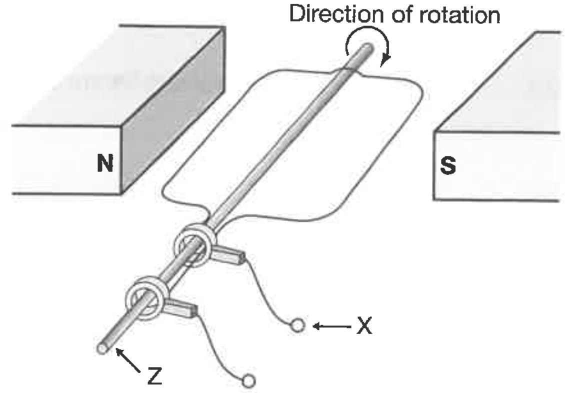
Use the following information to answer the next TWO questions.

The diagram shows a generator.



6.18.3.6 How does this generator differ structurally to the equivalent motor?

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6.18.3.7

(a) Which choice correctly identifies the way current flows through the generator coil (as you look at it) and parts X and Z while it is in the position shown?

(b) Explain how you arrived at your answer.

	Direction of current	X	Z
(A)	Anticlockwise	Negative terminal	Positive terminal
(B)	Anticlockwise	Positive terminal	Negative terminal
(C)	Clockwise	Negative terminal	Positive terminal
(D)	Clockwise	Positive terminal	Negative terminal

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6.18.4 Comparing DC and AC generators.

6.18.4.1 What causes the production of emf in a generator/alternator? ....

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6.18.4.2

(a) 'Both DC generators and AC alternators produce AC'. Evaluate this statement. ....

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(b) Explain why both DC generators and AC alternators produce AC internally. ....

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6.18.4.3

(a) Identify the diagram as showing an AC or a DC generator. Justify your answer.

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(b) Identify how the other type of generator would be different from the generator shown.

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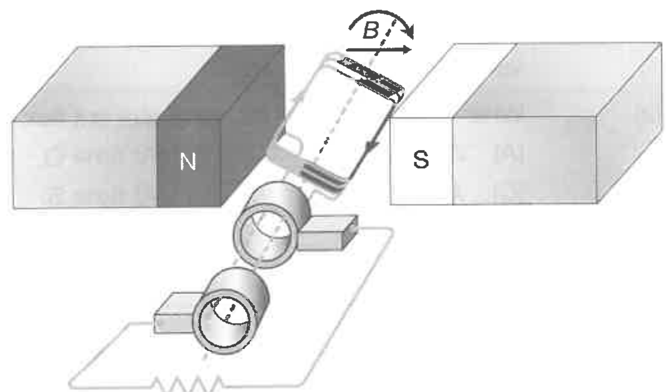

6.18.4.4

(a) Identify the structural difference between an AC and a DC generator. ....

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(b) Identify the structural difference between an AC and a DC motor. ....

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(c) Identify the structural difference between an AC generator and an AC motor. ....

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(d) Identify the structural difference between an AC generator and a DC motor. ....

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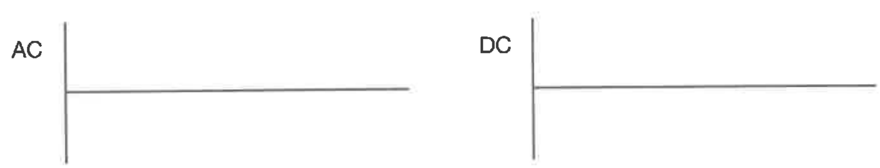
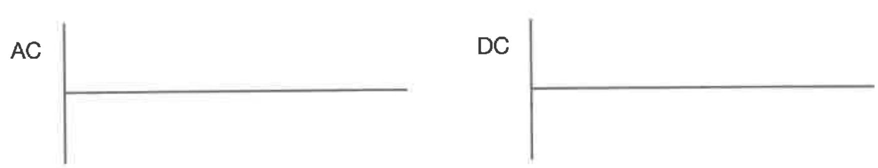
6.18.4.5 Sketch graphs to illustrate the difference in the output from simple AC and DC generators for two complete revolutions of their coils.



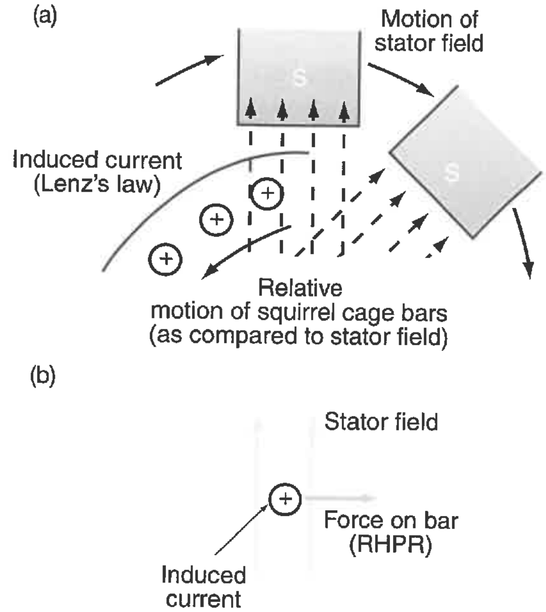
6.18.4.6 Sketch graphs to illustrate athe difference in the emf produced internally in simple AC and DC generators for two complete revolutions of their coils.



6.18.5 AC induction motors.

6.18.5.1 The diagrams show how an AC induction motor works.

With reference to any principles in physics involved, explain the message in these diagrams. Word process your answer, which will possibly be about a page in length, and summarise your main points here.



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6.18.5.2

(a) Why is the output from an AC induction motor lower than other motors?

(A) The squirrel cage is relatively heavy and difficult to move.

(B) The magnetic fields lose significant energy as they rotate.

(C) Significant energy is lost in the induction of currents in the squirrel cage.

(D) The squirrel cage becomes magnetised and opposes attempts to move it.

(b) Recall three devices in which we use AC induction motors. ....

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6.18.5.3 Which statement correctly describes an induction motor? It is:

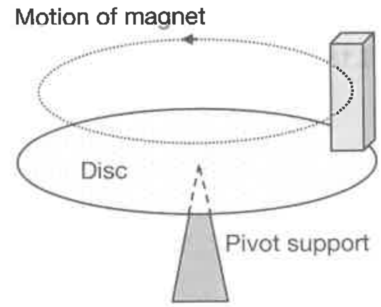
(A) An AC or DC motor in which torque is produced by the interaction of a rotating magnetic field in the stator with induced magnetic fields of the induced current in the rotor.

(B) An AC only motor in which torque is produced by the interaction of a rotating magnetic field in the stator with induced magnetic fields of the induced current in the rotor.

(C) An AC or DC motor in which torque is produced by the interaction of a rotating magnetic field in the stator with induced magnetic fields of the supplied current in the rotor.

(D) An AC only motor in which torque is produced by the interaction of a rotating magnetic field in the stator with induced magnetic fields of the supplied current in the rotor.

6.18.5.4 An aluminium disc which is free to move is pivoted horizontally as shown.



A magnet is moved in a circular path above the disc.

(a) What will the disc do as a result of the motion of the magnet?

(A) Stay stationary.
(B) Rotate in the same direction as the magnet.
(C) Rotate in the opposite direction of the magnet.
(D) Either (B) or (C) depending on the pole of the magnet closest to the disc.

(b) Who discovered the principle that is being applied here and what is that principle?

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(c) What does the effect shown apply to?
(A) DC motors. (B) AC generators. (C) Galvanometers. (D) Induction motors.

(d) Why would this device (as shown) be inefficient? ....

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6.18.5.5

(a) Which of the following statements about an AC induction motor is correct?

(b) What does move in an induction motor? Clarify.

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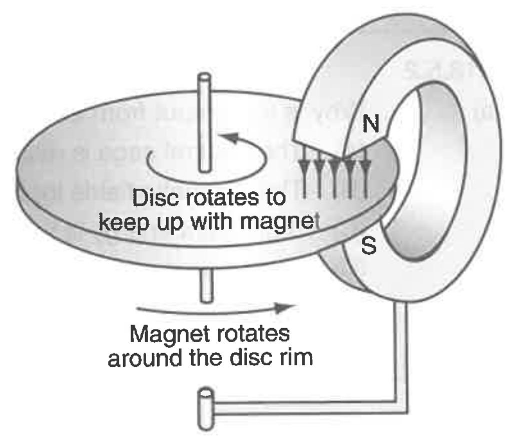
	Squirrel cage	Where electric currents are induced
(A)	Rotor	Rotor
(B)	Rotor	Stator
(C)	Stator	Rotor
(D)	Stator	Stator

6.18.5.6 The diagram shows an alternate structure for an induction motor.

(a) Explain how this might work. ....



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(b) Predict the efficiency of an induction motor designed on this principle. Justify your answer.

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6.19 Relate Lenz's law to the law of conservation of energy and apply the law of conservation of energy to DC motors and magnetic braking.

6.19.1 Lenz's law and the conservation of energy.

6.19.1.1 Account for Lenz's law in terms of conservation of energy (it may be useful to use an example).

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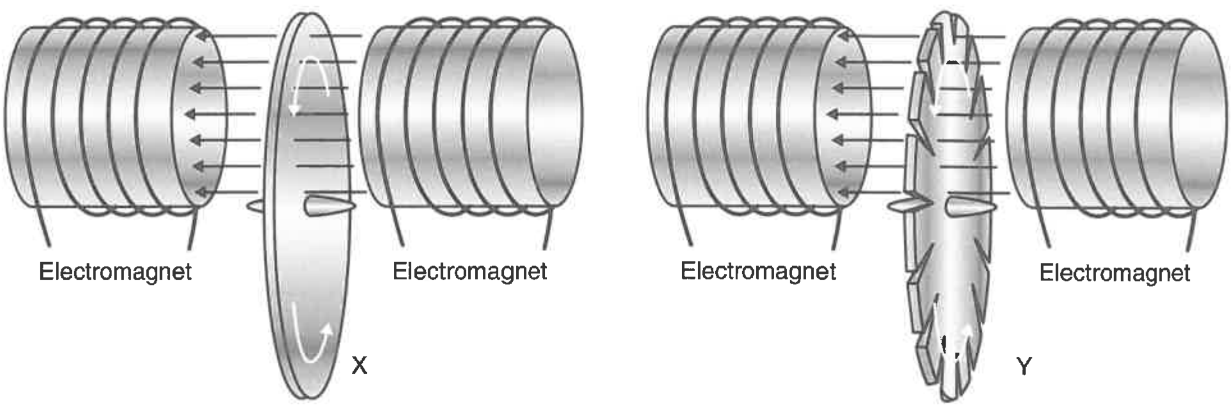
6.19.1.2 Two aluminium discs are rotated between electromagnets as shown in the diagram below.



(a) Predict, and account for, what happens to disc X as it spins on its axle. ....

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(b) Compare the rotation of disc Y with that of disc X. Account for any difference. ....

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(c) Explain what happens to both these discs with reference to the law of conservation of energy.

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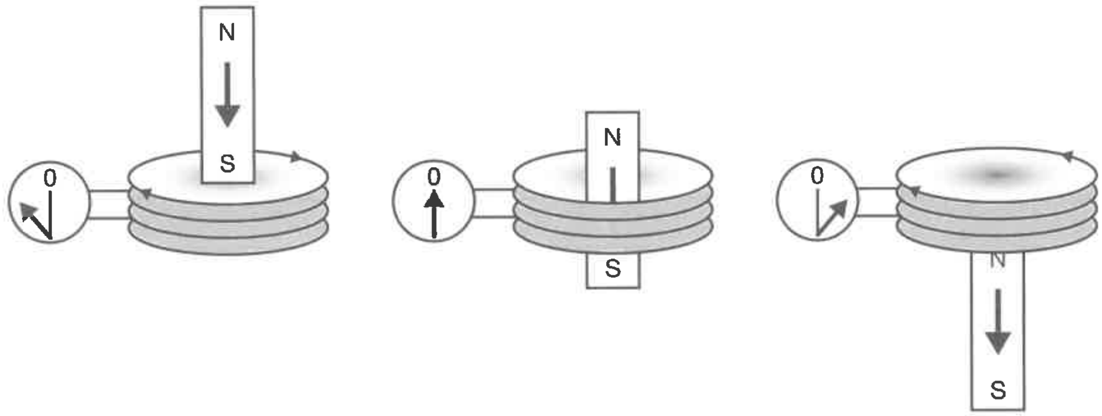
6.19.1.3 Consider the magnet falling through a coil of wire as shown in the diagrams below. Three position of the magnet are shown as it falls. Note that an ammeter is connected into the coil circuit. Account for the different readings on the ammeters as the magnet falls through the coil in terms of the law of conservation of energy.



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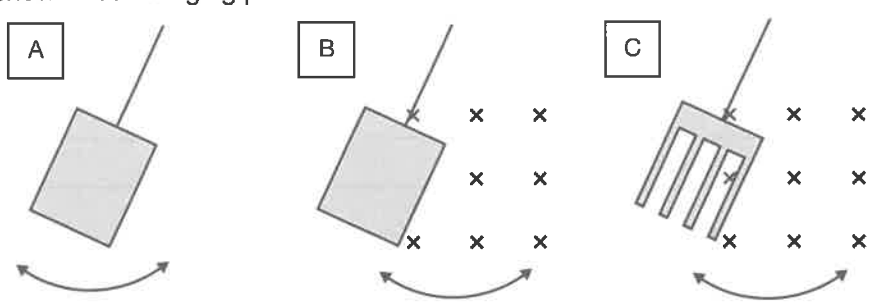
6.19.1.4 The diagrams show three swinging pendulums. In each case the 'bob' is a thin sheet of copper.



(a) Compare the ongoing back and forth motion of the three pendulums over a reasonable period of time.

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(b) Account for the differences indicated in your answer to (a) in terms of Faraday, Lenz, and the law of conservation of energy.

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DOT POINT

MODULE 7

The Nature Of Light

In this module you will:

- Examine evidence for the properties of light and evaluate the implication of this evidence for modern theories of physics.
- Study theories and models developed by early physicists, including Newton and Maxwell, about mechanics, electricity and magnetism and the nature of matter.
- Explore how major discoveries in physics in the 20th century challenged existing theories and models and led to the development of quantum theory and the theory of relativity.
- Understand how technologies arising from these new theories have shaped the modern world.
- Engage with all the Working Scientifically skills for practical investigations involving the focus content to examine trends in data and to solve problems and communicate scientific understanding about the nature of light.

Notes

Electromagnetic Spectrum

7.1 Investigate Maxwell's contribution to the classical theory of electromagnetism, including unification of electricity and magnets, prediction of electromagnetic waves and prediction of velocity.

INQUIRY QUESTION

What is light?

7.1.1 James Clerk Maxwell (1831-1879).

7.1.1.1 List Maxwell's four main contributions to the classical theory of electromagnetism.

7.1.1.2 Describe how electromagnetic radiation propagates.

7.1.1.3 What do all electromagnetic radiations have in common?

7.1.1.4

(a) What was the first electromagnetic radiation, other than visible light, to be identified?

(b) When and by whom?

7.1.1.5 Name the eight bands of known electromagnetic waves.

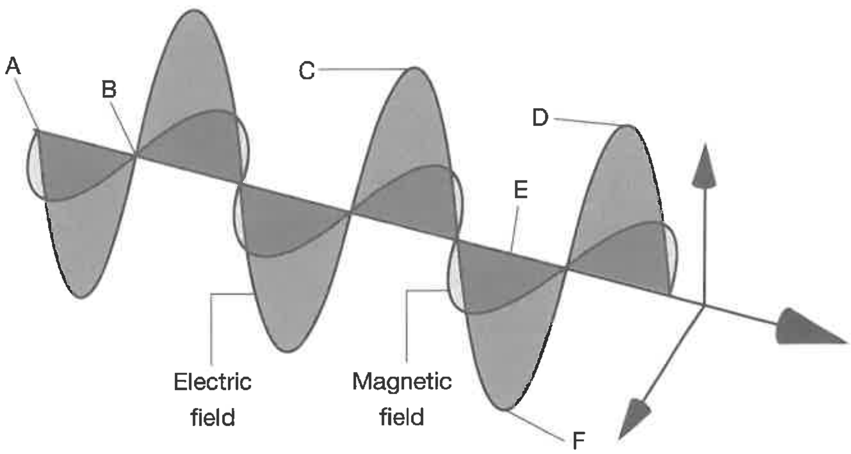
7.2 Describe the production and propagation of electromagnetic waves and relate these processes qualitatively to the predictions made by Maxwell's electromagnetic theory.

7.2.1 Transverse electromagnetic waves.

7.2.1.1 The last column in the table gives the second halves of the sentences. Choose the correct second half for each sentence and write it in the first column of the table to summarise the kinetic theory of matter.

Completed sentences	Second halves (not in order)
All electromagnetic waves can	in hertz (Hz).
Electromagnetic waves all travel at the speed of light (3×10^8 m s^{-1}) in a	wave is indicated by the amplitude of the wave.
Electromagnetic waves are self propagating alternating	the peaks of successive magnetic or electric field pulses.
Because the motion of the changing magnetic and electric fields are at right angles to the direction in which they carry energy, electromagnetic	vacuum – they slow down a little in other media.
Because electromagnetic waves are really hard to draw, we usually draw	its frequency.
The flaw in doing this is that the energy carried by a transverse	on the number of photons in the beam.
In electromagnetic waves, the energy is directly	travel through a vacuum
The wavelength of an electromagnetic wave is the distance between	proportional to the frequency of the photons which make up the radiation.
We usually refer to the intensity of an	that pass a point each second.
The intensity of an electromagnetic wave depends	electric and magnetic fields.
Each photon will have energy dependent on	wavelength to pass a given point.
The period of an electromagnetic wave is the time for one	waves are also classified as transverse waves.
The frequency of an electromagnetic wave is the number of wavelengths	electromagnetic wave rather than to its amplitude.
The frequency of electromagnetic waves is measured	them as transverse matter waves.

7.2.1.2 Consider the diagram which represents an electromagnetic wave in the air. The scale of the diagram is 1 cm = 10^{-11} m.



(a) What is the distance AB on this diagram? ....

(b) What distance is represented by CD? ....

(c) What is represented by the distance EF? ....

(d) What is the wavelength of the wave? ....

(e) How many wave pulses are shown in the diagram? ....

(f) How many wavelengths are shown in the diagram? ....

(g) What is the speed of this wave in air? Justify your answer. ....

(h) Using the wave equation, $v = f\lambda$, calculate its frequency. ....

(i) If the frequency of this wave in air was doubled, what would happen to its speed? Explain your answer.

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(j) If the frequency of this wave in air was doubled, what else would change? Explain your answer.

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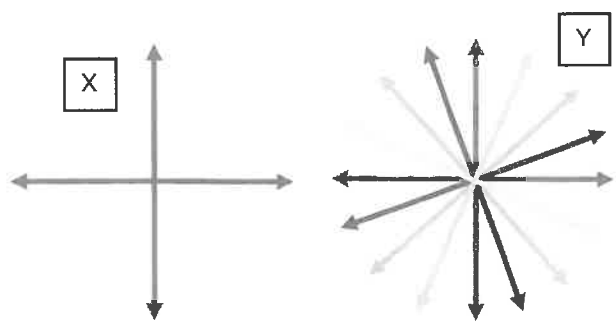
7.2.1.3 We usually always simplify the way we describe electromagnetic radiation by defining it as being composed of alternating electric and magnetic fields at right angles to each other, and represent it by the diagram above (Question 7.2.1.2) or by a simple diagram like that shown in diagram X.

A more correct representation of an electromagnetic wave would be as in diagram Y. Explain why.



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7.2.1.4 Outline two mechanisms by which electromagnetic radiation is produced by matter.

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7.2.1.5

(a) What is the distinguishing property of all electromagnetic radiation? ....

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(b) A scientist discovered a new radiation which travelled at 2.1×10^8 m s^{-1} through a glass slab and at 2.8×10^8 m s^{-1} through the air. He claimed it was a new, previously undiscovered band of the electromagnetic spectrum. Evaluate his statement.

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(c) What is the possibility of scientists discovering a new band of electromagnetic radiation in the electromagnetic spectrum?

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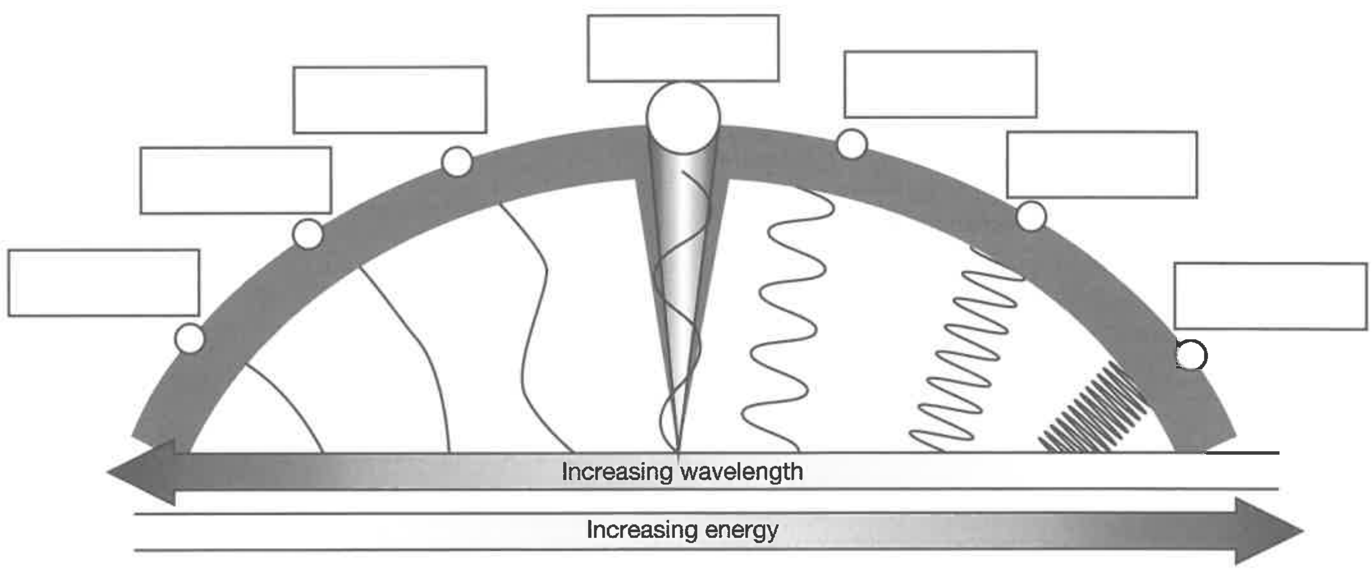
7.2.2 **Properties of electromagnetic waves.**

7.2.2.1 Identify the types of electromagnetic radiation labelled on the diagram. Write your answers in the boxes provided on the diagram.



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7.2.2.2 Which electromagnetic radiation has the lowest frequency?

(A) Radio waves.
(B) Gamma rays.
(C) Infra-red waves.
(D) Ultraviolet waves.

7.2.2.3 If electromagnetic radiation is listed from gamma rays in order to TV waves, they are listed in order of:

(A) Decreasing amplitude.
(B) Decreasing frequency.
(C) Decreasing intensity.
(D) Decreasing wavelength.

7.2.2.4 What is the same for all electromagnetic radiation in a vacuum?

(A) Amplitude.
(B) Frequency.
(C) Speed.
(D) Wavelength.

7.2.2.5 Two types of electromagnetic waves are microwaves and X-rays. Which of these statements describes a property that is shared by microwaves and X-rays?

(A) Both have high frequencies.
(B) Both have long wavelengths.
(C) Both have high intensity.
(D) Both have the same speed in a vacuum.

7.2.2.6 Infra-red rays from the Sun travel through space:

(A) At half the speed of visible light.
(B) At the same speed as visible light.
(C) Slower than visible light.
(D) Faster than visible light.

7.2.2.7 How does visible EMR from the Sun differ from the non-visible EMR from the Sun?

(A) It has different amplitudes.
(B) It travels a different distance.
(C) It travels at a different speed.
(D) It has different frequencies.

7.2.2.8 Visible light has a higher frequency than:

(A) X-rays.
(B) Ultraviolet rays.
(C) Infra-red rays.
(D) Gamma rays.

7.2.2.9 What is the relationship between the wavelength (λ) and frequency (f), of EMR?

(A) If λ increases, f decreases.
(B) If f increases, λ increases.
(C) If f remains constant, λ increases.
(D) If λ remains constant, f decreases.

7.2.2.10 Which statement is true regarding mechanical and electromagnetic waves?

(A) Both waves require a medium.
(B) Neither requires a medium.
(C) Mechanical waves requires a medium, but electromagnetic waves do not.
(D) The medium affects the speed of EMR but not the speed of mechanical waves.

7.2.2.11 Which photons carry the highest energy?

(A) Red photons.
(B) Yellow photons.
(C) Blue photons.
(D) Violet photons.

7.2.2.12 The energy carried by electromagnetic waves depends on their:

(A) Amplitude.
(B) Frequency.
(C) Period.
(D) Wavelength.

7.2.2.13 Which of the following electromagnetic waves has the longest wavelength?

(A) Radio waves.
(B) Gamma rays.
(C) X-rays.
(D) Visible light.

7.2.2.14 Complete the table to give two uses for each band in the electromagnetic spectrum.

Type of EMR	Use in society 1	Use in society 2
Gamma radiation		
X-rays		
UV radiation		
Visible light		
Infra-red		
Microwaves		
Radio waves		
TV waves		

7.3 Conduct investigations of historical and contemporary methods used to determine the speed of light and its current relationship to the measurement of time and distance.

7.3.1 Historical measurements of the speed of light.

7.3.1.1 What was the limiting factor faced by early scientists trying to measure the speed of light?

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7.3.1.2

(a) What is the currently accepted value for the speed of light? ....

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(b) How has this value been determined? ....

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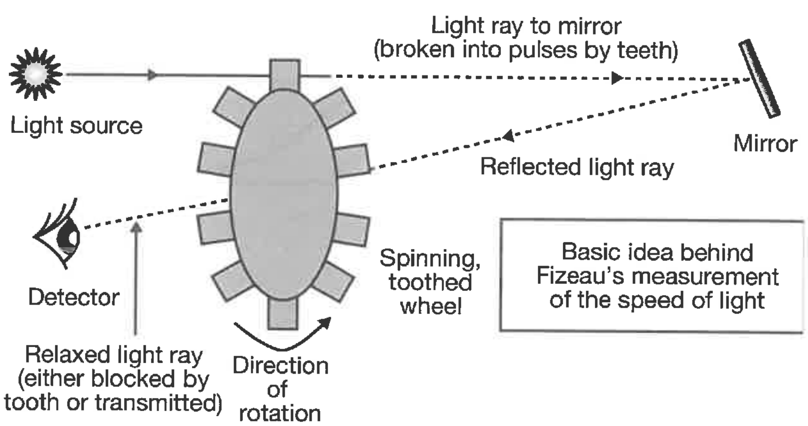
7.3.1.3 Some of the more notable attempts throughout history to measure the speed of light were done by the scientists listed below. Choose one of these and research the method used. Assess its validity, reliability, and accuracy.

(Note that the values calculated by these scientists vary from resource to resource, so it is difficult to obtain reliable figures. The values used here must, despite the degree of accuracy they sometimes state, therefore be taken as indicative rather than accurate.)

- 1638: Galileo: at least 10 times faster than sound
- 1675: Ole Roemer: 301 000 000 m s^{-1}
- 1577: Christiaan Huygens 201 168 000 m s^{-1}
- 1728: James Bradley: 301 000 000 m s^{-1}
- 1848: Hippolyte Louis Fizeau: 315 000 000 m s^{-1}
- 1848: Alfred Cornu: 300 400 000 m s^{-1}
- 1862: Leon Foucault 298 000 000 m s^{-1}
- 1879: Albert Michelson 299 310 000 m s^{-1}
- 1926: Albert Michelson 299 798 000 m s^{-1}
- 1958: Keith Davy Froome 299 7920500 m s^{-1}



Basic idea behind Fizeau's measurement of the speed of light

Armand Fizeau (1819-1896).

Science Press

7.4 Conduct an investigation to examine a variety of spectra produced by discharge tubes, reflected sunlight or incandescent filaments.

7.4.1 Comparing spectra from lighting sources.

7.4.1.1 List four factors which affect the spectrum of light emitted by a light source. ....

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7.4.1.2 Compare the light produced by three different filament light sources with different composition filaments at very high temperatures to that emitted by different vapour sources at low temperatures.

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7.4.1.3

(a) Clarify the essential difference between a light source that is described as a 'cool' light with one described as a 'warm' light.

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(b) What colour light is produced by cool and warm light sources? ....

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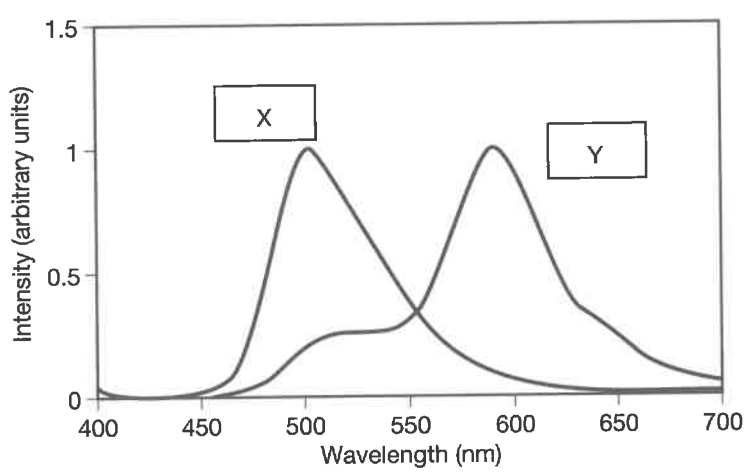
(c) Which spectrum shown below represents a cool light source and a warm light source?



X = ...

Y = ...

Science Press

7.4.1.4 Which of the following statements best describes the production of light in an incandescent light bulb?

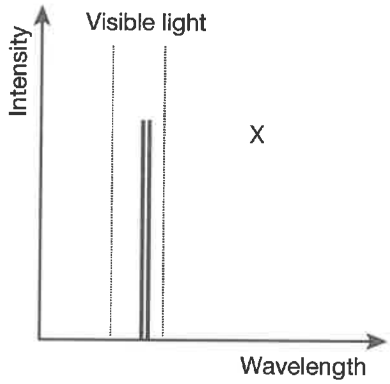
(A) Stimulated emission of photons by electrons in the electric current.

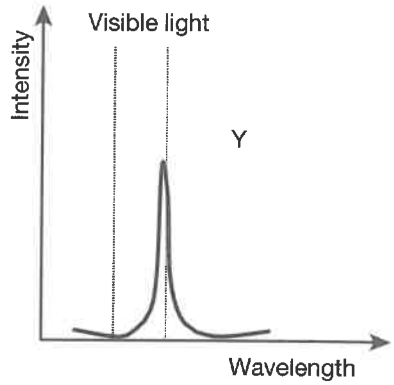
(B) Transition of excited valence electrons back to lower energy states.

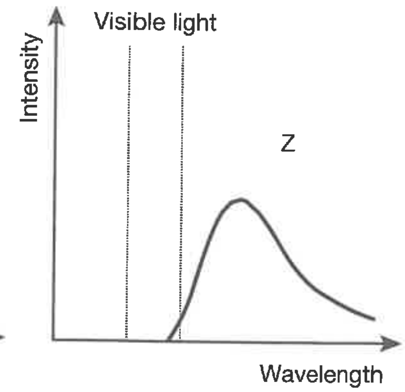
(C) Acceleration of electrons in random thermal collisions.

(D) Emission of electromagnetic radiation (light) by electrons accelerated by the applied voltage.

7.4.1.5 Consider the spectra of wavelengths produced by three different light sources and the six possible light sources shown below.







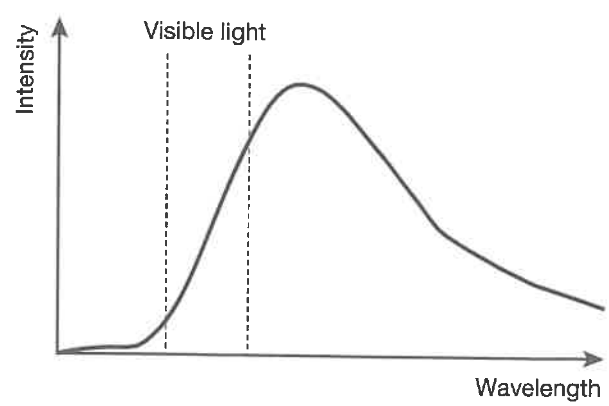
Possible light sources: Low pressure sodium vapour lamp, red hot metal rod, high pressure sodium vapour lamp, incandescent globe, red LED, blue laser, candle, the Sun.

For each spectrum X, Y and Z, identify the most likely light source to have produced this spectrum. Write the corresponding light source in the appropriate box below. Justify each answer.

Spectrum X	
Spectrum Y	
Spectrum Z	

7.4.1.6 The spectrum of wavelengths produced by a particular incandescent light globe is shown.

Explain how this spectrum is formed and why its emits most frequencies in the spectrum.



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7.5 Investigate how spectroscopy can be used to provide information about the identification of elements.

7.5.1 Using spectroscopy to identify elements.

7.5.1.1

(a) What are the three different types of atomic spectra? ....

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(b) Briefly describe the appearance of each. ....

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7.5.1.2 Describe the relationship between the emission and absorption spectrum of the same element.

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7.5.1.3

(a) What is the most common example of a continuous spectrum? ....

(b) Briefly describe how each of the other two types of spectra can be produced from a continuous spectrum.

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7.5.1.4 Describe the production of each type of spectrum in terms of electron behaviour. ....

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7.5.1.5

(a) Who first discovered atomic spectra? And when? ....

(b) What branch of science developed as a result of scientists trying to explain how atomic spectra formed?

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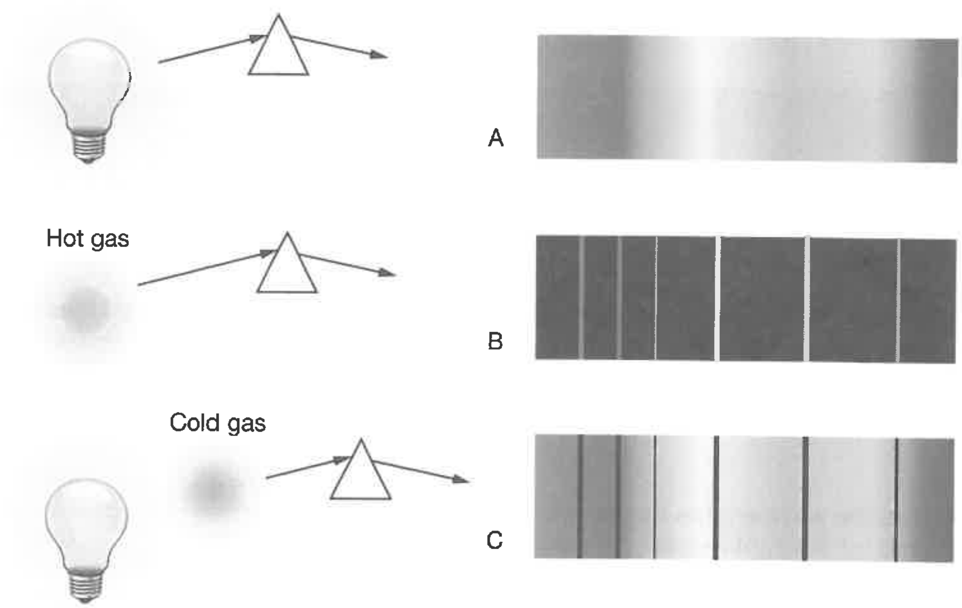
....

7.5.1.6 Which diagram shows how each type of spectrum is formed?



A = ...

B = ...

C = ...

7.5.1.7 The diagrams show three different atomic spectra.

(a) Identify the short wavelength end of each spectrum.

....

....

(b) Identify the high frequency end of each spectrum.

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(c) Which end of each spectrum is produced by electron transfers with the highest energy?

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7.5.1.8 What was the importance of the hydrogen spectrum in the study of the structure of matter?

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7.5.1.9 What is meant by the 'convergence limit' of a spectrum of an element and what does it signify?

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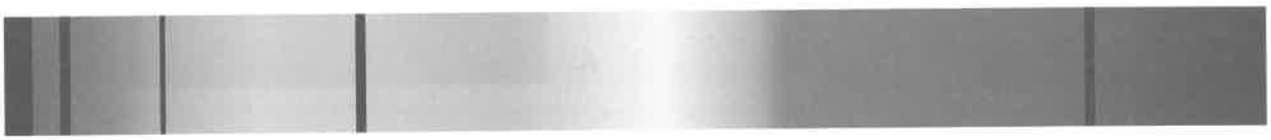
7.5.1.10 The diagram shows part of an uncoloured spectrum of hydrogen. Some of the spectral lines are numbered according to Balmer's notation.



(a) The table shows the actual wavelengths of these four lines in the hydrogen spectrum.

Using the Balmer equation:

$$\lambda = B\left(\frac{n^2}{n^2 - 2^2}\right)$$

Calculate the wavelengths that he would have predicted for the light resulting in these spectral lines. (B = 364.5 nm).

Line	Actual λ (nm)	Balmer λ (nm)
$n = 3$	656.3	
$n = 4$	486.1	
$n = 5$	434.0	
$n = 6$	410.2	
$n = 7$		

(b) Research and calculate the values for the $n = 7$ line in the hydrogen spectrum.

(c) Comment on the validity of using the Balmer equation to predict the wavelengths of the hydrogen spectrum lines.

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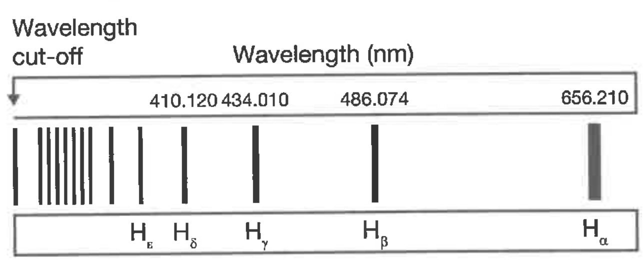
7.5.1.11 The diagram represents the spectrum of hydrogen.



The hydrogen spectrum

(a) Which of these lines would you see as blue?

....

(b) Which of the lines would have the highest frequency? Justify your answer.

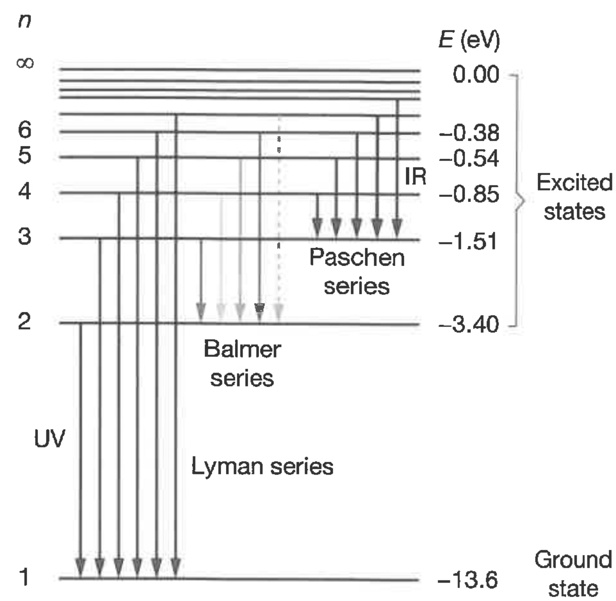
....

....

(c) Which line represents an electron transfer with the most energy? ....

....

7.5.1.12



(a) Explain the concept of a 'series' in the hydrogen spectrum.

....

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(b) Suggest a reason the Balmer series was the first to be discovered.

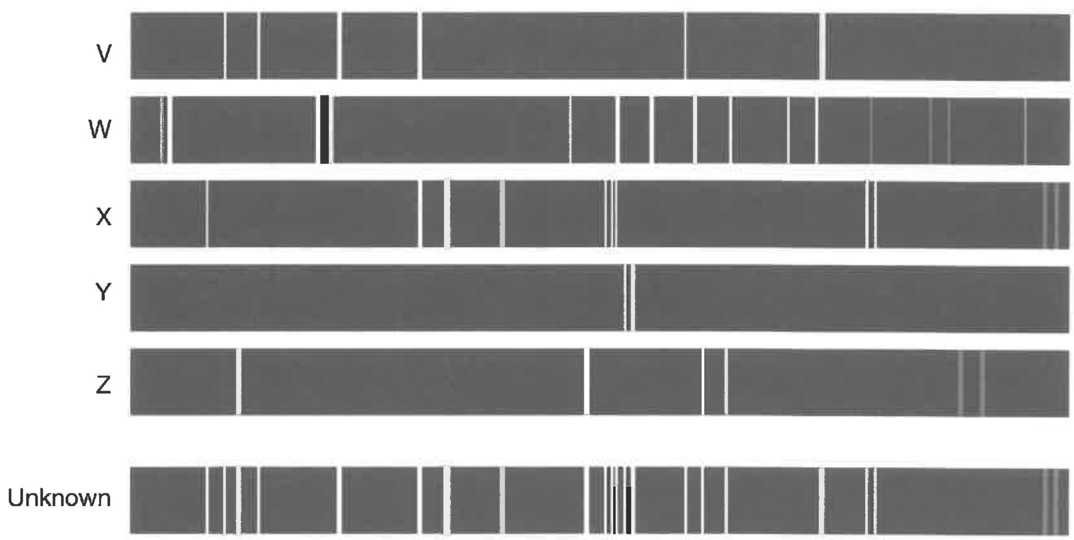
....

....

(c) Which of the three series shown in the diagram would emit electromagnetic radiations with the shortest wavelengths (on average). Justify your answer.

....

7.5.1.13 The diagram show the spectra of five different elements and an unknown mixture of those elements.



(a) Which of the identified elements is contained in the mixture? Justify your answer.

....

(b) There is a problem with including element Z in the mixture. What is this problem and propose an explanation for this.

....

....

(c) How do we know that the top two spectra represent different elements? ....

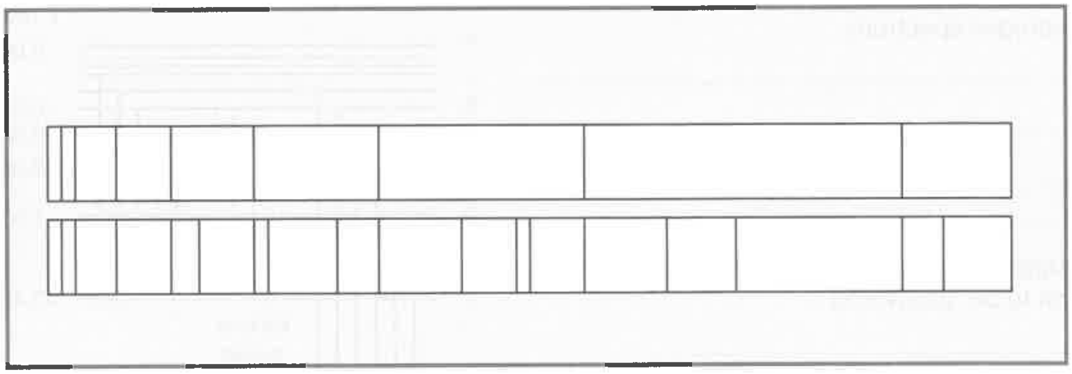
....

(d) The spectra of elements are sometimes referred to as the 'fingerprints' for the elements. Why is this analogy made?

....

....

7.5.1.14 The diagrams show the spectrum of hydrogen and that from a star.



(a) Can we conclude from this information that the star contains hydrogen? Justify your answer.

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(b) What evidence is there that elements other than hydrogen are in this star? ....

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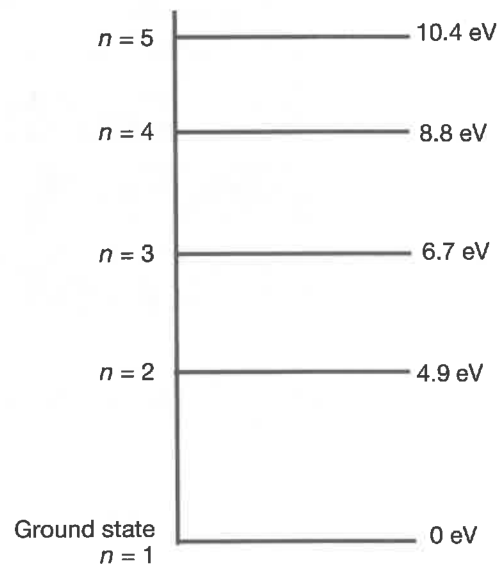
....

7.5.1.15 The diagram shows the energy levels for a mercury atom.



(a) An electron is in the third excited state ($n = 3$). How much energy will be emitted when it falls to $n = 2$?

....

(b) What energy is needed to excite an electron from $n = 3$ to $n = 5$?

....

(c) If an electron falls from $n = 4$ to $n = 2$, what energy is emitted/absorbed?

....

(d) An electron in the second excited state is hit by a photon with frequency 1.207×10^{15} Hz. What will happen to this electron?

....

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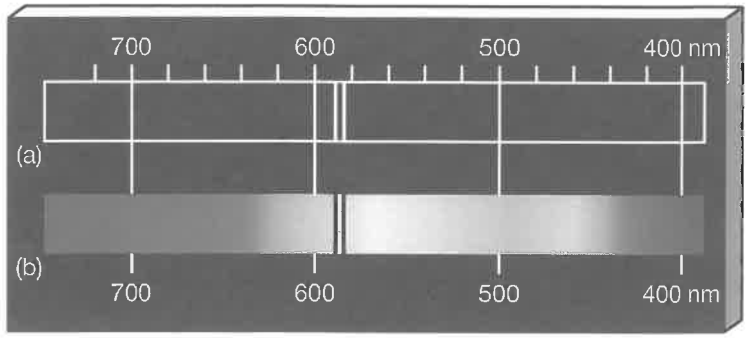
7.6 Investigate how the spectra of stars can provide information on their surface temperature, rotational and translational velocity, density and chemical composition.

7.6.1 Spectra of stars and their properties.

7.6.1.1 When heated to high temperatures, a sample of sodium vapour emits visible light strongly at just two wavelengths – 589.9 nm and 589.6 nm – lying in the yellow part of the spectrum. The emission and absorption spectra of sodium are compared in the diagram below, clearly showing the relation between emission and absorption features.



(a) State and explain the relationship between emission and absorption spectra.

....

....

....

(b) Find the frequency and energy (in eV and joules) of the two main sodium vapour spectrum lines.

(i) 589.9 nm ....

(ii) 589.6 nm ....

7.6.1.2 The line spectrum for mercury has over 500 lines representing over 500 energy transformations between energy levels. The table shows a few of these energy levels.

Energy levels for mercury	
n	**Energy (eV)**
1	–10.38
2	–5.74
3	–5.52
4	–4.95
5	–3.71
6	–2.68
7	–2.48
8	–1.57
9	–1.56
10	0.00

(a) Which listed energy level represents the ground state? Justify your answer.

....

....

(b) Why are the values in this table all negative?

....

....

(c) In moving from level $n = 8$ to $n = 3$ would an electron absorb or emit energy? Justify your answer.

....

....

(d) What would be the frequency of the photon emitted or absorbed when an electron moves between levels $n = 8$ and $n = 3$?

....

....

(e) What is the ionisation energy of mercury according to this data?

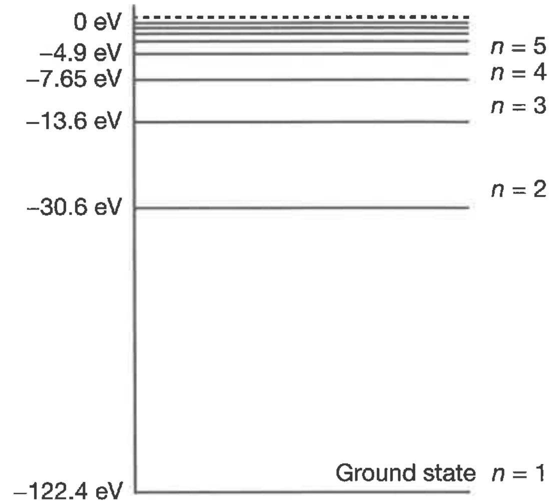
....

(f) What wavelength photon would have to hit an electron in the ground state in order to cause ionisation?

....

....

7.6.1.3 The diagram shows the energy diagram for an element. Use it to answer this question.



(a) An electron in an atom of this element is excited to $n = 3$. State the energy values of three possible photons which could be emitted as this electron falls back to the ground state. And identify the transition in each case.

(b) Calculate the wavelength and frequency of each of these three photons.

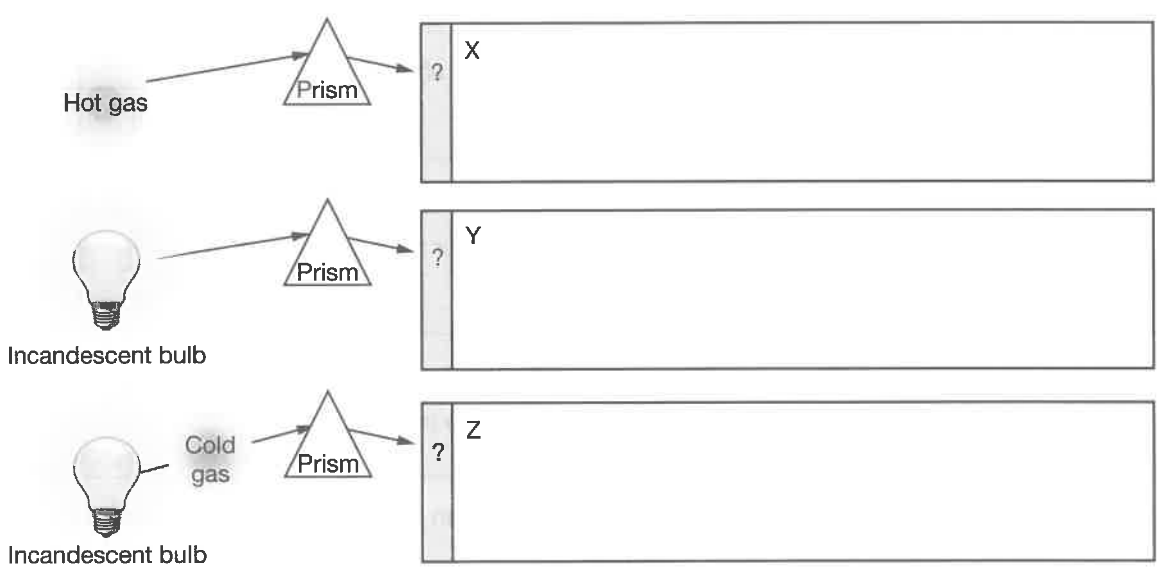
(c) Another excited electron emits a photon with wavelength 143 nm when it falls back to $n = 3$. What level did it fall from?

(d) An electron in the atom is hit by a photon with frequency 5.54×10^{15} Hz. All its energy transfers and the electron is excited to a higher level. What transition does this photon cause?

(e) A photon is emitted from the atom with a frequency of 2.21×10^{15} Hz. What happens to cause this?

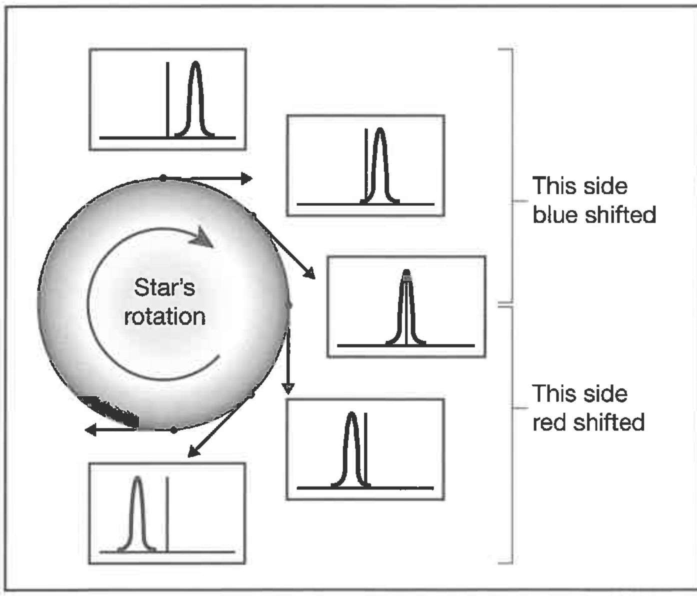
7.6.1.4 Consider the diagram.

(a) Identify the three types of spectrum shown in the diagram, X, Y and Z and describe what each looks like.



(b) Compare the emission and absorption spectrum for the same substance.

7.6.1.5 Consider the following diagram which shows the spectra observed from a rotating star. Explain how the observations made of this star prove that it is rotating.



Light: Wave Model

7.7 Conduct investigations to analyse qualitatively the diffraction of light.

INQUIRY QUESTION

What evidence supports the classical wave model of light and what predictions can be made using this model?

7.7.1 Diffraction.

7.7.1.1 What is diffraction? ....

....

....

7.7.1.2 What types of waves undergo diffraction? ....

7.7.1.3 Do particles undergo diffraction? Explain your answer. ....

....

....

7.7.1.4 Complete the sentences as they relate to diffraction patterns.

(a) The wider the opening ....

(b) The greater the wavelength ....

7.7.1.5 Describe the relative diffraction pattern in each of the following situations.

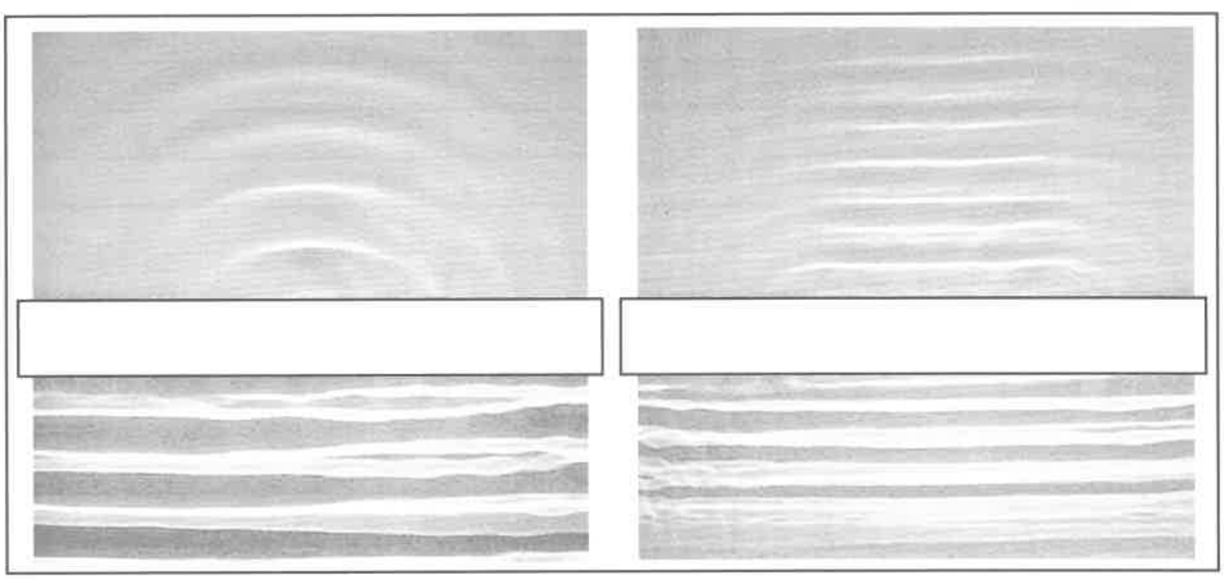
(a) If λ is small and w is large ....

(b) If λ is small and w is very small ....

(c) If λ is very large and w is small ....

(d) If λ is very small and w is small ....

7.7.1.6 The diagram shows two diffraction patterns for water waves passing through two openings in different barriers. The barriers are shown as white rectangles, but the openings are not shown. Complete the diagram by drawing in possible slits for each diffraction pattern.



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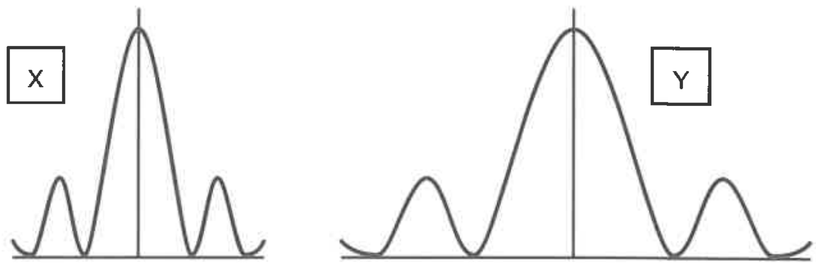
7.7.1.7 The diagram below shows two diffraction patterns as observed on screens equidistant from the slits. One pattern has been formed using blue light, the other using red light.



(a) Which of these two patterns would be formed by red light? Justify your answer.

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(b) If *both* patterns had been formed by red light, what might cause the difference in the patterns produced? Justify your answer.

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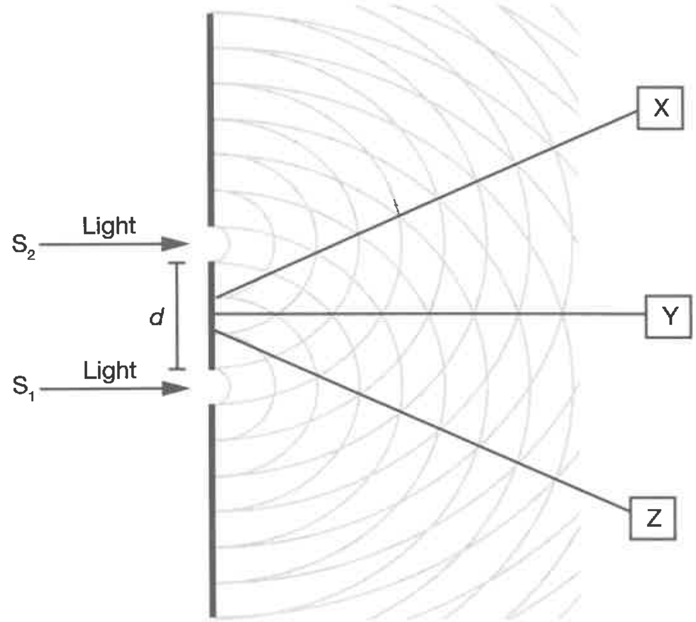
7.8 Conduct investigations to analyse quantitatively the interference of light using double slit apparatus and diffraction gratings: $d \sin \theta = m\lambda$.

7.8.1 Young's double slit experiment.

7.8.1.1 The diagram shows the wavefronts produced by two coherent (in phase) sources S_1 and S_2. X, Y and Z are three positions on the screen showing the diffraction pattern.

The circles in the diagram represent the wavefronts of the waves.



(a) Describe the appearance of positions X, Y and Z on the diffraction pattern. Justify each answer.

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(b) On the diagram, draw another antinodal line. Label it P.

(c) On the diagram draw a nodal line, representing positions of destructive interference. Label it Q.

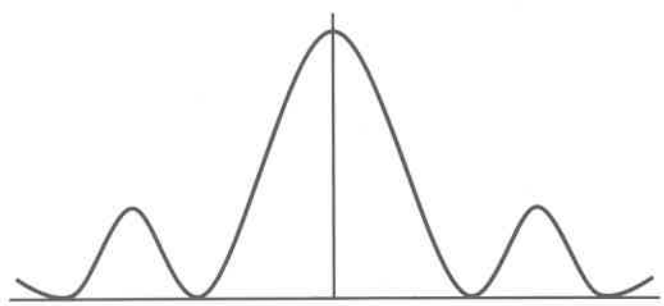
(d) How would the diffraction pattern be different if the students had used light with a shorter wavelength?

....

(e) How would the diffraction pattern be different if the students had used a first screen which had the holes closer together?

....

7.8.1.2 Consider the diffraction pattern shown.



(a) On the axes provided, draw a comparative diffraction pattern if the experiment was repeated with all variables controlled, but a lower frequency light was used.

(b) Justify your diagram. ....

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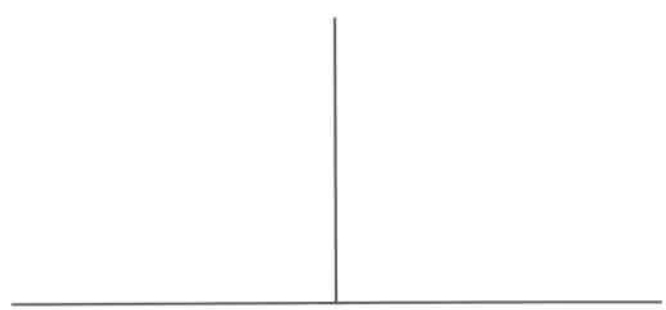

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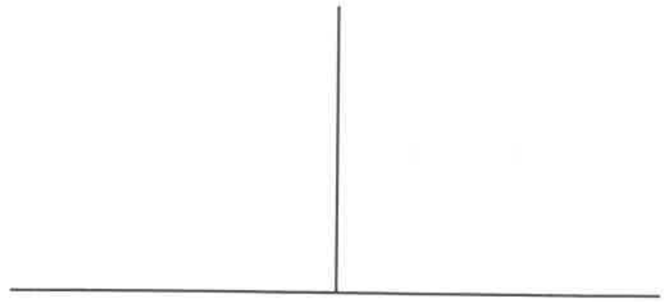
(c) On the axes provided, draw a comparative diffraction pattern if the experiment was repeated with all variables controlled, but using a first screen where the holes are further apart.



(d) Justify your diagram. ....

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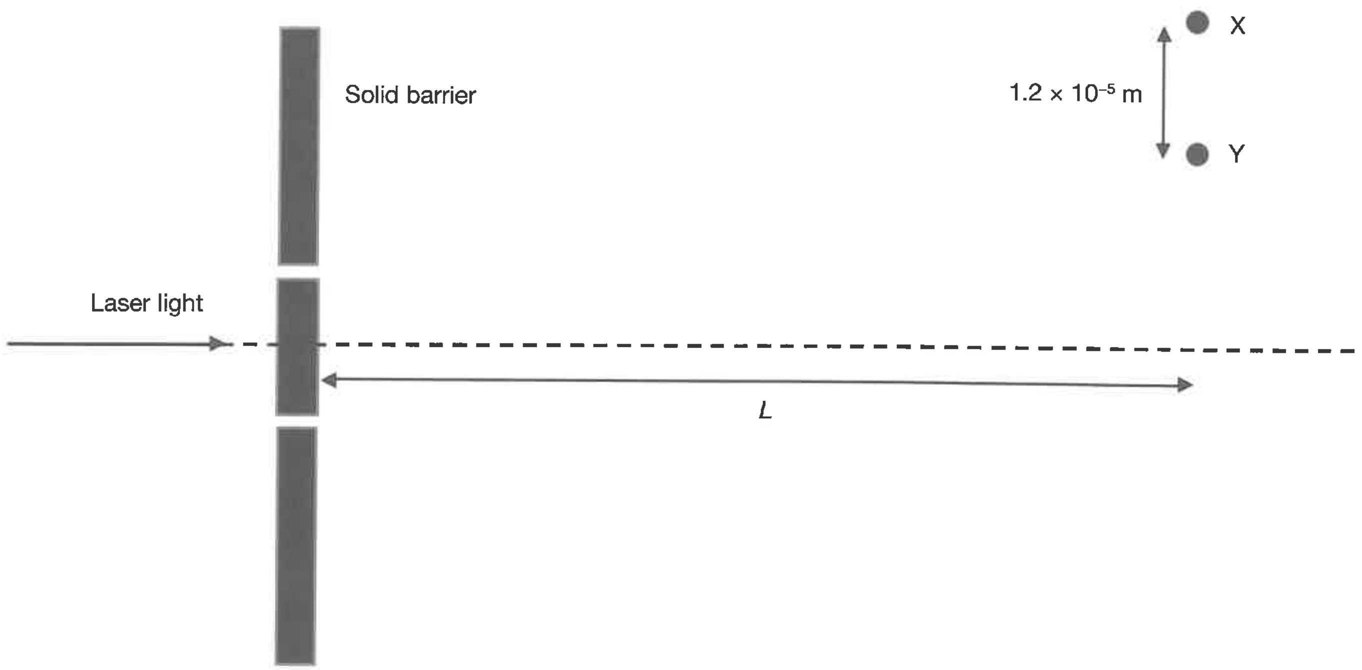
7.8.1.3 Consider the diagram drawn by a student following a double slit diffraction experiment using laser light of wavelength 450 nm.



(a) If the two points X and Y are adjacent dark fringes on the diffraction pattern, what is the path difference between the two beams forming them?

....

(b) If the distance between the two slits is 5 mm, how far apart are the screens?

....

(c) What would happen to the distance between X and Y if light of wavelength 500 nm was used, all other variables being the same?

....

(d) What would happen to the distance between X and Y if the distance between the slits was doubled was used, and all other variables being the same?

....

7.8.1.4

(a) Outline how diffraction limits our ability to see very small objects. ....

....

....

(b) How can we increase the resolution of the image we get when viewing very small objects?

....

....

(c) Briefly explain why electron microscopes can be used to obtain images of much smaller items than visible light microscopes.

....

....

(d) Microscopic imaging often involves using very small apertures (openings) in the microscopes and cameras used. Why does this limit the size of the object that can be viewed?

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7.8.1.5 The picture shows the blade of a carton cutter and its shadow. Explain why the point of the shadow of the blade is the most blurred part of the shadow.

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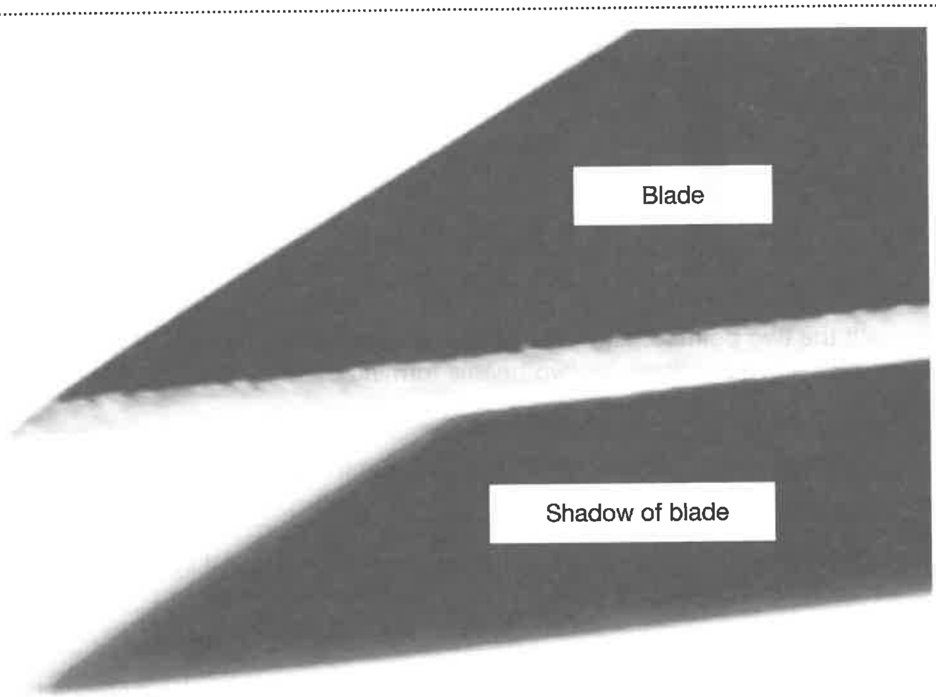

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7.8.2 Diffraction supporting the wave model.

7.8.2.1

(a) Outline what Young did to carry out his double slit experiment with light. ....

....

....

(b) What were the results of Young's double slit experiment? ....

....

(c) How did Young explain his results? ....

....

....

7.8.2.2 Explain how the results of Young's double slit experiment supported the wave nature of light.

....

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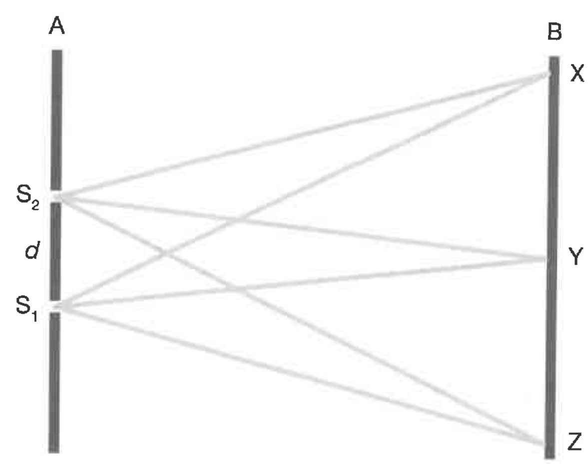
7.8.2.3 Consider the diagram which shows beams of light passing through two slits S_1 and S_2 and forming a diffraction pattern (only partly shown) and labelled as XYZ on the second screen.



(a) Under what path difference conditions would X be a bright spot on this diffraction pattern?

....

....

....

(b) Under what path difference conditions would X be a dull spot on this diffraction pattern?

....

(c) Position Y is the central position in the diffraction pattern. Explain its nature and the relationship between S_1Y and S_2Y.

....

(d) If a bright spot appeared at Y in the diffraction pattern, what can be said about the phase difference between the beams from S_1 and S_2?

....

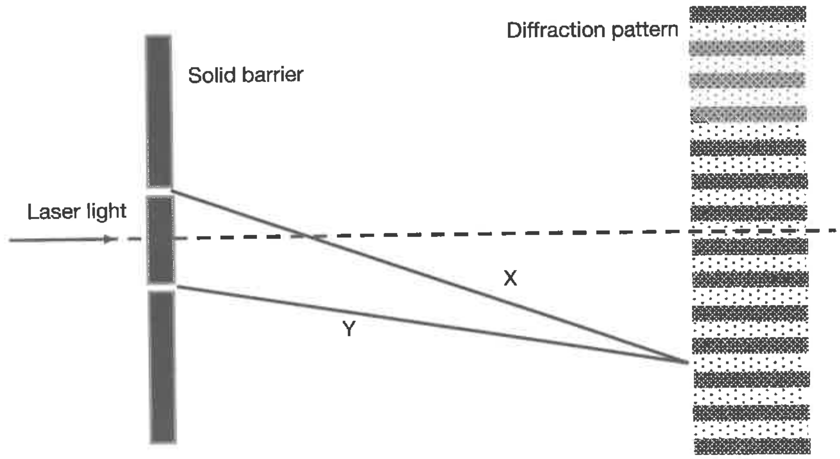
(e) If a dull spot appeared at Y in the diffraction pattern, what can be said about the phase difference between the beams from S_1 and S_2?

....

(f) Suppose two beams in this diffraction pattern had a path difference of $(n - \frac{1}{4})\lambda$. What would be the nature of their interference on the screen?

....

7.8.2.4 The diagram (not to scale) drawn by some students to represent the results of their double slit experiment is shown. In the experiment the students used a helium-neon laser of wavelength 632 nm.



(a) Explain the diffraction pattern they have drawn in terms of the wave nature of light.

....

....

....

(b) Estimate the path difference between beams X and Y. Justify your answer. ....

....

(c) One of the students said that the experiment would be better done using two lasers instead of one. Evaluate this statement in terms of the results they would have obtained.

....

....

7.8.2.5 Consider the equation: $\Delta x = \frac{n\lambda L}{d}$. Define each of the symbols used in this equation.

Δx = ...

n = ...

λ = ...

L = ...

d = ...

7.8.2.6 With the equation above in mind, state the effect on the interference pattern of the following changes to a Young's double slit experiment.

(a) Increasing the frequency of the incident light. ....

....

(b) Increasing the wavelength of the incident light. ....

....

(c) Increasing the distance between the two screens of the incident light. ....

....

(d) Increasing the distance between the two slits in the first screen of the incident light. ....

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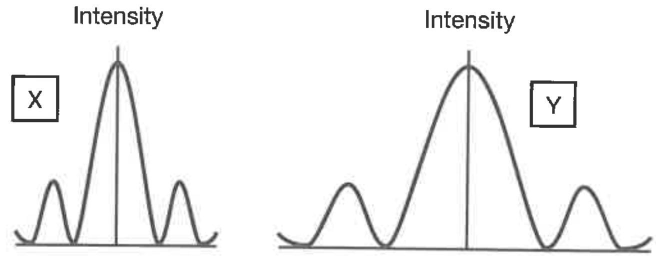
7.8.2.7 Consider the two double slit diffraction patterns X and Y.

(a) If all other conditions are the same, which of the two would have been made using higher frequency light? Justify your answer.



(b) If all other conditions are the same, which of the two would have been produced furthest from the screen containing the slits? Justify your answer.

7.8.3 Diffraction gratings.

7.8.3.1

(a) What is a diffraction grating?

(b) The slit width on a particular diffraction grating is 1.6 μm. How many slits per mm does this grating have?

(c) A diffraction grating has 800 lines per mm. What is the slit spacing in metres and micrometres?

7.8.3.2 Compare the spectrum produced by a diffraction grating with that formed by double slit diffraction.

7.8.3.3 Light is incident at 90° to a diffraction grating which has 4000 lines per cm. The angular separation of the first order maxima either side of the central maximum is 26°. What is the wavelength of the incident light in nm?

7.8.3.4 A diffraction grating has 750 lines mm^{-1}.

(a) What is the spacing of the slits in the grating?

(b) Monochromatic light is aimed straight at the grating and is found to give a first order maximum at 12°. Find the wavelength of the light source.

(c) Find the position of the first order maximum when light of wavelength 450 nm is shone on the grating.

(d) The longest visible wavelength is that of red light with $\lambda = 750$ nm. The shortest visible wavelength is violet where $\lambda = 400$ nm. Use this information to calculate the width of the angle into which the first order spectrum is spread out when white light is shone onto the grating.

7.8.3.5 A diffraction grating with 15 thousand lines per cm separates a bright line at 22.5 degrees. What is the wavelength of the incident light?

....

....

....

7.8.3.6 A grating in a spectrometer has a length of 1.6 cm and contains 8600 lines. Find the third order diffraction angle for light with a wavelength of 450 nm.

....

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7.8.3.7 A grating has 7500 slits ruled across a width of 3 cm. What is the wavelength, and the colour, of the light whose two fifth order maxima subtend an angle of 80 degrees?

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7.8.3.8 A diffraction grating 3 cm wide produces a deviation of 28 degrees in the second order with light of wavelength 450 nm. What is the total number of lines on the grating?

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7.8.3.9 A grating is illuminated with a parallel beam of light of wavelength 620 nm. The first order maximum is in a direction making an angle of 18° with the straight through direction.

(a) Calculate the spacing of the grating slits. ....

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(b) What would be the angle of the first order maximum if a diffraction grating of slit spacing of 4.0×10^{-6} m was used with the same light source?

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(c) Calculate the wavelength of light that would give a second order maximum at $\theta = 24°$ with a diffraction grating of slit spacing 4.0×10^{-6} m.

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7.8.3.10 A diffraction grating has 500 lines mm^{-1}.

(a) What is the spacing of the slits in the grating? ....

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(b) Monochromatic light is aimed straight at the grating and is found to give a first order maximum at 18°. Find the wavelength of the light source.

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7.9 Analyse the experimental evidence that supported the models of light that were proposed by Newton and Huygens.

7.9.1 Evidence supporting Newton's model of light.

7.9.1.1 Outline the four main ideas in Newton's corpuscular model of light.

7.9.1.2 State four properties of light that could be accounted for by Newton's particle model of light.

7.9.1.3 What were the two main factors at the time that led other scientists to accept Newton's corpuscular theory for light without question?

7.9.1.4

(a) What is refraction?

(b) How did Newton explain refraction of light using his particle model?

(c) Outline how Newton's model of light accounted for refraction.

7.9.1.5 How did Newton use the production of sharp shadows of objects in sunlight to support his particle theory of light?

7.9.2 Evidence supporting Huygens' model of light.

7.9.2.1 Complete the sentences to outline the main ideas in Huygens' wave model of light.

(a) Light is a form of ______________.

(b) Light travels in the form of ______________ which vibrate up and down ______________ to the direction of travel.

(c) A ______________ is necessary for the propagation of waves and space is filled with an imaginary medium called the ______________.

(d) Each ______________ in a source of light sends out waves in all directions in a hypothetical medium called the ______________.

(e) Each point on the wavefront acts as a source of ______________ for the next wavefront.

(f) Light waves have very short ______________.

7.9.2.2 State four properties of light that could be accounted for by Huygens' wave model of light.

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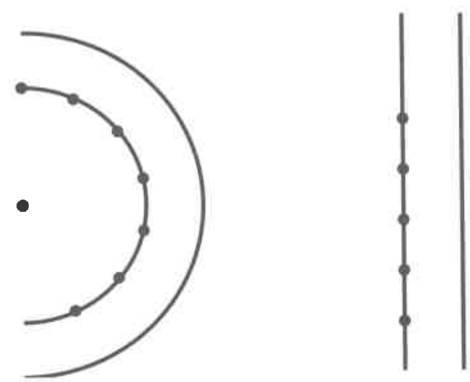
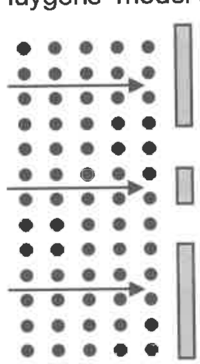
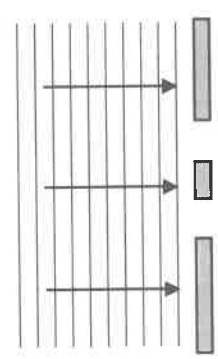
7.9.2.3 The diagrams represent a straight wavefront and a curved wavefront. Several points are marked on each wavefront. Add to the diagrams to illustrate Huygens' idea of wavelets being responsible for the propagation of a wave through a medium. The waves are moving from left to right.



7.9.2.4 Complete the diagrams below to show how Newton's particle model could not account for interference of waves while Huygens' model could.





Science Press

7.9.3 The electromagnetic wave theory of light.

7.9.3.1

(a) Who proposed an electromagnetic theory of light in 1847? ....

(b) Briefly outline this theory. ....

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(c) Who developed an electromagnetic theory of light in1873? ....

(d) Briefly outline this theory and how it was proposed. ....

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7.9.3.2

(a) Which property of light was the electromagnetic theory able to account for which neither the particle nor the wave theory could explain?

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(b) Describe this property. ....

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(c) Draw diagrams to distinguish between unpolarised light and two different forms of polarised light according to the electromagnetic theory of light.

Unpolarised light	Vertically polarised light	Horizontally polarised light

7.9.3.3 What is the limitation of the electromagnetic theory of light? ....

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Science Press

7.9.4 The quantum theory of light.

7.9.4.1

(a) Who proposed the idea of quantum theory and when? ....

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(b) Why did this scientist propose this model? ....

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(c) Briefly outline the idea behind this initial version of quantum theory. ....

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(d) How did these initial ideas become associated with a model for light? ....

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7.9.4.2 In the quantum model for light, what property determines the amount of energy carried by the light?

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7.9.4.3 Complete the following sentences by inserting one word in each box.

(a) All properties of light except [ ], [ ] and [ ] can be explained using the particle model for light.

(b) All properties except the [ ] [ ] in the photoelectric effect can be explained by a wave model for light.

(c) Since neither model explained all light properties, [ ] model is correct and because we have no better idea at the moment, we accept both and retain a [ ] [ ] for light.

7.9.4.4 Explain what is meant by the dual model for light and why we accept it as the current model.

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7.10 Conduct investigations quantitatively using the relationship of Malus' law: $I = I_{max} \cos^2 \theta$ for plane polarisation of light, to evaluate the significance of polarisation in developing a model for light.

7.10.1 Polarisation.

7.10.1.1

(a) What is polarisation? ....

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(b) How do we normally show an electromagnetic wave in a diagram? ....

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(c) With reference to polarisation, explain why a transverse wave model for electromagnetic radiation is incorrect.

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(d) What happens when polarisation occurs? ....

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7.10.1.2 Why do we use a transverse wave model for electromagnetic radiation? ....

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7.10.1.3 State five different ways by which light can be polarised. ....

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7.10.1.4 With the aid of an appropriately labelled diagram, explain how a polaroid filter polarises light.

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7.10.1.5 One of these photos was taken using a polaroid filter, the other was not. Which is which? Justify your answer.

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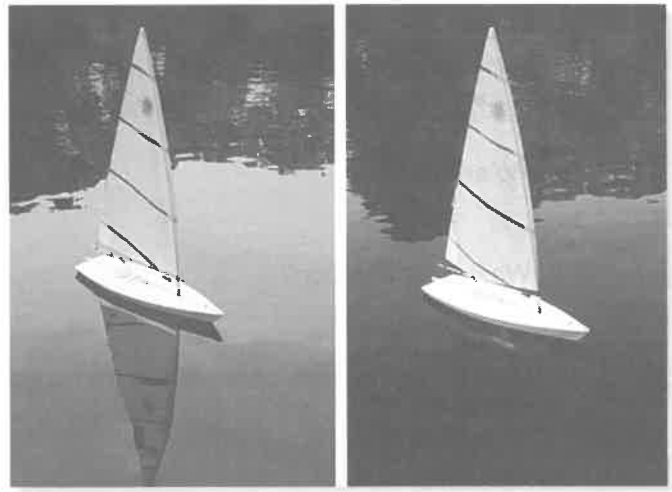
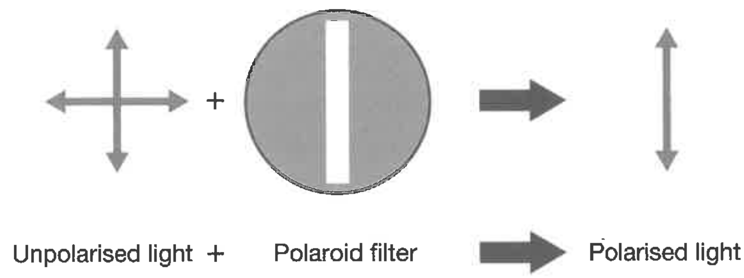
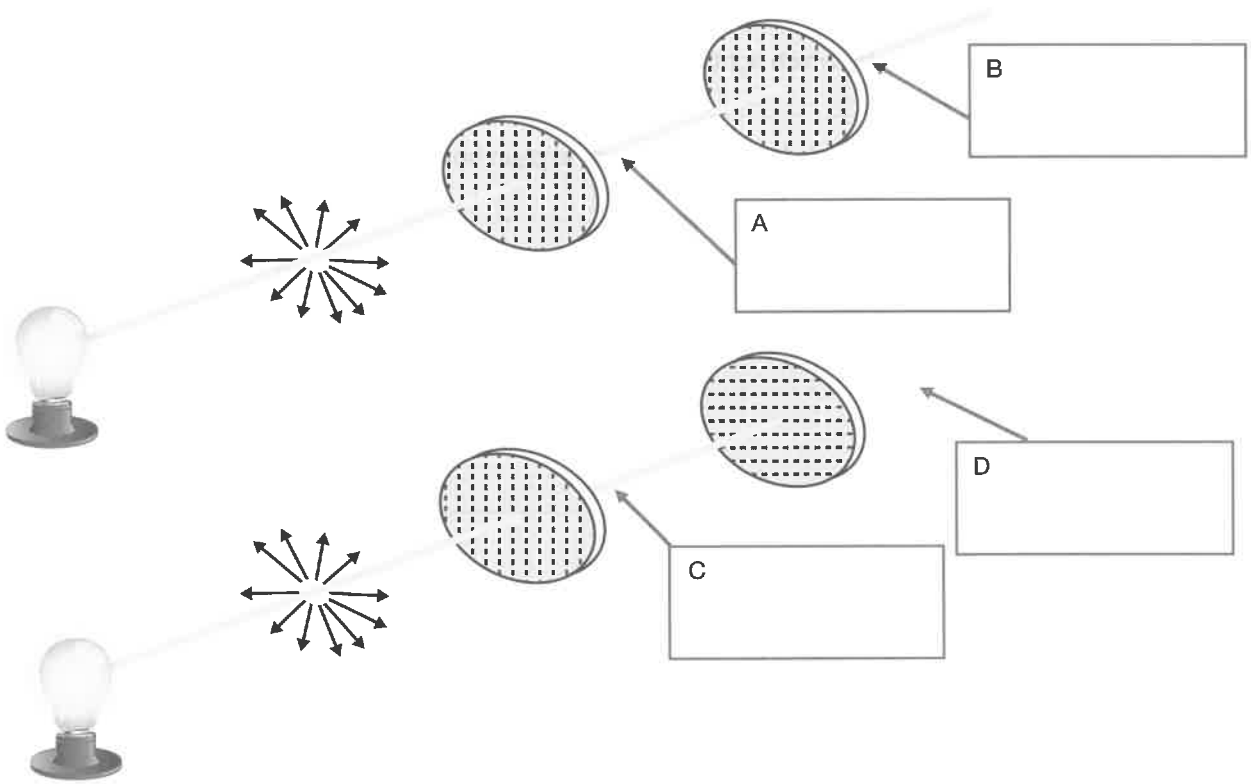


7.10.1.6 Complete the diagram to show how the filter polarises the light.



7.10.1.7 Consider the diagram below. Non-polarised light is incident on the polariser from the left. Indicate, in the boxes provided, what type of light would be seen at A, B, C and D.



7.10.2 Types of polarisation.

7.10.2.1 Light becomes partially polarised as it reflects off non-metallic surfaces such as glass, water, or a road surface. Describe the plane of polarisation of the polarised light.

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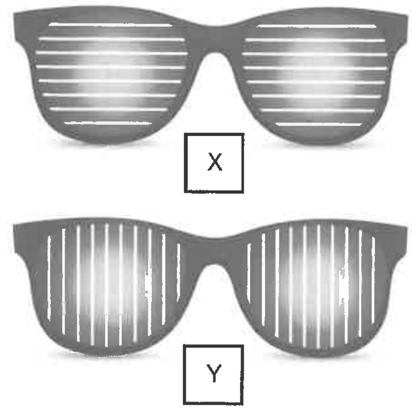
7.10.2.2

(a) Consider the two pairs of sunglasses, X and Y. The lines on the lenses indicate the directions of their polarising axes. Which pair would be best for eliminating the glare resulting from sunlight reflecting off the calm waters of a lake? Justify your answer.



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(b) What would be the effect if the other pair was worn? Justify your answer.

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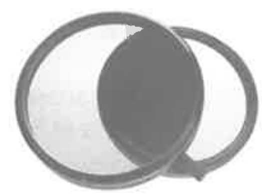
7.10.2.3 Explain why the overlapping camera lenses shown have a dark section where they overlap.



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7.10.2.4

(a) Why, even on a cloudy day, can the sky look quite glary, and photographs taken in these conditions often look 'washed out'?

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(b) What component of the light from the Sun is more likely to be scattered and polarised by the atmosphere? Justify your answer.

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7.10.2.5 Circular polarised waves are used to communicate with satellites rather than linear polarised waves. Explain why.

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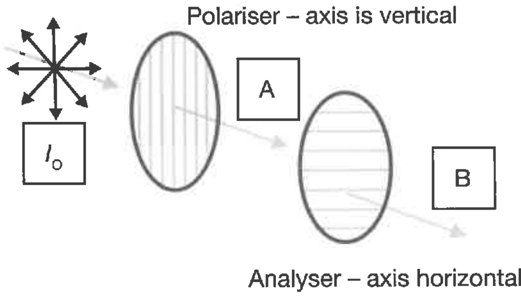
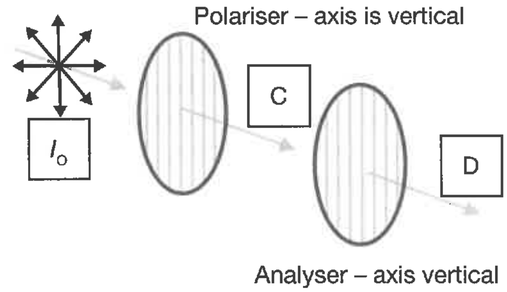
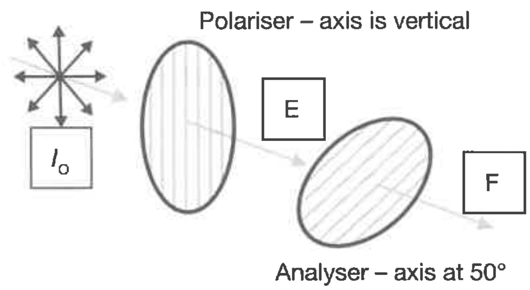
7.10.3 Malus' law.

7.10.3.1 A beam of light of intensity I_o passes through three pairs of two Polaroid filters whose polarisation axes are at different angles as shown in the diagrams. What is the intensity of light passing through each of the filters? Put your answer in the table.





Beam	Intensity
A	
B	
C	
D	
E	
F	



7.10.3.2 Unpolarised light of intensity I_0 is incident on a series of three polarising filters. The axis of the second filter is at 30° to that of the first filter, while the axis of the third filter is at 60° to that of the first filter.

(a) What is the intensity of the light transmitted through the first filter? ....

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(b) What is the intensity of the light transmitted through the second filter? ....

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(c) What is the intensity of the light transmitted through the third filter? ....

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(d) What would be the intensity passing though the third filter if its axis was oriented at 60° if its axis was at 60° to the second filter?

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7.10.3.3 What angle would the axis of a polarising filter need to make with the direction of polarised light of intensity 45 W m^{-2} to reduce the intensity to 9.0 W m^{-2}?

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7.10.3.4 What percentage of plane polarised light passes through an analyser which has its polarising filter at an angle of 36° to the direction of polarisation.

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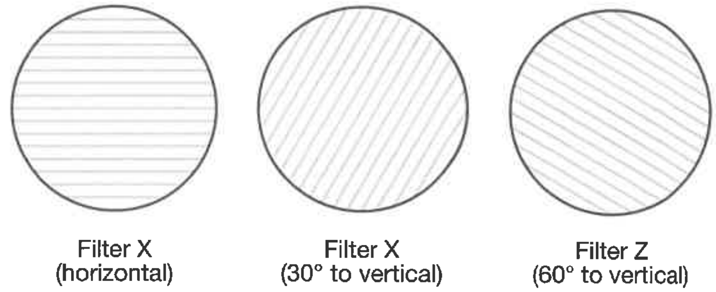
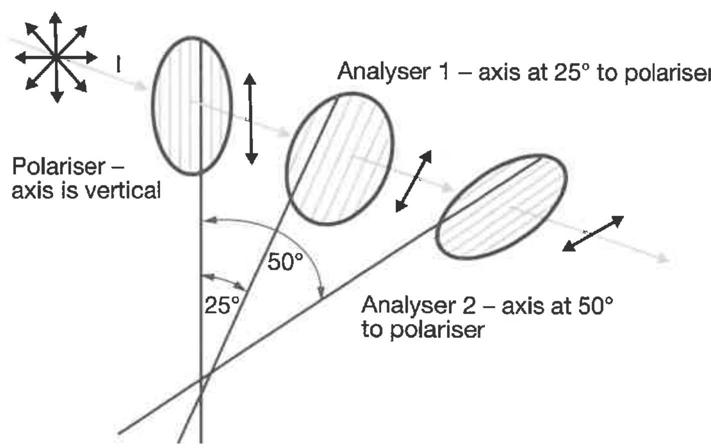
7.10.3.5 Plane polarised light of intensity 200 W m^{-2} is incident on a polarising filter which has its axis aligned at 15° to the angle of the light's polarisation direction. What intensity will be transmitted?

7.10.3.6 You have thee polarising filters as shown in the diagram. In what order should you place these filters so that the maximum intensity of the incident light passes through the last filter in the sequence? Justify your answer calculating the transmitted intensities.



7.10.3.7 Consider the diagram which shows three polarising filters in sequence. Calculate the intensity of the light incident on the polariser passing through it, and through each of the analysers.



7.10.3.8 Unpolarised light of intensity 128 W m^{-2} passes through three polarising filters. The polarising axes of the first and third filters are at 90°. If the intensity of the light passing out of the third filter is 16 W m^{-2}, what is the angle between the polarising axes of the first two filters?

Science Press

Light: Quantum Model

7.11 Analyse the experimental evidence gathered about black body radiation, including Wien's law: $\lambda_{max} = \frac{b}{T}$ related to Planck's contribution to a changed model of light.

INQUIRY QUESTION

What evidence supports the particle model of light and what are the implications of this evidence for the development of the quantum model of light?

7.11.1 Max Planck – The beginning of quantum theory.

7.11.1.1 Why is Max Planck's work on hot body radiation important to the idea of the particle nature of light?

7.11.1.2 Outline Planck's contribution to the idea of quanta.

7.11.1.3 Assess the importance of Planck's contribution to quanta.

7.11.1.4 Compare Planck's idea of the origin of photons of energy with the modern view.

7.11.1.5 Clarify the idea of a black body.

7.11.1.6 Recall Planck's hypothesis as to the source of black body radiation.

7.11.1.7 Recall Planck's (and other scientists') observations on black body radiation.

7.11.1.8 Clarify the term 'quantised' as it is applied to electromagnetic radiation. ....

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7.11.1.9 Recall the two main ideas Planck put forward to explain the idea of quanta involved in black body radiation.

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7.11.1.10 Draw a graph to show a typical black body radiation intensity curve. Label both axes. On the same axes, draw another line to represent the radiation curve as expected from classical theory. Explain the differences.

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7.11.1.11 In what way did Planck contribute to the concept of quantised energy?

(A) He explained black body radiation in terms of oscillating atoms.

(B) He observed that the radiation given out by hot bodies was limited in its frequency range.

(C) He observed that objects at the same temperature emitted the same radiations regardless of their composition.

(D) He proposed the concept of quanta of energy to explain black body radiation.

7.11.1.12 Which phrase best explains the idea of 'quanta' of energy?

(A) Discrete bursts. (B) Finite value. (C) Small packages. (D) Specific amounts.

7.11.1.13

(a) In what way did Planck's idea of quanta go against the then current thinking about the nature of light?

(A) Scientists accepted radiation as being small packets of energy rather than a continuous flow.

(B) The idea of quanta helped explain the photoelectric effect.

(C) Scientists were beginning to accept the wave nature of light and quanta started the particle/wave argument again.

(D) Scientists were starting to accept evidence as to the particle nature of light and quanta provided evidence for the wave nature of light.

(b) Explain your answer. ....

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7.11.1.14

(a) What name has been given to the wave pulses which carry electromagnetic radiation?

(A) Corpuscles. (B) Photons. (C) Particles. (D) Quanta.

(b) How did scientists think energy was transported before this idea was proposed?

....

7.11.1.15 Which of Planck's observations led him to the concept of quanta?

(A) The limited ranges of frequencies of energy emitted by hot objects.

(B) The oscillations of the atoms in the hot matter in the black bodies he used.

(C) The fact that all hot objects gave the same radiation graph regardless of their temperature.

(D) The observation that the peak frequency was different for objects at different temperatures.

7.11.1.16 What is meant by the idea of quanta?

(A) Charged particles can only carry particular amounts of energy depending on their frequency.

(B) The energy gaps between electron orbits in atoms can only have specific values.

(C) Photons of electromagnetic radiation can only have particular amplitudes.

(D) Photons of electromagnetic radiation carry specific amounts of energy dependent on their frequency.

7.11.1.17

(a) Which statement is correct?

(A) The electromagnetic radiation emitted by a hot body depends on its temperature and what it is made of.

(B) The electromagnetic radiation emitted by a hot body depends on its size and what it is made of.

(C) The electromagnetic radiation emitted by a hot body depends on its colour and what it is made of.

(D) The electromagnetic radiation emitted by a hot body depends only on its temperature.

(b) How does this idea differ from that predicted from classical physics? ....

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7.11.1.18 Which choice best describes the source of the energy emitted by a hot object?

(A) The oscillation of its atoms.

(B) The oscillation of the nuclei of its atoms.

(C) Electrons moving from high energy level orbits to lower energy level orbits.

(D) Electrons moving from low energy level orbits to higher energy level orbits.

7.11.1.19 Which of the following was *not* an observation from Planck's black body radiation experiments?

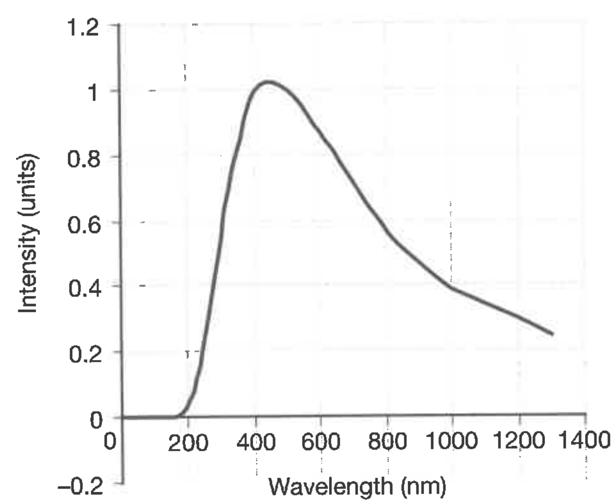
(A) The general shape of the radiation curve is the same for all materials.

(B) The energy given out by a hot body is defined by $E = hf$.

(C) The peak radiation for all substances is the same for the same temperatures.

(D) The peak radiation for all substances is higher at higher temperatures.

7.11.1.20 The graph shows the relationship between the intensity of the radiation given off by a hot body and the wavelength of that radiation.



In 1900 Planck proposed a mathematical formula to predict this relationship. What hypothesis did he make in order to do this?

(A) The intensity of the radiation is directly proportional to the wavelength.

(B) The radiation was quantised with energy proportional to the wavelength.

(C) The radiation was quantised with energy proportional to the frequency.

(D) The radiation was quantised with only certain values allowed.

7.11.1.21 Two cavity radiators are identical in every aspect except than one is made of copper and the other is made of aluminium. Copper is both a better thermal and electrical conductor than aluminium. Both are heated to the same temperature.

Which statement correctly describes the radiation each emits?

(A) The radiations emitted from each metal would be identical.

(B) The copper would emit radiations of higher frequency than the aluminium.

(C) The copper would emit radiations of lower frequency than the aluminium.

(D) The copper would emit radiations of higher intensity than the aluminium.

7.11.1.22 What was Planck's hypothesis regarding black body radiation?

(A) The radiation emitted by a hot body is quantised.

(B) The peak frequency indicates the surface temperature of the object.

(C) All types of hot matter emit electromagnetic radiation with a limited frequency range.

(D) The frequency of the radiation emitted by hot objects is proportional to the temperature of the object.

7.11.2 Wien's displacement law.

7.11.2.1

(a) What is a 'black body'? ....

....

(b) What is black body radiation? ....

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(c) What were the two main properties Planck found out about black body radiation?

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7.11.2.2 State Wien's displacement law as it relates to black bodies. ....

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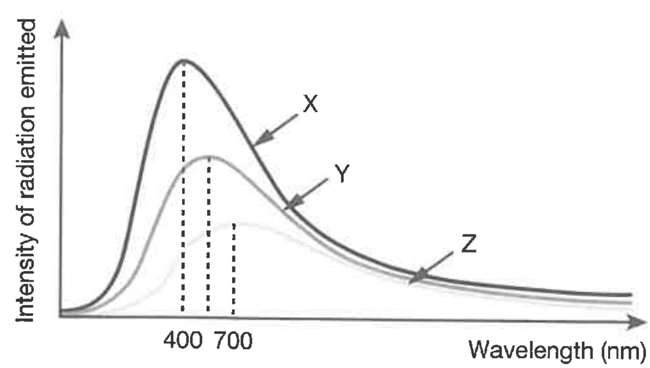
7.11.2.3 The diagram shows the Planck curves for three different black bodies X, Y and Z.



(a) Which of the black bodies would be at the highest temperature? Justify your answer.

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(b) If these were the Planck curves emitted by three stars, which star would be most likely to be a red star? Justify your answer.

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7.11.2.4 Use the Wien's displacement law equation below to answer this question.

$$\lambda_{max}T = b$$

Where λ_{max} = the peak wavelength

T = the absolute temperature of the black body

b = Wien's displacement constant, equal to 2.898×10^{-3} m K

(a) What will be the peak radiation given out by a typical wood fire at a temperature of 2000 K?

(b) The peak frequency of the cosmic background radiation, thought to be the remnant radiation from the Big Bang is about 280 GHz. What temperature does this indicate for outer space?

7.11.2.5 The peak radiation of the star Betelgeuse is about 1200 nm. What would the surface temperature of Betelgeuse be if this data was correct?

7.11.2.6 If the surface temperature of a planet is 27°C, what is its wavelength of peak intensity of its radiation curve?

7.11.2.7 Eta Carinae, the hottest star in our galaxy is about 7500 light years from Earth and about 5 million times as bright as our Sun. It has a calculated surface temperature of about 40 000 K.

(a) What will be the peak wavelength of its emission curve?

(b) What colour is Eta Carinae most likely to be?

7.11.2.8

(a) Frogs are ectothermic, taking their body temperature from their surroundings which is why they like to sunbake a lot – it keeps them warm. Calculate the wavelength of the peak radiation emitted from frogs which are at a daytime temperature of 15°C.

(b) What is the frequency of this radiation?

7.12 Investigate the evidence from photoelectric effect investigations that demonstrated inconsistency with the wave model for light.

7.12.1 Albert Einstein and the photoelectric effect.

7.12.1.1 Define the photoelectric effect. ....

7.12.1.2 Outline Einstein's explanation of the following aspects of the photoelectric effect.

(a) Work function. ....

(b) The kinetic energy of the photoelectrons. ....

(c) Threshold frequency. ....

(d) Why photocurrent increased as the intensity of the light shining on an emitter increased. ....

(e) Why photocurrent increased as the intensity of the light shining on an emitter increased, but only to a maximum value.

....

7.12.1.3 Identify the concerns that some other scientists had with Einstein's explanation of the photoelectric effect.

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7.12.1.4 What are the two main ideas in quantum theory? ....

7.12.1.5 Assess Einstein's contribution to quantum theory and its relation to black body radiation.

....

7.12.1.6 Einstein's explanation of the photoelectric effect was based on the work done by another scientist. Who was that scientist?

(A) Bohr (B) Coulomb (C) Planck (D) Thomson

7.12.1.7

(a) Einstein used the idea that light is quantised to explain the photoelectric effect. What property of photocells supports this idea?

(A) Intensity of the incident light increases the kinetic energy of photoelectrons.

(B) Increasing the frequency of the incident light increases the photocurrent.

(C) Increasing the intensity of the incident light increases the voltage across the cell.

(D) No photocurrent is observed below a particular frequency of incident light.

(b) Explain this answer. ....

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7.12.1.8 Which of the following correctly identifies Einstein's contribution to quantum theory?

(A) His discovery of the photoelectric effect.

(B) His using quantum theory to explain the photoelectric effect.

(C) His proposal that black body radiation is quantised.

(D) His discovery that hot objects emit photoelectrons.

7.12.1.9

(a) When a negatively charged electroscope with a sheet of zinc on top of it has ultraviolet light shone on it it discharges rapidly. Which choice best explains this observation?

(A) The ultraviolet light causes the zinc to lose electrons.

(B) The ultraviolet radiation carries a positive charge.

(C) The ultraviolet light ionises the air around the electroscope.

(D) The zinc becomes warm and thermionically emits electrons.

(b) Explain your answer. ....

....

7.12.1.10 Which of the following identifies how Einstein supported Planck's quantum theory?

(A) By using quantum theory to explain the black body radiation he showed the scientific world that it worked.

(B) By using quantum theory to explain the black body radiation he showed that it had value as a theory.

(C) By using quantum theory to explain the photoelectric effect he showed that it had value as a theory.

(D) By using quantum theory to explain the photoelectric effect he proved that it was correct.

7.12.1.11

(a) In what way did Einstein apply quantum theory?

(A) He developed a mathematical relationship between the energy of a photon of light and its frequency.

(B) He used it to explain the idea of the work function associated with black body radiation.

(C) He was able to account for the energy of a photon of light in terms of the work function and the kinetic energy of electrons.

(D) He expanded the idea of quanta developed to explain black body radiation to be applicable to light.

(b) How did the wave theory and the quantum theory for light differ? ....

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7.12.1.12

(a) Explain why Einstein's explanation of the photoelectric effect required light to be composed of particles rather than being waves.

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(b) Explain how this has this impacted our understanding of the nature of light? ....

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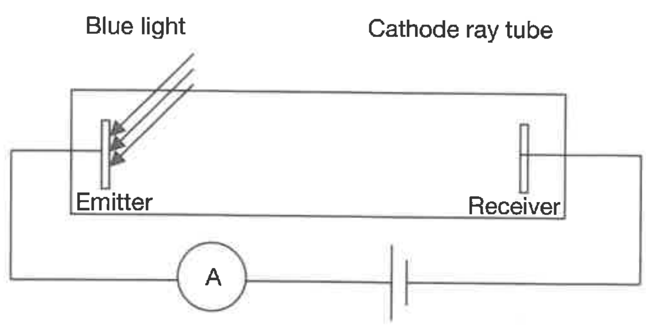
7.12.2 Quantum theory and the photoelectric effect.

Use the following information to answer the next SIX questions.

A group of students set up the apparatus shown to study the photoelectric effect. The emitter produced a photocurrent when illuminated by blue light.



7.12.2.1 What happens to the atoms on the surface of the emitter when blue light shines on it?

(A) They vibrate more rapidly.
(B) They lose valence electrons.
(C) They become warmer.
(D) They move towards the receiver.

7.12.2.2 What happens to the reading on the ammeter when the ultraviolet light shines on the same emitter?

(A) It increases because more photoelectrons are emitted.
(B) It decreases because fewer photoelectrons are emitted.
(C) It increases because photoelectrons are emitted with more kinetic energy.
(D) It decreases because photoelectrons are emitted with less kinetic energy.

7.12.2.3 What happens to the reading on the ammeter when the voltage of the power supply is increased?

(A) It increases because more photoelectrons are emitted.
(B) It decreases because fewer photoelectrons are emitted.
(C) It increases because photoelectrons are emitted with more kinetic energy.
(D) It decreases because photoelectrons are emitted with less kinetic energy.

7.12.2.4 What happens to the reading on the ammeter when a less intense blue light shines on the emitter?

(A) It increases because more photoelectrons are emitted.

(B) It decreases because emitted photoelectrons travel more slowly to the receiver.

(C) It increases because photoelectrons are emitted with more kinetic energy.

(D) It decreases because photoelectrons are emitted with less kinetic energy.

7.12.2.5 What does classical theory say about what happens when light is shone on the emitter?

(A) No electrons will be emitted unless the frequency is above the threshold frequency.

(B) Electrons will be emitted if the intensity of the light is above the threshold intensity.

(C) Electrons will be emitted at all frequencies because the work function is zero in classical theory.

(D) Electrons will be emitted at all frequencies after they absorb energy equal to the threshold energy.

7.12.2.6 How does quantum theory account for the threshold energy?

(A) In collisions between photons and surface electrons all energy from the photon is transferred but only if it is equal to or greater than the threshold energy.

(B) In collisions between photons and surface electrons energy equal to the work function is transferred from the photon only if it is greater than the threshold energy.

(C) In collisions between photons and surface electrons no energy from the photon is transferred if it is greater than the threshold energy.

(D) In collisions between photons and surface electrons all energy from the photon is transferred to the surface electrons regardless of the frequency of the incident light.

7.12.2.7 A hot object emits a dull red glow. What happens when it is heated to a higher temperature?

(A) It will emit the same radiation with a higher intensity.

(B) It will emit the same radiation with a shorter wavelength.

(C) It will emit a higher frequency, shorter wavelength radiation.

(D) It will emit a lower frequency, longer wavelength radiation.

7.12.2.8 What was the main reason quantum theory replaced the classical physics of Maxwell and Newton?

(A) Classical physics could explain black body radiation but not the photoelectric effect.

(B) Classical physics could explain the photoelectric effect but not black body radiation.

(C) Classical physics could explain neither black body radiation nor the photoelectric effect.

(D) There were aspects of both black body radiation and the photoelectric effect that quantum theory could explain better than classical physics.

7.12.2.9 What evidence from photoelectric effect experiments supported Einstein's proposal that the energy of light photons is quantised?

(A) The kinetic energy of photoelectrons increases as the frequency of incident light increases.

(B) Below the threshold frequency the photoelectric effect does not occur.

(C) Increasing the intensity of incident light increases the photocurrent.

(D) Increased intensity of light of a particular frequency means there are more photons of that light.

7.12.2.10 An observation causing scientists problems was that as the light intensity falling on the photocathode increases, the photocurrent flowing increased but only to a maximum value. After that, further increases in intensity did not increase the photocurrent.

(a) What did classical theory predict in this situation? ....

....

(b) How does Einstein's explanation explain this observation? ....

....

....

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(c) Explain the statement 'Intense light is not light with more energy, it is simply more photons, each with the same energy.'

....

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7.12.2.11

(a) What were the major concerns scientists had with Einstein's explanation of the photoelectric effect?

....

....

....

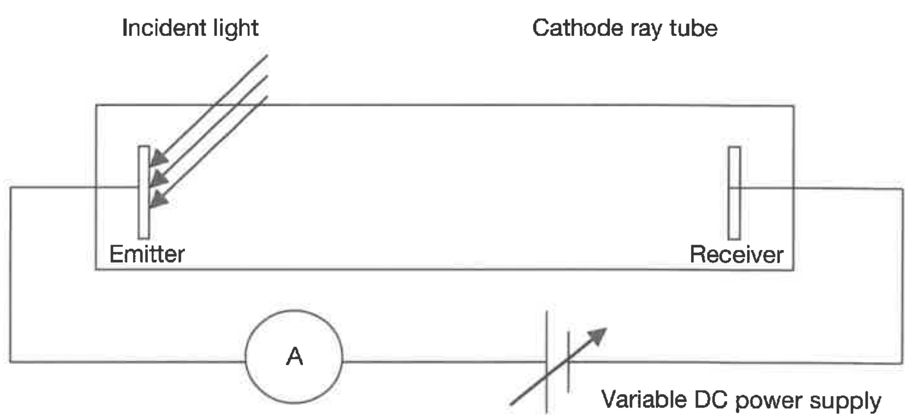
(b) What was the impact of Einstein's explanation of the photoelectric effect on quantum theory?

....

....

7.12.3 Analysing experimental data 1.

7.12.3.1 The following circuit was set up to investigate the photoelectric effect. The variable DC power supply was used to provide a stopping voltage to the photoelectrons.



The results of the experiment are shown in the table.

Incident light	Frequency of incident light ($\times 10^{14}$ Hz)	Energy of photon of incident light (J)	Energy of photon of incident light (eV)	Maximum kinetic energy of photoelectrons (eV)	Maximum current (mA)
Red	4.8		2.0		
Green	5.4			0.1	0.2
Blue	7.3			0.9	
UV1	10.1		4.2	2.1	4.2
UV2	12.0				

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(a) Use the information in the table for the blue light to calculate the work function of the metal used in the emitter.

(b) Check your answer by using the data for the UV1 light.

(c) Estimate the photocurrent emitted by the red light. Justify your answer.

(d) Calculate the threshold frequency of the emitter.

(e) Calculate whatever additional data is needed so that you can graph the maximum kinetic energy of the photoelectrons against the frequency of the incident light. Label and scale your axes in an appropriate way.

(f) Use your graph to determine the experimental value for Planck's constant.

(g) Use your graph to estimate the threshold frequency of the emitter and compare it with your calculated value (answer (d)).

(h) Use your graph to estimate the maximum kinetic energy for the photoelectrons if the incident light has a frequency of 11.0×10^{14} Hz.

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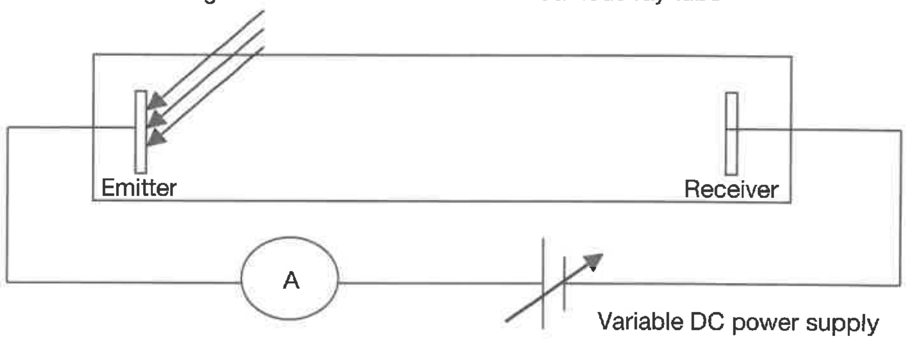
7.12.4 Analysing experimental data 2.

7.12.4.1 The following circuit was set up to investigate the photoelectric effect. The variable DC power supply was used to provide a stopping voltage to the photoelectrons.



The results of the experiment are shown in the table.

Incident light	Frequency of incident light ($\times 10^{14}$ Hz)	Energy of incident photons (eV)	Stopping voltage (V)	Maximum kinetic energy of photoelectrons (eV)	Work function (eV)
Red	4.8		0		
Yellow	5.3		0		
Green	5.8		0.1		
Blue	6.3		0.3		
Violet	7.0		0.6		
UV	10.0		1.9		

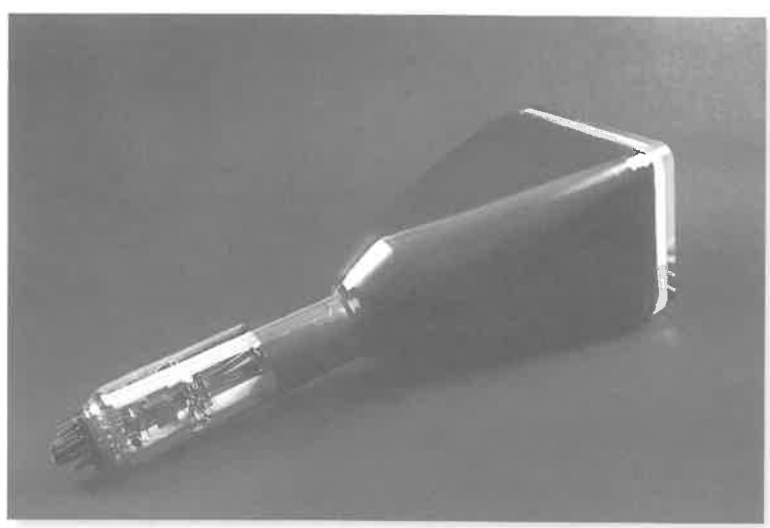
(a) Fill in the missing values for the energy of the incident photons and the kinetic energy of the photoelectrons in the table.

(b) Outline how the stopping voltage in an experiment like this can be used to determine the work function of the photoemitter.

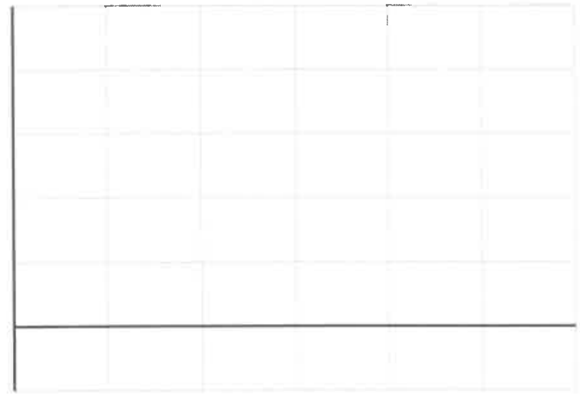
....

....

(c) Use your idea in (b) to calculate the work function of the emitter used in this experiment. Add your values to the last column in the table.



(d) Graph the stopping voltage against the frequency of the incident light. Label and scale your axes in an appropriate way.

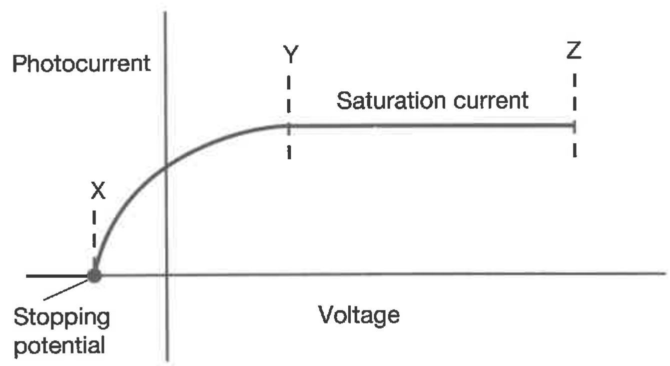


(e) Explain the zero values for the stopping voltage for red and yellow light.

(f) Use your graph (and additional data if needed) to determine a value for Planck's constant. Outline your reasoning by showing all working out.

7.12.5 Analysing experimental data 3.

7.12.5.1 The graph shows the relationship between the voltage applied across the electrodes of a photoemitter and the photocurrent produced.



(a) What is the significance of the stopping potential?

(b) Explain the increase in current between X and the y-axis when the applied voltage is actually negative.

(c) Explain the increase in current between the y-axis and Y when the applied voltage is positive.

(d) Explain why the current does not increase after Y even though the applied potential is increased.

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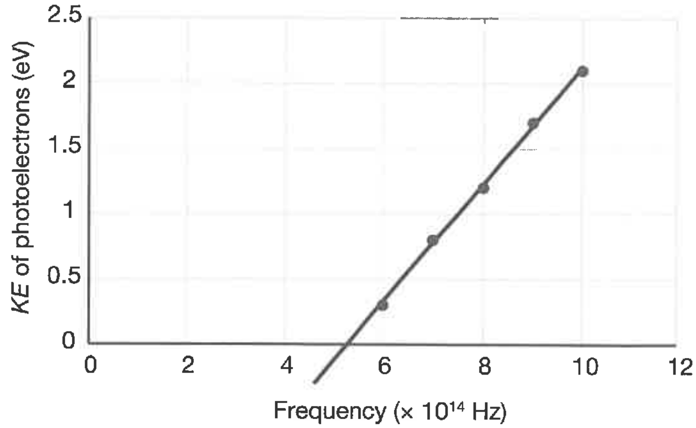
7.12.5.2 The graph shows the result of an experiment where students were investigating the photoelectric effect.



(a) Use this data to determine the work function of the emitter in joules and eV.

....

....

(b) What would be the kinetic energy of the photoelectrons if the incident light was blue light with a wavelength of 450 nm?

....

(c) Use these results to calculate a value for Planck's constant. ....

....

(d) The students used a filter which removed all light with frequencies above 4×10^{14} Hz and hypothesised that if they increased the intensity of the incident light sufficiently, they would eventually get a photocurrent. Evaluate their hypothesis and indicate the result they would get. Justify your answer.

....

....

7.12.5.3 The graphs show the results of an experiment which studied the kinetic energy of the photoelectrons emitted from two different surfaces X and Y as the wavelength of the source of light shining on them was changed.

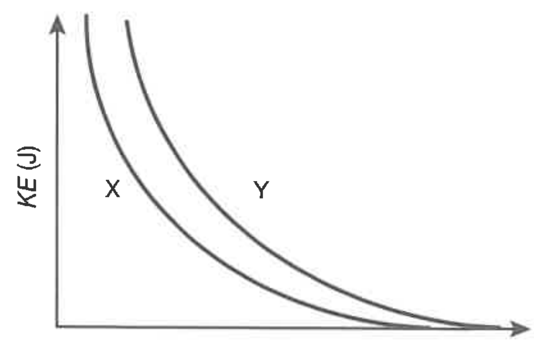
Which conclusion drawn from this experiment is correct?

(A) The greater the kinetic energy of the electrons, the shorter their wavelength.

(B) The kinetic energy of the electrons increases as the intensity of the incident light increases.

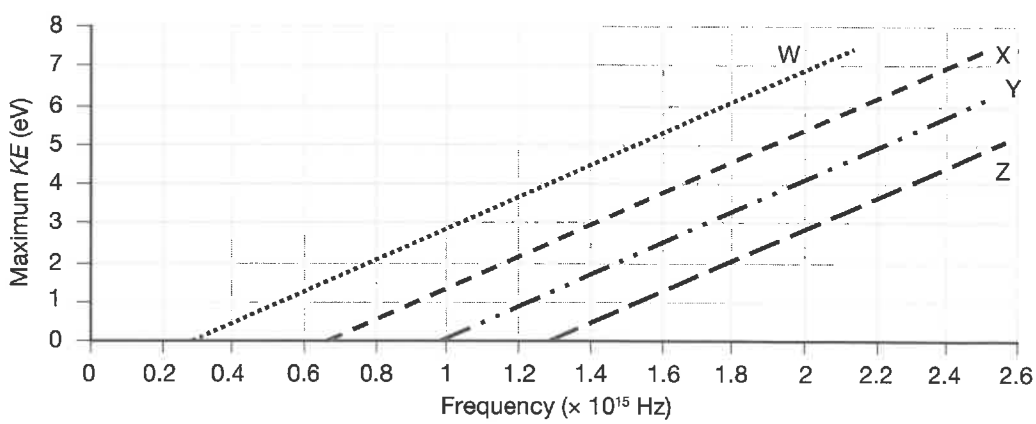
(C) The work function of X is greater than the work function of Y.

(D) The wavelength of the incident light is inversely proportional to its frequency.



Use the following information to answer the next FOUR questions.

The graph shows the response of four photoemitters to incident light.



7.12.5.4 Which of these photoemitters has the highest threshold energy?

(A) W (B) X (C) Y (D) Z

7.12.5.5 Light above the threshold frequency of all four is shone onto each emitter. Which will produce the largest current?

(A) W (B) X (C) Y (D) Z

7.12.5.6 Which of the four emitters has a threshold energy of 4.1 eV?

(A) W (B) X (C) Y (D) Z

7.12.5.7 EMR of wavelength 275 nm is incident on one of these emitters. Photoelectrons are emitted from the surface with kinetic energy of 1.74 eV. Which of the photoemitters is the light falling on?

(A) W (B) X (C) Y (D) Z

7.12.5.8 The table show the results of an experiment done using a photoemitting cathode ray tube.

Frequency of incident light (Hz)	Energy of incident photon (J)	Stopping voltage (V)	Kinetic energy of electrons (J)
4.0×10^{14}		0.06	
6.0×10^{14}		1.0	
8.0×10^{14}		1.81	
1.0×10^{13}		2.56	
1.2×10^{13}		3.56	
1.4×10^{13}		4.38	

(a) Make calculations to complete the table.

(b) Draw a graph of the frequency of the incident light against the kinetic energy of the electrons.

(c) Use your graph to determine the threshold frequency of the emitter.

....

(d) Use your graph to determine the work function of the emitter.

....

(e) Use your graph to determine a value for Planck's constant.

....

7.12.5.9 With the aid of an appropriate, labelled electrical circuit diagram, explain the concept of a stopping voltage.

....

....

7.12.5.10 Explain how measuring the stopping voltage of a beam of photoelectrons enables us to calculate both the kinetic energy of the photoelectrons and the work function of the emitter.

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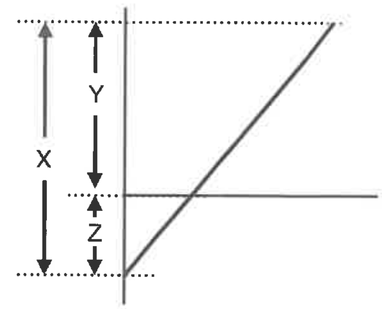
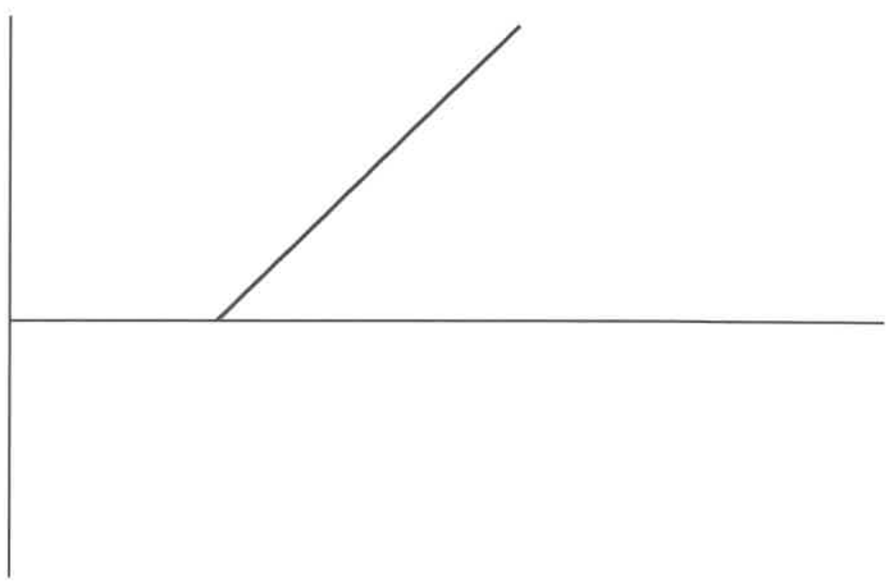
7.12.5.11 The graph shows the results from an experiment which studied the photoelectric effect. Which choice correctly identifies quantities X, Y and Z?



	X	Y	Z
(A)	Work function	*KE* of photoelectrons	Energy of photon
(B)	*KE* of photoelectrons	Energy of photon	Work function
(C)	Energy of photon	*KE* of photoelectrons	Work function
(D)	Energy of photon	Work function	*KE* of photoelectrons

7.12.5.12 The diagram shows a typical graph obtained from an experiment on the photoelectric effect.



(a) Label the axes with their most common labels.

(b) Place the following labels on the graph.

- Energy of photon.
- Kinetic energy of photoelectron.
- Work function.
- Threshold frequency.

(c) Identify the quantity represented by the gradient of the graph. ....

(d) Draw in the line representing another emitter with a higher work function than the one shown.

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7.12.6 Limits of the wave model.

7.12.6.1 Explain how the wave model of light can/cannot account for the threshold frequency of materials in regard to the photoelectric effect.

7.12.6.2 Explain why the wave model of light cannot account for the instantaneous emission of photoelectrons from a surface regardless of the frequency of the incident light, as long as it is above the threshold frequency.

7.12.6.3 Explain the inability of wave theory to account for the constancy of the kinetic energy of photoelectrons when the intensity of the incident light is increased.

7.12.6.4 Explain the fact that the stopping voltage of photoelectrons does not change if the intensity of the incident beam is increased in terms of wave theory.

7.13 Analyse the photoelectric effect: $E_k = hf - \Phi$ as it occurs in metallic elements by applying the law of conservation of energy and the photon model of light.

7.13.1 Solving problems on the photoelectric effect 1.

7.13.1.1 In the year 1900 Planck proposed the equation $E = hf$. Identify the hypothesis he made which led him to develop this equation.

....

7.13.1.2 Use the equations given above, and the wave equation to derive an alternate equation for the energy of a photon based on its wavelength.

....

7.13.1.3 Calculate the energy of a photon of ultraviolet light of wavelength 3.0×10^{-7} m. Express your answer in both joules and electron volts.

....

....

7.13.1.4

(a) How much energy does a photon with wavelength 600 nm have?

(A) 1.1×10^{-25} J (B) 1.1×10^{-27} J (C) 3.3×10^{-21} J (D) 3.3×10^{-19} J

(b) What would be the energy of a photon with twice this wavelength? ....

7.13.1.5 A photon has a wavelength of 350 nm. How much energy does it possess?

(A) 0.3 eV (B) 2.99 eV (C) 4.8×10^{-17} eV (D) 4.8×10^{-19} eV

7.13.1.6 Z has a work function of 2.6 eV. Light of frequency 3.5×10^{15} hertz is shone on it. With what kinetic energy will each photoelectron be released??

(A) 0.9 eV (B) 2.6 eV (C) 10.0 eV (D) 11.9 eV

7.13.1.7 The table shows the threshold frequencies for five metals.

Metal	Threshold frequency ($\times 10^{14}$ Hz)
Aluminium	9.9
Magnesium	8.7
Zinc	7.4
Sodium	5.5
Caesium	4.4

Which metals will emit electrons when they are hit by photons of wavelength 435 nm?

(A) Only aluminium. (B) Aluminium and magnesium only.

(C) Zinc, sodium and caesium only. (D) Zinc and caesium only.

7.13.1.8 How much energy does a photon with wavelength 450 nm have?

(A) 2.98×10^{-24} J (B) 2.98×10^{-26} J

(C) 4.42×10^{-21} J (D) 4.42×10^{-19} J

7.13.1.9 A photon of light has a wavelength of 475 nm. How much energy is carried by each photon of this light?

....

....

7.13.1.10

(a) A photon carries 4.6 eV of energy. How much energy does it carry in joules? ....

....

(b) What is its frequency? ....

(c) What is its wavelength? ....

(d) What band of electromagnetic radiation does this photon belong to? ....

7.13.2 Solving problems on the photoelectric effect 2.

7.13.2.1 Ultraviolet light of frequency 7×10^{15} Hz falls on a photoemitter. Photoelectrons are emitted with kinetic energy equal to 9×10^{-19} J.

(a) Calculate the work function of the emitter.

....

(b) Calculate the stopping voltage of the emitter.

....

....

(c) Determine the threshold frequency of the emitter.

....

....

7.13.2.2 A photon, energy 2.32×10^{-19} J, is incident on a photoemitter with work function 0.85 eV.

(a) Calculate the frequency of the photon.

....

(b) Calculate the kinetic energy with which the photoelectrons are emitted.

....

(c) Light of wavelength 750 nm is shone onto the same emitter. Explain any difference between the photoelectrons emitted using this light compared to the original light.

....

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7.13.2.3

(a) The stopping voltage of a beam of photoelectrons is 1.7 eV. How much kinetic energy does each electron in the beam have as it is released from the cathode?

(A) 1.7 eV
(B) 1.7 eV + work function
(C) 1.7 eV – work function
(D) 1.7 joules

(b) If the beam of light used to release the electrons has energy equal to 4.5 eV, what would be the work function of the emitter?

....

....

7.13.2.4 For a particular cathode material the kinetic energy of emitted photoelectrons was 2.0 eV for light of wavelength 450 nm. What is the work function of this cathode material?

(A) 0.76 eV (B) 1.76 eV
(C) 2.76 eV (D) 4.76 eV

7.13.2.5

(a) Z has a work function of 4.5 eV. Light of frequency 2×10^{15} hertz is shone on it. With what kinetic energy will each photoelectron be released?

(A) 3.8 eV (B) 4.5 eV
(C) 8.3 eV (D) 12.8 eV

(b) Justify this answer. ....

....

....

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7.13.2.6 For a particular cathode material the kinetic energy of emitted photoelectrons was 3.0 eV for light of wavelength 300 nm. What is the work function of this cathode material?

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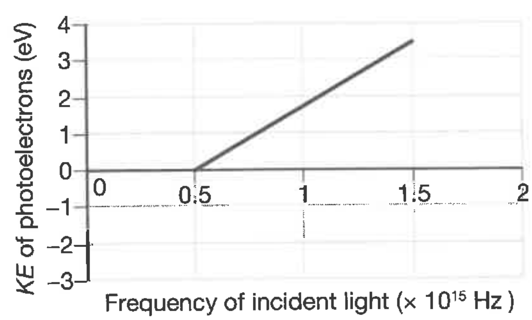
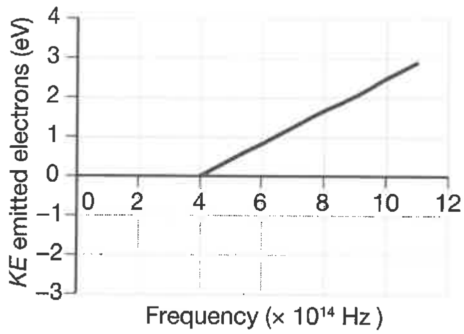
7.13.2.7 Consider the information about a photoemitting substance, X, shown in the graph.



What is the value of the work function for substance X?

(A) 1.0 eV (B) 1.5 eV
(C) 2.0 eV (D) 2.5 eV

7.13.2.8 The graph shows the kinetic energy of electrons emitted by a particular photoemitter when light of different frequencies shines on it.



Which statement is correct?

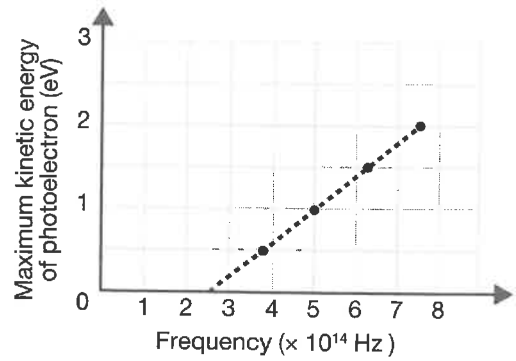
(A) The threshold frequency is 4000 nm.

(B) The work function is about 1.65 eV.

(C) The maximum energy of the emitted electrons is 3 eV.

(D) The threshold energy is −4.0 eV.

7.13.2.9 The maximum kinetic energy of the photoelectrons emitted from a particular emitter for different frequencies is shown in the graph.



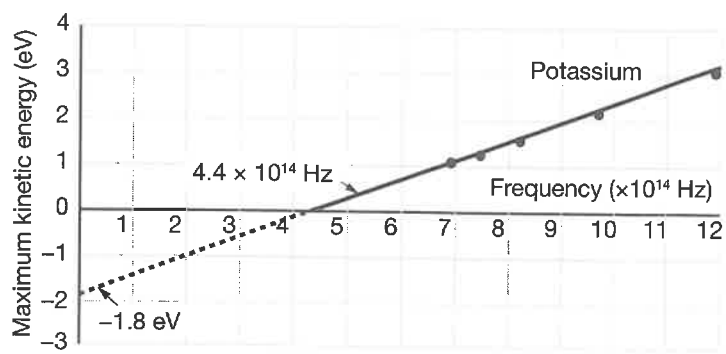
(a) What is the work function of the emitter?

....

(b) Calculate the stopping voltage needed to prevent an electron of kinetic energy 4.8×10^{-19} J.

....

7.13.2.10 In an experiment to investigate the photoelectric effect, beams of light of varying frequencies were directed at a clean surface of potassium metal. The maximum kinetic energy of electrons which were ejected from the potassium was measured. The results of the experiment are shown in the graph.



(a) What is the minimum energy (in both joules and eV) of a light photon that can eject an electron from potassium metal?

....

(b) The graph above shows that electrons ejected by light of frequency 6.0×10^{14} Hz have a maximum kinetic energy of 0.7 eV.

The maximum kinetic energy of electrons ejected by light of frequency 1.2×10^{15} Hz is 3.2 eV.

Explain why the maximum kinetic energy of electrons ejected by light of a higher frequency is greater than the maximum kinetic energy of electrons ejected by light of a lower frequency.

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7.13.3 **Incident intensity and photoemission.**

7.13.3.1 Which coloured beam of light is most likely to cause the emission of electrons from a photoemitting surface?

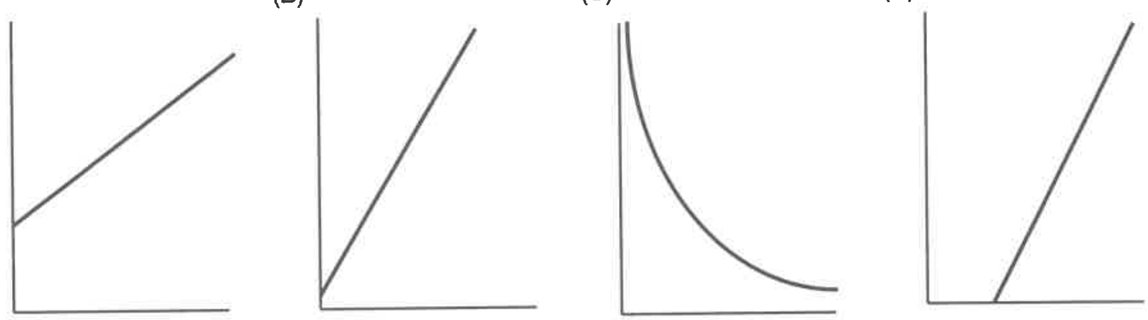
(A) Red
(B) Orange
(C) Yellow
(D) Green

7.13.3.2 Which statement about photons of green light compared to photons of blue light is correct?

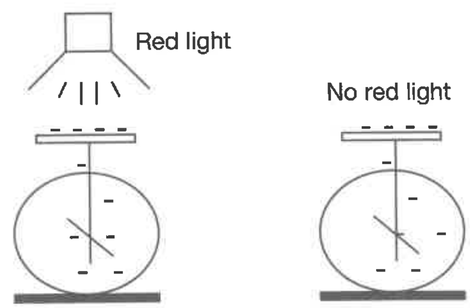
(A) They have greater wavelength.
(B) They have more momentum.
(C) They have more energy.
(D) They have higher frequency.

7.13.3.3 Which graph best shows the relationship between the energy of photoelectrons and the wavelength of the incident light on the photoemitter?

(A) (B) (C) (D)



7.13.3.4 A student set up two negatively charged electroscopes to demonstrate the photoelectric effect as shown in the diagram. He predicted that the electroscope under the red light would discharge more quickly than the other electroscope. It didn't.



Negatively charged electroscopes

(a) What change in method might make this experiment work?

(A) Use a brighter red light.
(B) Use a yellow light.
(C) Move the red light closer to the top of the electroscope.
(D) Use positively charged electroscopes instead of negatively charged ones.

(b) Justify your answer. ....

....

7.13.3.5 A semiconductor produces a current of 15 mA when it is activated using yellow light. Which choice best shows possible values for the current when it is activated with red, blue and ultraviolet light?

	Red	Blue	Ultraviolet
(A)	10	30	20
(B)	20	25	30
(C)	0	10	30
(D)	10	20	25

7.13.3.6 Blue light is shone onto a photoemitter and a current of 2.5 mA is produced. Predict any change in this current if the following light is used. In each case, justify your answer.

(a) UVL.

(b) Green light.

(c) Red light.

7.13.3.7 Why is a beam of UV-rays of the same intensity as a beam of green light considered to be more dangerous?

(A) The photons in each beam have the same energy but there are more photons in the UV-ray beam than in the beam of green light.

(B) There is the same number of photons in each beam but the photons in the UV-ray beam have more energy than the photons in the beam of green light.

(C) There is the same number of photons in each beam but the photons in the UV-ray beam travel much faster than the photons in the beam of green light.

(D) The photons in each beam have the same energy but there are more photons per second in the UV-ray beam than in the beam of green light.

7.13.3.8 The stopping voltage for white light and blue light are the same even though white light has many more frequencies of light making up the beam and is usually much more intense than a blue light. Explain why.

7.13.3.9 What will increase the current from a photoemitter?

(A) Shine less intense light on it.

(B) Shine light with a longer wavelength on it.

(C) Shine light with a lower frequency on it.

(D) Shine light with a higher frequency on it.

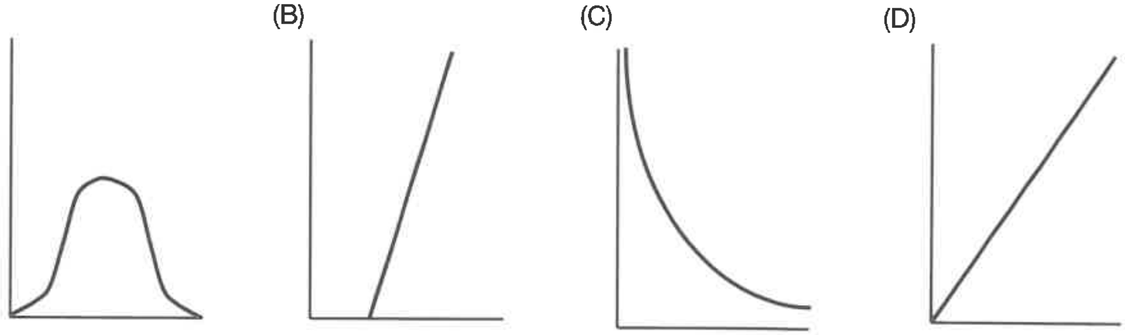
7.13.3.10 Sodium has a work function of 2.28 eV. Which of the following incident colours is most likely to cause photoemission from its surface?

(A) Green (B) Orange (C) Red (D) Yellow

7.13.3.11

(a) Which graph best shows the relationship between the energy (*y*-axis) carried by a photon and the wavelength (*x*-axis) of the photon?

(A) (B) (C) (D)



(b) Justify this answer.

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7.14 Analyse and evaluate the evidence confirming or denying Einstein's two postulates: the speed of light in a vacuum is an absolute constant and all inertial frames of reference are equivalent.

INQUIRY QUESTION

How does the behaviour of light affect concepts of time, space and matter?

7.14.1 Frames of reference.

7.14.1.1

(a) What is a frame of reference? ....

....

....

(b) Identify the two common types of frames of reference used in the study of motion. ....

....

....

(c) Describe the difference between these two types of frames of reference. ....

....

....

7.14.1.2

(a) What is the principle of relativity? ....

....

....

....

....

(b) Outline the importance of the principle of relativity with reference to both types of frames of reference.

....

....

7.14.1.3

(a) There are three frames of reference that we classify as being inertial frames. What are they?

....

....

....

(b) According to your answer to (a), the Earth would be considered as an inertial frame of reference (and for most simple applications we do accept it as such). In fact, technically it is not. Explain why.

....

....

....

7.14.1.4 Classify each of the following as an inertial or non-inertial frame of reference and explain your choice.

(a) The Earth. ....

(b) Your bedroom. ....

(c) A helicopter in constant, level flight. ....

(d) A roller coaster. ....

(e) A car turning a corner. ....

(f) A 'wheel of terror' at a fun park. ....

(g) A satellite in a geostationary orbit. ....

7.14.1.5 A passenger in a train took off his tie and hung it from a hook on the luggage rack above him. Throughout the journey he noticed sometimes:

(i) The tie hung straight down. ....

(ii) The tie seemed to lean towards the windows of the train. ....

(iii) The tie seemed to lean towards the centre aisle. ....

(iv) The tie seemed to lean backwards. ....

(v) The tie seemed to lean forwards in the same direction the train was moving. ....

Assuming the windows of the train are on the passenger's left, then by writing your answers in an appropriate table:

(a) Account for each of these observations in terms of the motion of the train.

(b) Identify the frame of reference for each observation, justifying each answer.

	(a) Explanation	**(b) Frame of reference**
(i)		
(ii)		
(iii)		
(iv)		
(v)		

7.14.1.6 You regain consciousness some time after an asteroid hit your spaceship. You are unaware of any movement of the craft. You wonder if you are still on course and moving towards Andromeda Galaxy. A comet shoots past you, seemingly parallel to your path and moving straight ahead.

(a) Which of the following interpretations of this observation is *not* possible?

(A) Both you and the comet are travelling towards Andromeda, but the comet is moving faster than you.

(B) You are stationary and the comet is moving past you towards Andromeda.

(C) You are moving backwards and the comet is moving towards Andromeda.

(D) You are moving towards Andromeda and the comet is moving away from Andromeda.

(b) Give two other possible interpretations of the relative motion that could lead to the same observation.

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7.14.1.7

(a) Which of the following is a correct statement?

(A) A net force cannot exist in an inertial frame of reference.

(B) A net force cannot exist inside a non-inertial frame of reference.

(C) An inertial frame of reference can be detected by an observer inside the system.

(D) A non-inertial frame of reference cannot be detected by an observer inside the system.

(b) Explain your answer. ....

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7.14.1.8 State the principle of relativity and describe how a non-inertial frame of reference relates to the principle of relativity.

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7.14.1.9 What *best* summarises the characteristics of an inertial frame of reference?

(A) It is stationary.

(B) It is moving with constant velocity.

(C) It is stationary or moving with constant velocity.

(D) It is stationary, moving with constant velocity or in stable orbit.

7.14.1.10

(a) A spaceship in a stable orbit around a planet is an inertial frame of reference despite the fact that it is travelling in a circular path and therefore has an acceleration towards the centre of the orbit. Why?

(A) Its acceleration is negligible.

(B) The centripetal force is balanced by the gravitational force.

(C) It is in 'free fall', usually referred to as 'free float'.

(D) It is moving with constant velocity.

(b) Explain your answer. ....

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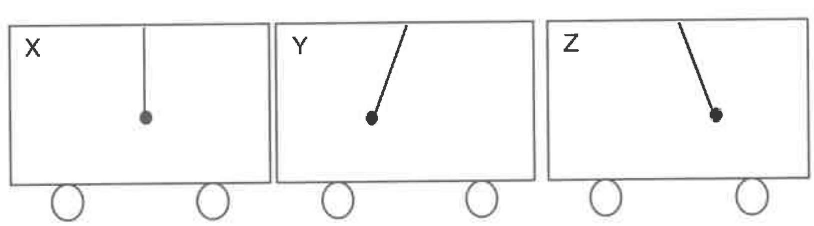
7.14.1.11 The diagrams show tennis balls hanging on light strings from the ceilings of three different vehicles X, Y and Z.



Which vehicle(s) is/are non-inertial frames of reference?

(A) X only (B) Y only (C) Z only (D) Y and Z only

7.14.2 Einstein's postulates.

7.14.2.1

(a) What were the two postulates Einstein proposed in his special theory of relativity?

(b) What additional statement did Einstein make as a result of publishing his special theory of relativity?

(c) Explain the rationale behind this third proposal.

7.14.2.2 As well as publishing his paper on special relativity in 1905, Einstein also proposed a relationship between mass and energy. What was this relationship?

7.14.2.3 In 1908, Hermann Minkowski made a proposal that influenced Einstein's further development of his work on relativity. What was Minkowski's proposal and how did it impact on Einstein's work.

Hermann Minkowski (1864-1909).

7.14.2.4 What was the significance of Einstein's assumption on the constancy of the speed of light?

(A) Light will reach an observer at the speed of light regardless of the speed of the observer.

(B) Length and time can no longer be regarded as constant quantities.

(C) There is no need for an aether.

(D) The aether did not exist.

7.14.2.5

(a) An astronomer measures the 'red shift' of a distant galaxy and calculates it to be travelling towards Earth at 1.3×10^8 m s^{-1}. At what speed will light rays from this galaxy reach us?

(A) 1.3×10^8 m s^{-1}

(B) 1.7×10^8 m s^{-1}

(C) 3.0×10^8 m s^{-1}

(D) 4.3×10^8 m s^{-1}

(b) Which answer *must* be incorrect? Explain why.

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7.14.2.6 Earth sends a microwave message to a spaceship which is travelling directly away from Earth at 0.4 *c*. At what speed is the message received by the spaceship?

(A) 0.4 *c*

(B) 0.6 *c*

(C) 1.0 *c*

(D) 1.4 *c*

7.14.2.7

(a) What is a consequence of Einstein's proposal that the speed of light is constant regardless of the frame of reference of the observer?

(A) There was no need for the existence of the aether.

(B) The speed of light cannot vary.

(C) We need to consider the Universe in four dimensions, not three.

(D) All of the above.

(b) Explain your choice. ....

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7.14.2.8 Why don't we notice relativistic effects in the normal motion in our lives?

(A) They only apply at speeds approaching the speed of light.

(B) They apply only at the speed of light.

(C) They only apply if the observer is travelling near the speed of light.

(D) They are too small to notice at normal speeds.

7.14.2.9 Which of the following statements is correct?

(A) Space and time are constant factors in the Universe.

(B) Stationary observers see space and time as it really is.

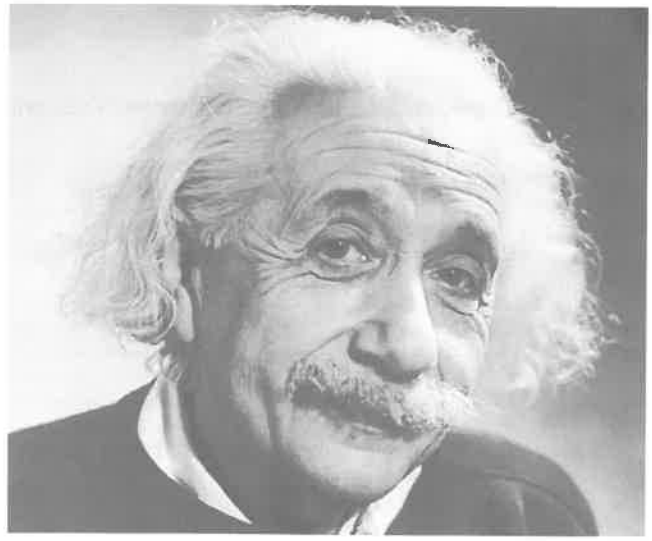
(C) Moving observers see a distorted version of space and time.

(D) Space and time change according to the motion of the observer.

7.15 **Investigate the evidence, from Einstein's thought experiments and subsequent experimental validation, for time dilation: $t = \dfrac{t_o}{\sqrt{\left(1-\dfrac{v^2}{c^2}\right)}}$ and length contraction: $L = L_o\sqrt{\left(1-\dfrac{v^2}{c^2}\right)}$.**

7.15.1 **Einstein's first thought experiment.**

7.15.1.1 Describe Einstein's first thought experiments and the rationale behind his conclusion.



Albert Einstein (1879-1955).

7.15.1.2 What were the three consequences of the idea that the speed of light is constant for other aspects of science?

7.15.2 **Einstein's second thought experiment.**

7.15.2.1 Name and state the principle that led Einstein to start thinking along the lines of his second thought experiment.

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7.15.2.2

(a) Briefly outline the idea in Einstein's second thought experiment. ....

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(b) What were the results of Einstein's second thought experiment? ....

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(c) What conclusion did Einstein come to as a result of his second thought experiment? ....

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(d) What has this conclusion become known as? ....

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(e) Recall the equation used to summarise Einstein's findings in his second thought experiment.

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7.15.2.3

(a) Time dilation 'works both ways'. With the use of an appropriate example, clarify this statement.

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(b) When writing about time dilation many authors use the term 'the event'. Clarify this idea with reference to an observer on Earth and a second observer in a spaceship moving away from Earth at constant speed.

(c) Using an appropriate example, explain how t_o relates to 'the event'.

(d) Using an appropriate example, explain how t_v relates to 'the event'.

(e) When teaching this work, this author summarises Einstein's second thought experiment results by saying that 'the observer is always watching TV'. How does this help clarify Einstein's conclusion?

7.15.2.4 What were three consequences of the ideas that came from Einstein's second thought experiment?

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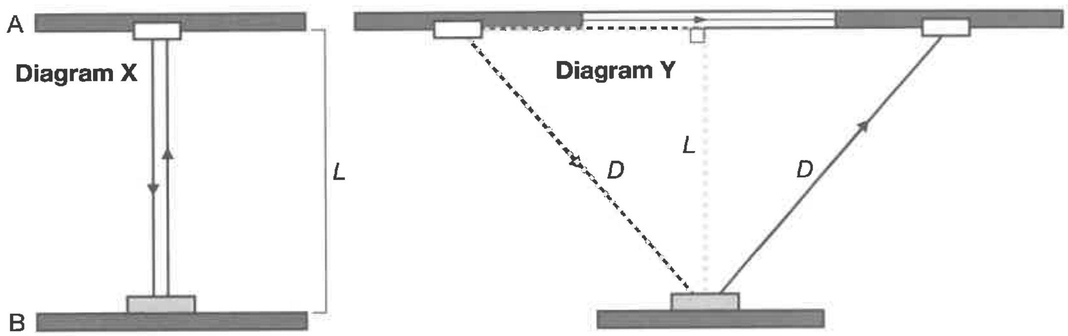
7.15.2.5 The two diagrams below ae used to illustrate Einstein's second thought experiment. In both, the same beam of light travels from the ceiling of a train carriage moving towards the right, reflects off a mirror on the floor and back to the light source.



(a) Account for the difference between the two diagrams.

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(b) If the time taken for the light beam to travel from floor to ceiling in each case is t, write an equation for each diagram to show how we could use the information in the diagram to calculate the speed of the light beam.

For diagram X [ ] For diagram Y [ ]

(c) What was the essential idea, derived from his first thought experiment, that Einstein then applied to this situation?

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(d) Show how the application of this idea gives us a simple illustration of the fact that the times for the observers inside and outside the train are not the same.

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7.15.3 t_v or not t_v? That is the question!

7.15.3.1 Complete the sentences below by filling in the missing words.

(a) By definition, t_o is always the time measured on the clock which is ______ relative to 'the ______'.

(b) For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the ______ ______ ______ ______ ______.

(c) Therefore the clock in the spaceship, which is moving along with the spaceship, is at ______ to the spaceship.

(d) The clock on the spaceship therefore records ______.

(e) The clock on the desk next to the Earth observer is therefore measuring ______ and his clock is in ______ ______ to 'the ______'.

(f) Therefore, according to the observer on ______, the clock on the spaceship will be running ______ ______ than his clock on Earth.

7.15.3.2

(a) The same definition holds – t_o is always the time measured on the clock which is ______ relative to 'the ______'.

(b) In this example, for the observer on the spaceship comparing times of clocks on Earth and in the spaceship, 'the event' is the ______ ______ ______ ______ ______ ______.

(c) Therefore the clock on ______, which is moving with the Earth, is at ______ to the Earth.

(d) The clock on ______ therefore records t_o.

(e) The clock on the desk next to the ______, is therefore measuring t_v and his clock is in ______ ______ to 'the event'.

(f) Therefore, according to the observer on the ______, the clock on the Earth will be ______ ______ ______ than his clock on the spaceship.

7.15.3.3 What is meant by the phrase 'the observer is always watching TV!'

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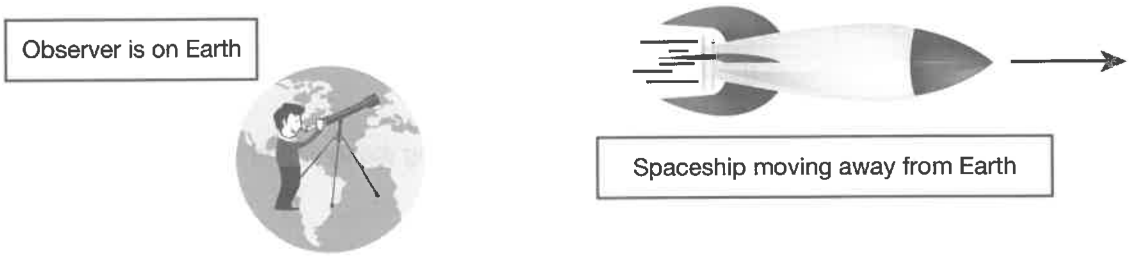
7.15.3.4 Imagine an observer on Earth looking at a spaceship travelling away from him at constant speed.

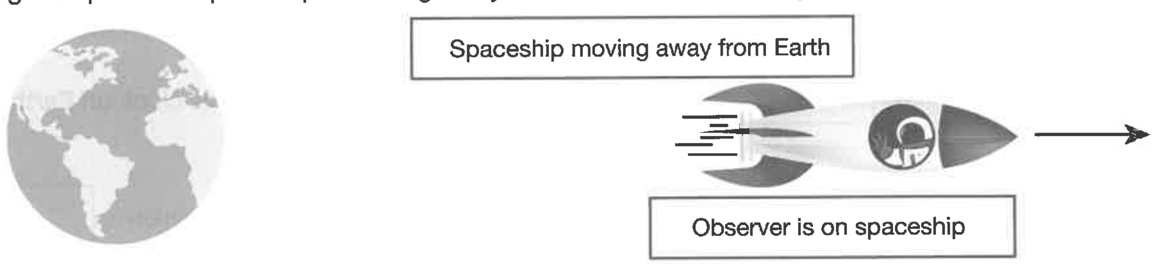


(a) For this observer, what is 'the event'? ....

(b) Who measures t_o? ....

(c) What time does the Earth observer measure? ....

7.15.3.5 Imagine a pilot in a spaceship travelling away from Earth at constant speed.



(a) For this observer, what is 'the event'? ....

(b) Who measures t_o? ....

(c) What time does the pilot measure? ....

7.15.3.6 A spaceship flies past Mars. A Martian on Mars and the captain of the spaceship both observe the rate at which time is passing on their clocks and on the clock of the other person.

(a) According to the Martian, what is the event? ....

(b) According to the Martian, which clock is running faster? ....

(c) In this situation, is the clock in the spaceship, or the Martian's clock recording t_v? ....

(d) According to the captain of the spaceship, which clock is running faster? ....

(e) In this situation, is the clock in the spaceship, or the Martian's clock recording t_o? ....

7.15.3.7 Two spaceships, X and Y, are heading away from each other at constant velocities. The captains of the spaceships observe the rate at which time is passing on their clocks and on the clocks in the other spaceship.

(a) According to the captain of spaceship X, what is the event? ....

(b) According to the captain of X, which clock is running faster? ....

(c) According to the captain of X, which clock is recording t_v? ....

(d) According to the captain of Y, which clock is running faster? ....

(e) According to the captain of Y, which clock is recording t_o? ....

7.15.4 Time dilation 1.

7.15.4.1 Describe the concept of a light clock, and explain the concept of 'proper time'. ....

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7.15.4.2 Imagine a spaceship moving at various fractions of the speed of light as given in the table. Calculate the missing values in the table.

Speed of ship (c)	Lorentz factor (also known as gamma or boost factor) = $\left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$
0.1	
0.3	
0.5	
0.7	
0.9	
0.99	

7.15.4.3

(a) Use the data from the previous question to graph the Lorentz factor against the velocity of the spacecraft.

(b) From your graph, describe what happens to the Lorentz factor as the speed of the object gets closer and closer to the speed of light.

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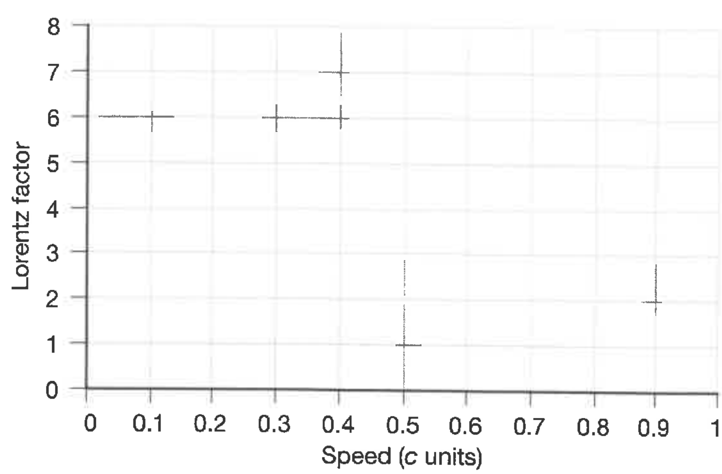

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7.15.4.4 Calculate the missing values in the table.

Time on spaceship (s)	Speed of ship (c)	Lorentz factor	Length of 1 second on spaceship as perceived by observer on Earth(s)	Time dilation effect (%)
1	0.1			
1	0.3			
1	0.5			
1	0.7			
1	0.9			
1	0.99			

7.15.4.5

(a) Use the data from the previous question to graph the percentage time dilation against the velocity of the spacecraft.

(b) From your graph, describe what happens to the time dilation effect as the speed of the object gets closer and closer to the speed of light.

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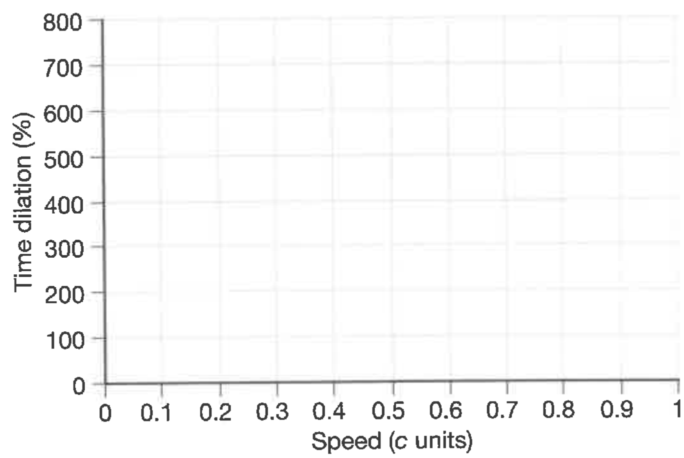

7.15.4.6 Alpha Centauri is 4.5 light years from Earth. Imagine a spaceship able to fly at 0.9 *c*. How long would it take to get there as observed:

(a) By its pilot? ....

(b) By Mission Control on Earth? ....

7.15.4.7 A spaceship moves at 6.8×10^{7} m s^{-1}. Astronauts stand an 8 hour watch. Find:

(a) How much time would pass on Earth as measured by the astronaut. ....

(b) How long the 8 hour watch would be to Mission Control on Earth. ....

7.15.4.8 Mesons have a life of 2.2 μs, but mesons formed in the upper atmosphere take 15.6 μs to reach the ground. Calculate the speed of the mesons.

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7.15.4.9

(a) An astronaut moving at 0.5 *c* takes 10 hours ship time to reach planet X. How much time has passed on Earth as measured by this astronaut?

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(b) The Earth observer recorded 10 hours on his clock. What time does this represent on the ship?

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7.15.4.10 The Klingon captain notices that it takes 0.5 s to fly past the stationary Enterprise at 0.1 *c*. Calculate the time of this fly-by as measured by Captain Kirk on the Enterprise.

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7.15.4.11 A UFO flies past Earth at 0.2 *c*. An Earth observer watches it for 5.0 s Earth time. Calculate how much time passes in the UFO as measured by the same observer on Earth.

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7.15.4.12 A spaceship flies past a planet at 0.4 *c*. The pilot sees his girlfriend on Earth wave to him for 5 s Earth time. How much time passes on the spaceship according to the spaceship clock?

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7.15.4.13 Calculate how fast a spaceship would have to go so that each year on the ship would correspond to 3 years on Earth.

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7.15.4.14 A spaceship travelling at 0.75 *c* sends a microwave message to Earth. Calculate the speed of the transmission relative to Earth if the spaceship was travelling:

(a) Away from Earth. ....

(b) Towards Earth. ....

(c) Calculate its speed relative to the spaceship in each case. ....

7.15.4.15 The distance between a star and Earth is 5.0×10^{16} m as measured by an astronomer on Earth. An astronaut in a spaceship launches and travels towards the star at 0.6 *c* as measured by the same observer.

(a) Find the time for the astronaut to travel from Earth to the star as measured by observers on Earth.

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(b) Calculate the time taken for the astronaut to travel from Earth to the star as measured by the astronaut.

....

(c) Which of these times is the proper time? Explain your answer. ....

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(d) At the time of launch, the astronomer and the astronaut are exactly the same age. After reaching the star, the astronaut returns to Earth. Explain any age difference between the astronomer and the astronaut when he lands back on Earth.

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7.15.4.16 Star X is 16.0 light years from Earth. A spaceship travels at 0.4 *c* to reach the star.

(a) Calculate how long the trip takes as measured by an observer on Earth. ....

(b) Calculate how long the trip takes as measured by the astronauts in the ship. ....

(c) Calculate the distance travelled as measured by the astronauts. ....

(d) Calculate the speed of the ship as measured by the astronauts. ....

7.15.5 Time dilation 2.

7.15.5.1 Imagine a stationary observer outside the Solar System watching Earth and a spaceship travelling away from Earth. How would this observer perceive time on Earth and the spaceship? Explain.

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7.15.5.2

(a) A spaceship flies past Earth at 0.6 *c*. The pilot observes a clock on Earth and an observer on Earth observed a clock on the spaceship. (Do we ever wonder how they can do this?) Which statement about their observations is correct?

(A) Neither observer will notice a change in the clocks of the other observer.

(B) Both observers will notice the other person's clock running more slowly than their own.

(C) The observer in the spaceship will notice the clock on Earth running more slowly than his own, and the observer on Earth will notice the clock on the spaceship running faster than his own.

(D) The observer on Earth will notice the clock on the spaceship running more slowly than his own, and the observer on the spaceship will notice the clock on the spaceship running faster than his own.

(b) Explain your answer. ....

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7.15.5.3 What is a consequence of special relativity on time?

(A) Time passes more slowly in a stationary frame of reference.

(B) Time passes more quickly in a non-inertial frame of reference.

(C) Time passes more quickly in a frame of reference which is moving.

(D) The rate at which time passes depends on the speed of the frame of reference.

7.15.5.4

(a) Two trains, X and Y, pass each other at 0.7 *c*. Which statement about the time on each train as observed by a person on the other train is correct?

(A) Neither observer will notice a change in the clocks of the other observer.

(B) Both observers will notice the other person's clock running more slowly than their own.

(C) The observer in train X will notice the clock in train Y running more slowly than his own, and the observer in train Y will notice the clock on train X running faster than his own.

(D) The observer in train Y will notice the clock in train X running more slowly than his own, and the observer in train X will notice the clock in train Y running faster than his own.

(b) Explain your answer. ....

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7.15.5.5 An astronaut stands a 5 hour watch on his spaceship which is moving through space at 0.4 *c*. How much time passes on Earth?

(A) 4.20 hours (B) 4.58 hours (C) 5.46 hours (D) 5.95 hours

7.15.5.6 As Mission Control awaits the return of the ship, they record that 7 days have passed since they lost contact with the 0.75 *c* explorer. How long is it since the astronauts lost contact with Mission Control?

(A) 3.06 days (B) 3.50 days (C) 4.63 days (D) 6.06 days

7.15.5.7

(a) A 60 year old mother has a natural birth 60 year old daughter. How could this be possible?

(A) The mother has gone on a long space journey at near light speed while the daughter stayed on Earth.

(B) The daughter has gone on a long space journey at near light speed while the mother stayed on Earth.

(C) They both went on a long space trip at near light speed but in different directions.

(D) They both went on a long space trip at near light speed, but the daughter travelled further and faster than the mother.

(b) Would an observer in Mission Control on Earth notice any differences in the pulse rate and heartbeat of astronauts travelling at a significant proportion of the speed of light? Explain.

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7.15.5.8

(a) An astronaut in a spaceship moving at 0.2 *c*, and her friend on Earth each wave at each other for what they measure to be 5.0 s. What statement about this it correct?

(A) Each will notice the other waving for longer than 5 s.

(B) The astronaut will notice her friend waving for longer than 5 s.

(C) The friend will notice the astronaut waving for longer than 5 s.

(D) They will each notice the other waving for less than 5 s.

(b) Explain your answer. ....

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7.15.5.9 A spaceship travelling through space experiences a 90% time dilation. How fast is it travelling?

(A) 0.036 *c* (B) 0.32 *c* (C) 0.44 *c* (D) 0.91 *c*

7.15.5.10 A spaceship travels through space at 2×10^8 m s^{-1} for 16 days as measured on the ship. How much time has passed on Earth?

(A) 48 days (B) 21.5 days (C) 11.9 days (D) 5.3 days

7.15.5.11 Captain Kirk, who is on the Enterprise which is moving with speed 0.6 *c* , waves to the Klingons on an asteroid the ship is passing at four second intervals as measured in Captain Kirk's frame of reference. How long would the Klingons measure between each wave?

(A) 2.56 s (B) 3.30 s (C) 5.00 s (D) 6.25 s

7.15.5.12 A spaceship travels from Earth to a distant star at 0.8 *c*. The star is 80 light years from Earth. How long does it take for the ship to make the journey as measured by Mission Control, and how much time does Mission Control see as passing in the actual spaceship?

(A) 10 years and 6 years (B) 6 years and 10 years

(C) 10 years and 16.67 years (D) 16.67 years and 10 years

7.15.6 Length contraction 1.

7.15.6.1 Define proper length. ....

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7.15.6.2 Jenny is at rest. John is moving with a constant velocity of 0.2 *c*. John is sitting at a desk which, to him, is 1.5 m wide. The desk is orientated so that it is parallel to the direction of his velocity.

(a) What is the proper length of the desk, L_0? ....

(b) Write an equation which we could use to find the length of the desk as observed by Jenny. ....

....

(c) Which of these lengths will be the shorter? Explain your answer. ....

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7.15.6.3 Calculate the speed that would cause a length contraction of 15%.

7.15.6.4 A 100 m long spaceship flies past a space station at 0.8 *c*. Calculate its length as it appears to be to:

(a) Its pilot.

(b) An observer on the space station.

If the space station is 250 m long, calculate its length as observed by:

(c) The pilot.

(d) An observer on the space station.

7.15.6.5

(a) A moving spaceship appears to be 75 m long. If it is actually 100 m long, calculate its speed.

(b) At what speed would the ship be going if a stationary observer observed its length to be 50 m?

7.15.6.6 A 100 m Klingon spaceship flies past Saturn at 0.25 *c*. The diameter of Saturn as seen from Earth is 120 000 km. Find:

(a) Its diameter as seen by the Klingons.

(b) The length of the Klingon vessel as seen from Saturn.

7.15.6.7

(a) A 38 m long spaceship orbits Earth at 30 000 km h^{-1}. Find its length as seen on Earth.

(b) The pilot of the ship looks down on a wall which has a proper length of 250 m. Find the wall's length as seen by the pilot.

(c) If the pilot saw the section to be 250 km long, calculate its proper length on Earth.

7.15.6.8 An Earth observer sees a spaceship moving away from Earth at 0.8 *c* as 100 m long. The ship's pilot sends a signal to Earth every hour as measured by a clock on the ship. Find:

(a) The time between the signals as measured by the pilot.

(b) The time between the signals as measured by the Earth observer.

(c) The distance the ship travels between signals as measured by the pilot.

(d) The distance the ship travels between signals as measured by an Earth observer.

(e) The length of the ship as measured by the pilot.

(f) The length of the ship as measured by the Earth observer.

7.15.6.9 A rocket ship from Jupiter is 400 m long. It flies past Earth at 0.95 *c*. Find its length as seen by a stationary observer on Earth.

7.15.6.10 Astronomers measured the length of a meteorite passing Earth at 0.35 *c* to be 275 m. What would be its proper length?

7.15.6.11 A Klingon space vessel flies past the Enterprise at 0.4 *c*. The Klingons measure the distance between their forward and rear cannons as 150 m. Find their distance apart as measured by crew on the Enterprise.

7.15.6.12 Which statement about a spaceship flying past Earth is correct?

(A) It will contract in length, breadth and height.
(B) It will contract in length and breadth only.
(C) It will contract in length and height only.
(D) It will contract in length only.

7.15.6.13 A transparent spaceship passes a stationary asteroid at near light speed. The passengers in the ship and the visitors on the asteroid surface are both having a party. Which statement about what each sees is correct?

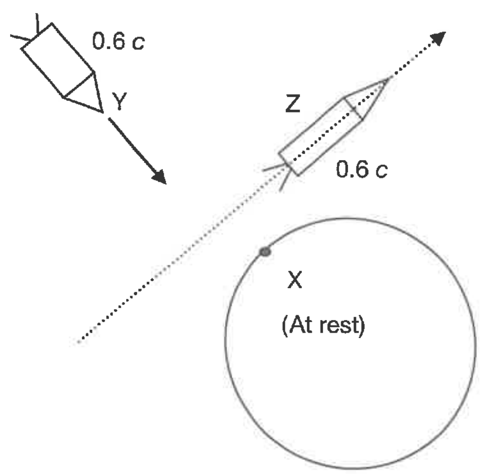
(A) Everyone appears to be normal to everyone else.
(B) People on the ship appear thinner to the observers on the asteroid and people on the asteroid appear thinner to the observers on the spaceship.
(C) People on the ship appear normal to the observers on the asteroid and people on the asteroid appear thinner to the observers on the spaceship.
(D) People on the ship appear thinner to the observers on the asteroid and people on the asteroid appear normal to the observers on the spaceship.

7.15.6.14 An person on Earth notices that a passing spaceship is 25 m long. Its rest length is 100 m. Which statement about this person's observation of time on this spaceship is correct?

(A) Four seconds on Earth is one second on the spaceship.
(B) One second on Earth is four seconds on the spaceship.
(C) Four seconds on Earth is two second on the spaceship.
(D) Two second on Earth is four seconds on the spaceship.

7.15.7 Length contraction 2.

7.15.7.1 The diagram shows the positions of three observers X, Y and Z. X is stationary on Earth. Y is in a spaceship heading towards Earth at 0.6 *c*. Z is in a spaceship heading across, and away from Earth at 0.6 *c*.



Which statement best agrees with Einstein's theory of special relativity?

(A) X observes more length contraction in Z than in Y because Z is moving away from Earth while Y is approaching Earth.
(B) Both Y and Z notice the same length contraction in the ships because they are moving at the same speeds.
(C) Because of the directions of their relative motions, X and Y notice no length contraction in each other, but both observe length contraction in Z.
(D) Because X is at rest, Y and Z observe no length contraction of X.

7.15.7.2

(a) A 120 m long spaceship flies past the Earth at 0.8 *c*. What is its apparent length as observed by an astronomer on Earth?

(A) 72 m (B) 96 m (C) 125 m (D) 200 m

(b) A 120 m cube flies past Earth at 0.8 *c*. What are its dimensions as observed from Earth? Explain.

....

....

....

7.15.7.3

(a) A spaceship flying past Earth at 0.6 *c* appears to be 100 m long. What would be its length if it was stationary?

(A) 80 m (B) 125 m (C) 156.25 m (D) 167.7 m

(b) If the diameter of the spaceship appeared to be 50 m, what would its stationary diameter be?

(A) 40 m (B) 50 m (C) 62.5 m (D) 78 m

7.15.7.4 As a spaceship flies past Jupiter, a Jovian noticed that its length contracted by 30%. How fast was it going?

(A) 0.51 *c* (B) 0.55 *c* (C) 0.71 *c* (D) 0.95 *c*

7.15.7.5 A 150 km long spaceship flies past the Earth at 0.6 *c*. Calculate the apparent length of the spacecraft as seen from Earth.

(A) 32 m (B) 90 m (C) 120 m (D) 180 m

7.15.7.6 A spacecraft flying past Earth at constant speed appears to have a length which is 60% its stationary length. Calculate how fast it is travelling.

(A) 0.2 *c* (B) 0.4 *c* (C) 0.6 *c* (D) 0.8 *c*

7.15.7.7 At what speed would a spacecraft have to travel so that an external observer would see it as contracted by 20%?

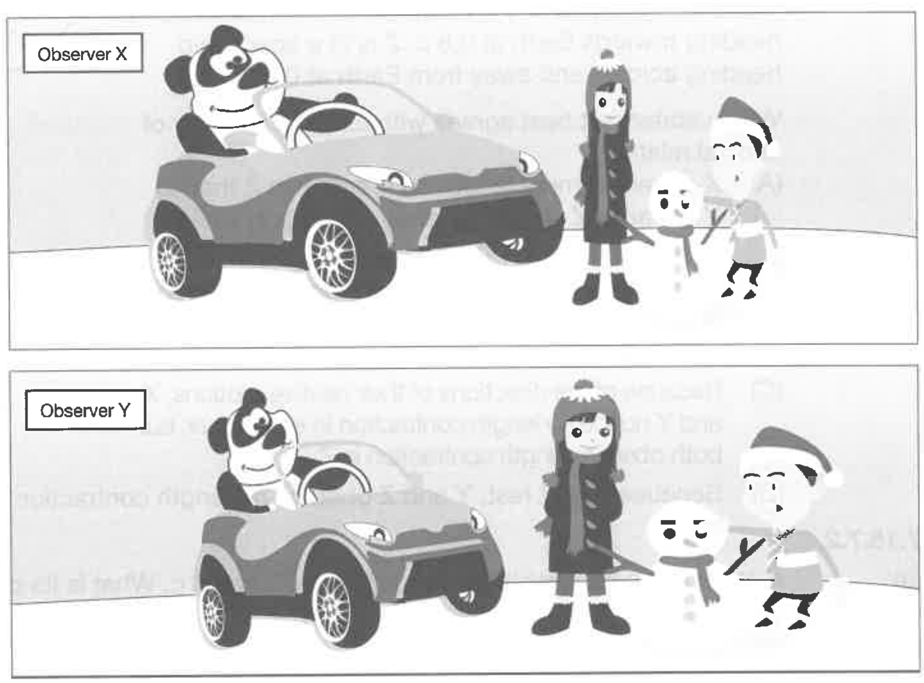
(A) 0.3 *c* (B) 0.4 *c* (C) 0.5 *c* (D) 0.6 *c*

7.15.7.8 Which statement about a spaceship flying past Earth is correct?

(A) It will contract in length only.
(B) It will contract in length and breadth only.
(C) It will contract in length and height only.
(D) It will contract in length, breadth and height.

Use the following information to answer the next FIVE questions.

The diagrams show two different observers' views of the same event.



7.15.7.9 Which statement about these two observers is correct?

(A) Both observers are in stationary frames of reference.
(B) Both observers are in a moving frame of reference.
(C) Observer X is in a moving frame of reference and Y is in a stationary frame of reference.
(D) Observer Y is in a moving frame of reference and X is in a stationary frame of reference.

7.15.7.10 Which statement is correct?

(A) X and Y are both in inertial frames of reference.

(B) X and Y are both in non-inertial frames of reference.

(C) X is in a non-inertial frame and Y in an inertial frame of reference.

(D) X is in an inertial frame and Y in a non-inertial frame of reference.

7.15.7.11 What is the size of the length contraction in diagram X?

(A) About 20% (B) About 35% (C) About 50% (D) About 80%

7.15.7.12 Predict the speed of the car in diagram X.

(A) About 0.6 *c* (B) About 0.75 *c* (C) About 0.8 *c* (D) About 0.95 *c*

7.15.7.13 Which statement best justifies your answer to the last question?

(A) Length contraction occurs only in non-inertial frames of reference.

(B) Length contraction occurs only in inertial frames of reference.

(C) Only observer X will see length contraction because he is the only observer moving.

(D) More information is needed to make this justification.

7.15.8 Combined relativity questions.

7.15.8.1 An electron, mass 9.109×10^{-31} kg, is travelling at a constant speed in a linear accelerator. A laboratory observer measures its speed as 0.8 *c* and the length of its journey to be 150 m.

(a) Show that $\gamma = 1.67$ for these electrons. ....

....

(b) How far does the electron travel in its frame of reference? ....

....

(c) What is the time taken for this journey in the electron's frame of reference? ....

....

(d) What is the time for the journey in the laboratory frame of reference? ....

....

(e) What will be the mass of the electron in its frame of reference? ....

....

(f) What is the mass of the electron according to the laboratory observer? ....

....

(g) Sketch a graph to show how the observed mass of the electron will change with velocity as measured by the laboratory observer (calculations not required).

7.15.8.2 An astronaut, moving away from Earth at nearly the speed of light, is observed on TV and is monitored by electronic devices in Mission Control on Earth.

(a) What changes would the astronaut notice in his body dimensions, mass and pulse rate, and the length of the ship as compared to what he would observe if he was back on Earth?

....

(b) What changes would the observers in Mission Control notice in his body dimensions, mass and pulse rate, and the length of the ship as compared to what they would observe if he was back on Earth? Explain your answer.

....

7.15.8.3 Star Sonex is 15.8 light years away from Earth.

(a) At what speed would a spaceship have to travel to make this journey in 16 years as measured by observers on Earth?

....

(b) What time would elapse according to the astronauts during the journey?

....

(c) Explain how, from the astronauts' point of view, that after this amount of time (answer (b)), they will have arrived at Sonex.

....

7.15.8.4 Compare the passage of time on a spaceship as perceived by an Earth observer and by the astronaut of the spaceship.

....

7.15.8.5 Knowing a little about time dilation, a doctor thought that if he put his patients with terminal diseases in a spaceship that orbits the Earth then enough time may pass on Earth to find a cure for the disease before the patient died from it. Is his logic correct? Explain your answer.

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7.15.8.6 A spaceship is on its way to Alpha Centauri, 4.2 light years from Earth, at 0.6 c.

(a) How long will observers on Earth predict this journey will take? ....

(b) What time passes on the ship clock as observed by Earth observers during the trip? ....

(c) How far do the observers on Earth measure the journey to be? ....

(d) How far will the ship travel in the time predicted by the astronauts? ....

(e) How long will the astronauts predict this journey will take? ....

(f) Explain how these two distances are consistent with the fact that according to the astronauts and the Earth observers, the ship reaches Alpha Centauri at the same time.

....

7.15.8.7 A 200 m long spaceship flies past a space station which is 2.0 km long at a speed of 0.4 c.

(a) How long is the spaceship as observed by the astronaut in the spaceship? ....

(b) How long is the spaceship as observed by an observer on the space station? ....

(c) How long is the space station as observed by the astronaut? ....

(d) How long is the space station as observed by an observer on the space station? ....

7.15.8.8 Suppose that in the future it will be possible for astronauts to travel to a distant star, 10.5 light years away, at a constant speed of 0.75 c.

(a) How long would it take to get there as measured by observers on the Earth?

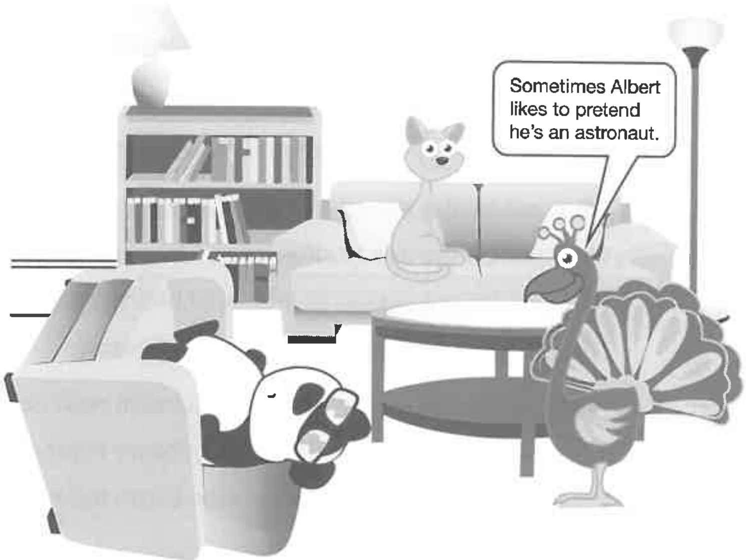
(b) How long would it take for them to get there as measured by the astronauts?

On arrival at Alpha Centauri, they immediately set out on the return journey, at the same speed. On their arrival back on Earth how much time has passed, since the astronauts first left Earth, as measured by:

(c) Observers on the Earth?

(d) The astronauts?

7.15.8.9 A proton, mass 1.673×10^{-27} kg, is accelerated to 0.75 c in a cyclotron which has a circumference of 100 m and then travels around the cyclotron at constant speed.



(a) How long does the proton take to travel around the cyclotron once as measured by a scientist in the laboratory?

(b) How long does the proton take to travel around the cyclotron once as measured by the proton?

(c) What is the circumference of the cyclotron as calculated by the laboratory scientist?

(d) What is the circumference of the cyclotron as calculated by the proton?

(e) What is the mass of the proton as calculated by the laboratory scientist?

(f) What is the mass of the proton as calculated by the proton?

7.15.8.10 A 3000 kg, 500 m long spaceship flies past a 1600 m long space station at a speed of 0.6 c.

(a) How long is the spaceship as observed by the astronaut?

(b) How long is the spaceship as observed by an observer on the space station?

(c) How long is the space station as observed by the astronaut?

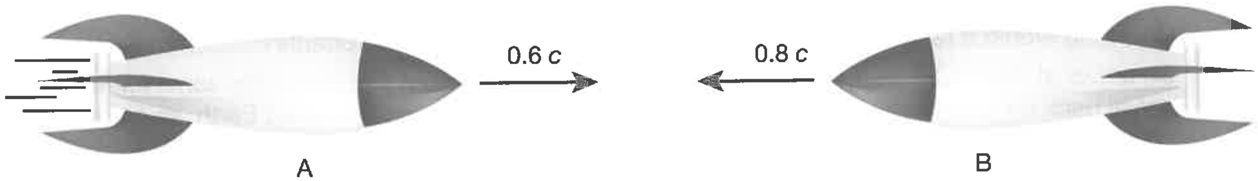
(d) How long is the space station as observed by an observer on the space station?

(e) What is the mass of the spaceship as observed by the pilot?

(f) What is the mass of the spaceship as observed by an observer on the space station?

(g) How fast would the spaceship need to go for the captain to see the space station as 500 m long?

7.15.8.11 Two rockets, A moving at 0.6 *c* and B at 0.8 *c* approach each other as shown in the diagram.



(a) What would be the relative speed of the rockets as measured by a stationary outside observer?

....

The captain of A sends a radio message to the captain of B.

(b) What will be the speed of this radio beam relative to the captain of A? ....

(c) What will be the speed of this radio beam relative to the captain of B? ....

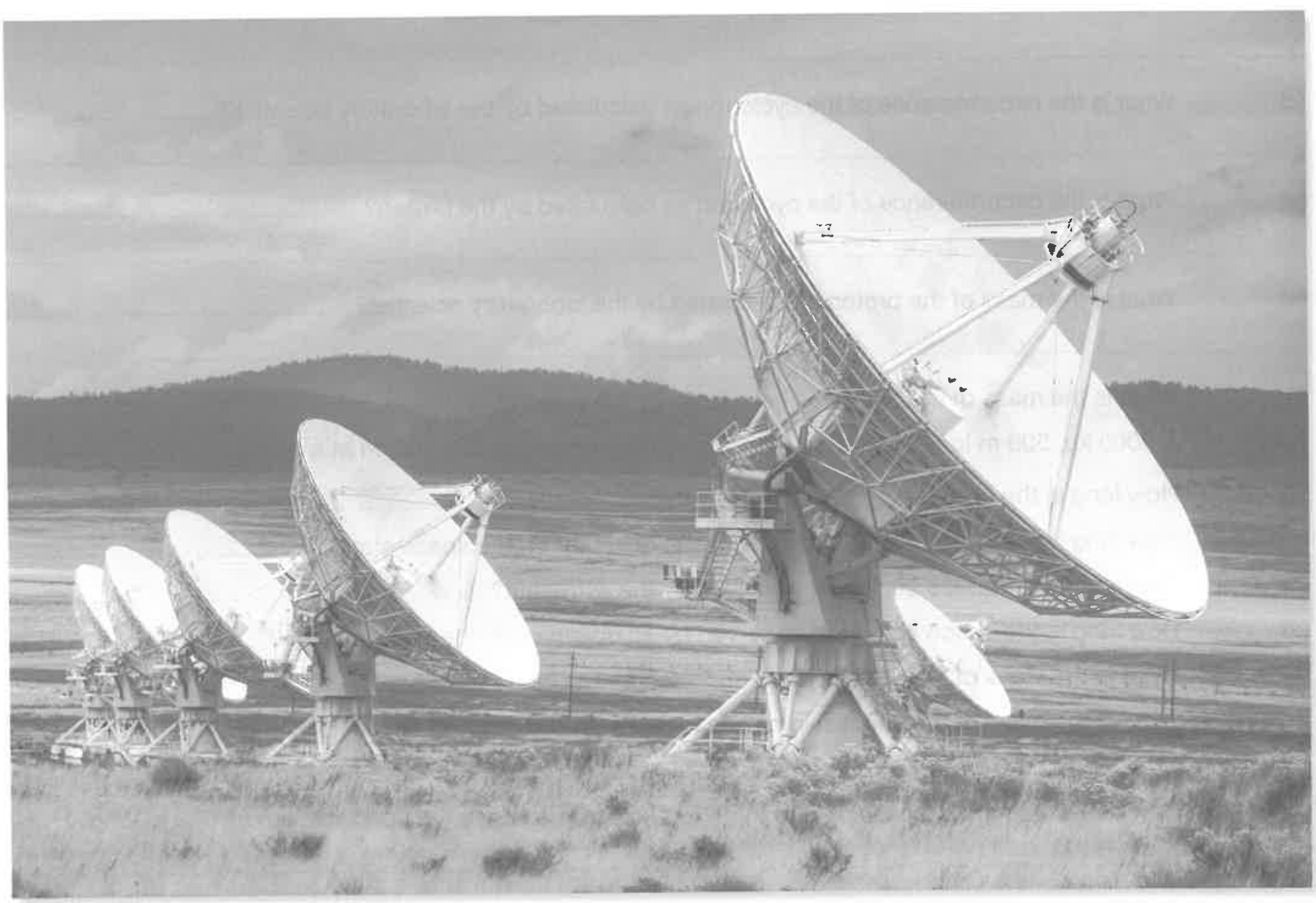
(d) What will be the speed of this radio beam relative to the stationary outside observer? ....

The captain of B replies to this radio message.

(e) What will be the speed of this radio beam relative to the captain of A? ....

(f) What will be the speed of this radio beam relative to the captain of B? ....

(g) What will be the speed of this radio beam relative to the stationary outside observer? ....



7.16 Analyse experimental validation for special relativity, for example observations of cosmic-origin muons at the Earth's surface, atomic clocks (Hafele-Keating experiment), evidence from particle accelerators and evidence from cosmological studies.

7.16.1 Validation of special relativity.

7.16.1.1 Briefly describe one piece of evidence that supports time dilation. ....

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7.16.1.2 Briefly describe one piece of evidence that supports length contraction. ....

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7.16.1.3 Briefly describe one piece of evidence that supports relativistic mass increase.

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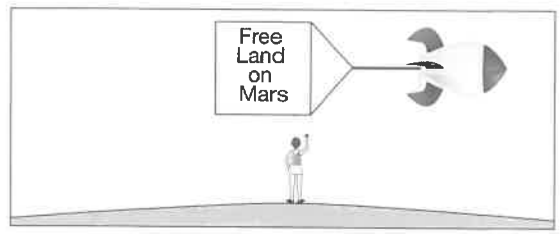
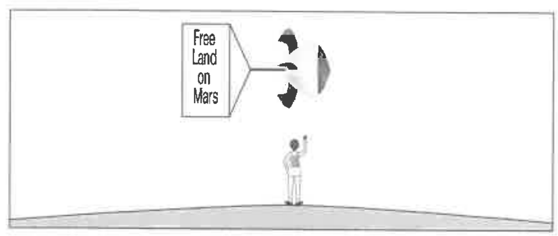
Spaceship moving at 10% of the speed of light

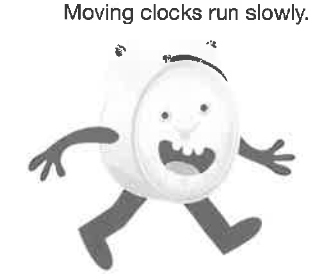


Spaceship moving at 86.5% of the speed of light

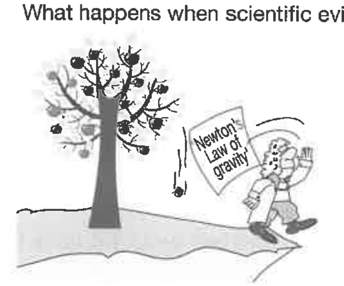


7.16.1.4 In what way did the Michelson-Morley experiment, in retrospect, give evidence for Einstein's proposal of the consistency of the speed of light?

Moving clocks run slowly.



What happens when scientific evidence is ignored.



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7.16.2 Muons and special relativity.

7.16.2.1 What does the term 'half-life' refer to? ....

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7.16.2.2 The measured half-life of muons is 2.2 μs (2.2×10^{-6} s). Use this information to complete the following table to predict how many muons would be remaining after the times indicated. For this exercise, imagine we are starting at time zero with 1 000 000 muons. In the number of muons column, round down any fractions.

Time (μs)	Number of half-lives	Number of muons
0		1 000 000
2.2		
4.4		
6.6		
8.8		
11.0		
13.2		

Time (μs)	Number of half-lives	Number of muons
15.4		
17.6		
19.8		
22.0		
24.2		
26.4		
28.6		

7.16.2.3

(a) Muons form as cosmic ray particles hit molecules in the atmosphere at an average altitude of 14 km. If muons travel at 0.994 c, how far would they travel in 2.2 μs?

....

....

(b) How long would it take them to reach the ground if they did not decay? ....

....

(c) How many half-lives does this time represent? ....

(d) Out of the 1 000 000 muons, how many would reach the ground? ....

7.16.2.4

(a) The half-life of muons in the laboratory frame of reference is 2.2 μs. What is it in the muon frame of reference?

....

....

(b) How far would a muon travel in one half-life? ....

....

(c) How many half-lives would it take to reach the ground from 14 km? ....

....

(d) According to this, estimate how many muons out of the 1 000 000 would reach the ground?

....

....

7.16.2.5

(a) In the laboratory frame of reference the muons have to travel 14 000 m. How far is this in the muon frame of reference?

....

(b) How long will it take the muons to travel this distance? ....

....

(c) How many half-lives does this represent? ....

....

(d) According to this, estimate how many muons out of the 1 000 000 would reach the ground?

....

....

7.16.2.6 Scientists predict that 20% of the muons formed at about 14 km altitude will reach the surface if relativistic effects are taken into account. This is what is found to be the case in practice. What is the impact of this observation on Einstein's theory of special relativity?

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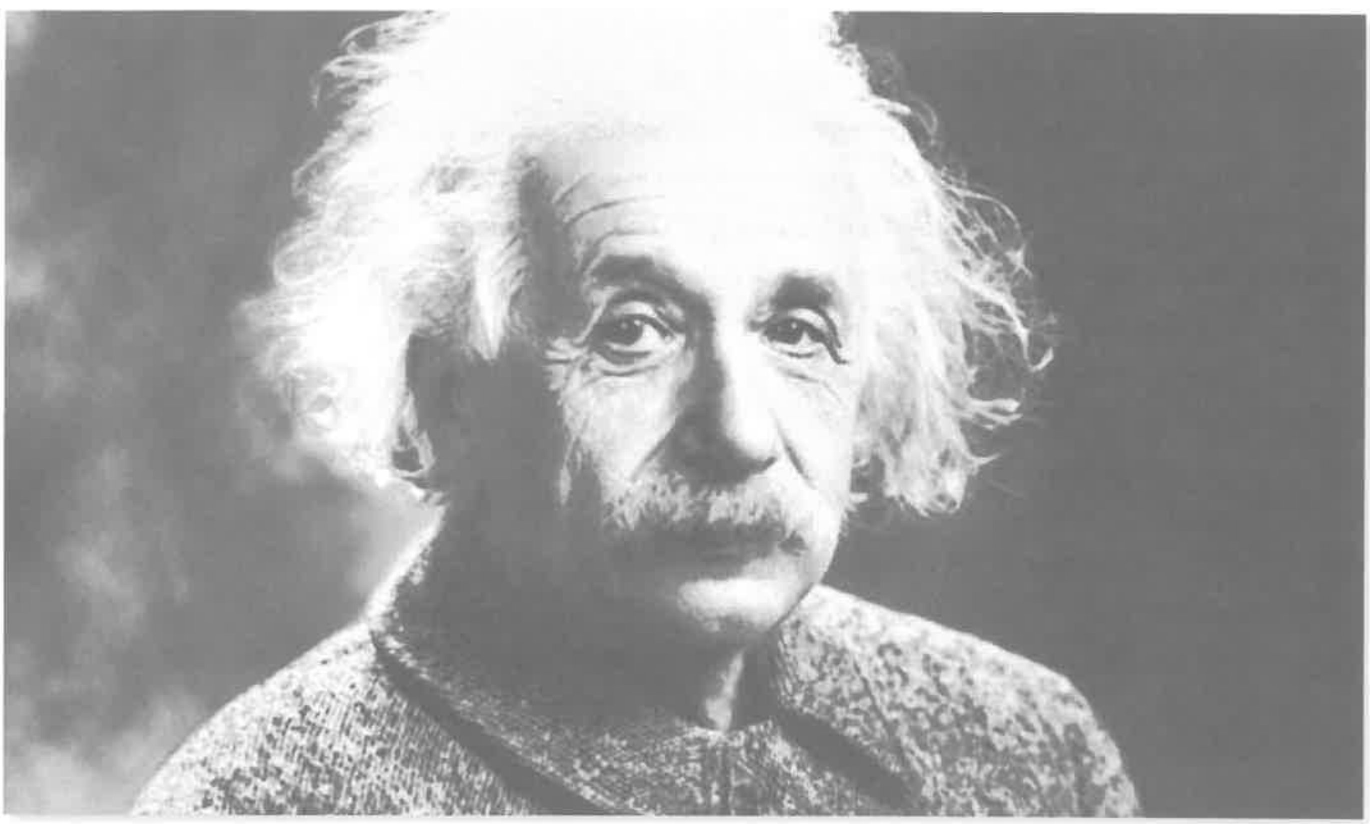

7.17 Describe the consequences and applications of relativistic momentum with reference to $p_v = \frac{mv}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}}$ and the limitation on the maximum velocity of a particle imposed by special relativity.

7.17.1 **Relativistic mass 1.**

7.17.1.1 Explain the concept of 'rest mass'.

7.17.1.2 Explain why the concept of rest mass is needed.

7.17.1.3 Explain qualitatively the consequence of special relativity in relation to mass.

7.17.1.4 The mass of an electron at rest is 9.11×10^{-31} kg. Calculate its mass when it is moving at 0.15 *c*.

7.17.1.5 Calculate the mass of a proton, rest mass 1.673×10^{-27} kg when it is moving at 0.8 *c*.

7.17.1.6

(a) How fast would a particle in a linear accelerator need to go to increase its mass by 50%?

(b) Calculate the percentage increase in the mass of a rocket moving at 40 000 km h^{-1} on a journey from Earth to Mars.

7.17.1.7 The mass of an electron at rest is 9.11×10^{-31} kg.

(a) Calculate the mass of an electron in a cathode ray tube, moving at 0.1 *c*.

(b) Calculate its mass in a linear accelerator when it is moving at 0.95 *c*.

(c) At what speed would an electron be travelling if its relativistic mass was 1.54×10^{-30} kg?

7.17.1.8 An electron is accelerated from rest by a potential difference of 5×10^5 V.

(a) Calculate the velocity this electron would have using classical physics.

(b) Comment on this velocity.

7.17.1.9 Find the percentage increase in the mass of a cricket ball which is:

(a) Bowled at 15 m s^{-1}.

(b) Bowled at 150 km h^{-1}.

(c) Fired from an automatic bowling machine at 2.0×10^8 m s^{-1}.

7.17.1.10 An electron in a linear accelerator has a mass of 8.5×10^{-29} kg. How fast is it moving?

7.17.1.11 An electron, mass 9.11×10^{-31} kg is moving at 0.75 times the speed of light. What is its kinetic energy according to:

(a) Classical physics?

(b) Relativistic physics?

7.17.1.12

(a) Calculate the amount of work that must be done to accelerate an electron from rest to 0.4 c. The mass of an electron is 9.11×10^{-31} kg.

....

(b) Calculate the amount of work that must be done to accelerate an electron from 0.4 c to 0.8 c.

....

(c) Calculate the work that must be done to accelerate the electron from 0.8 c to 0.99 c.

....

(d) How much work is needed to accelerate it from 0.99 c to 0.999 c? ....

(e) In what way do your answers support the idea that the speed of light cannot be exceeded?

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7.17.1.13 An electron, mass 9.11×10^{-31} kg and initially at rest, is accelerated through a potential difference of 1.0×10^5 V.

(a) How much work is done on the electron by the electric field in electron volts? ....

(b) How much work is done on the electron by the electric field in joules? ....

(c) How fast will the electron be moving as measured in the frame of reference of the electron?

....

(d) How fast will the electron be moving as measured in the frame of reference of the laboratory?

....

(e) What will be the mass of the electron as measured in the frame of reference of the electron?

....

(f) What will be the mass of the electron as measured in the frame of reference of the laboratory?

....

7.17.1.14 Two protons X and Y, each having a rest mass of 1.673×10^{-27} kg are moving at 0.6 c and 0.9 c respectively.

(a) What is the difference in their relativistic masses? ....

(b) What is the difference in their kinetic energies as calculated using Newtonian physics?

....

(c) What is the difference in their kinetic energies using relativistic physics? ....

(d) If E joules of work was done on each of the protons to increase their speeds, which would increase in speed by the greater amount? Explain your answer.

....

(e) If E joules of work was done on each of the protons to increase their speeds, which would increase in mass by the greater amount? Explain your answer.

....

7.17.2 Relativistic mass 2.

7.17.2.1

(a) If an object is moving at near light speed then more energy than is obvious from its increase in velocity needs to be used to accelerate it further. Where does the extra energy go?

(A) Into the surroundings as wasted heat.
(B) Into the object as kinetic energy.
(C) Into the object as increased mass.
(D) Into the object as momentum.

(b) What experimental evidence do we have for this? ....

....

7.17.2.2

(a) What is a consequence of special relativity for mass?

(A) Mass is zero only when an object is stationary.
(B) The mass of the object in an inertial frame of reference is zero.
(C) The mass of an object is constant throughout the Universe.
(D) We can no longer regard mass as a constant quantity.

(b) When will the mass of an object be zero? ....

....

7.17.2.3 Which statement is correct?

(A) The real mass of a meteorite will always be smaller than its rest mass.
(B) The rest mass of a meteorite will always be larger than its observed mass.
(C) The observed mass of a meteorite will always be less than its real mass.
(D) The observed mass of a meteorite will always be more than its real mass.

7.17.2.4 A mass is moving at 0.6 c. How does its mass change?

(A) 20% increase (B) 25% increase (C) 80% increase (D) 125% increase

7.17.2.5 A proton, rest mass of 1.673×10^{-27} kg is moving at 0.5 c. What is its mass at this speed?

(A) 1.255×10^{-27} kg (B) 1.449×10^{-27} kg (C) 1.932×10^{-27} kg (D) 2.231×10^{-27} kg

7.17.2.6 The mass of a charged particle in a linear accelerator is 2.5×10^{-26} kg. It is moving at 2×10^8 m s^{-1}. What is its rest mass?

(A) 1.11×10^{-26} kg (B) 1.86×10^{-26} kg (C) 3.35×10^{-26} kg (D) 5.63×10^{-26} kg

7.17.2.7 The mass of a charged particle, X, in a linear accelerator is 40% greater than its rest mass. How fast is the particle moving?

(A) 0.49 c (B) 0.70 c (C) 0.77 c (D) 0.98 c

7.17.2.8 Two particles of rest mass M and $2M$ are travelling at the same speed. The mass of the smaller particle increases by 30% as a result of its high speed. By how much will the mass of the larger particle change?

(A) 15% (B) 30% (C) 45% (D) 60%

7.17.2.9 How fast must a particle go in order for its mass to increase by 25%?

(A) 0.25 c (B) 0.45 c (C) 0.67 c (D) 0.76 c

7.17.2.10 A 2500 kg spaceship is travelling at 0.3 c. What mass increase does the pilot observe in the ship?

(A) None (B) 4.7% (C) 5% (D) 9.9%

7.17.2.11

(a) An observer on Earth noticed a passing spaceship X accelerate from 0.6 *c* to 0.7 *c* using a constant thrust, *T*. Later, an identical spaceship, Y, accelerated from 0.8 *c* to 0.9 *c* using an identical, constant thrust. If we consider only relativistic mass effects, which statement about the acceleration of the two ships is correct?

(A) The acceleration of X and Y is equal.

(B) The acceleration of X will be greater than that of Y.

(C) The acceleration of X will be less than that of Y.

(D) The acceleration of X will take longer than the acceleration of Y.

(b) Explain your answer. ....

....

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7.17.3 Relativistic momentum.

7.17.3.1 The relativistic momentum equation is as follows. $p = \dfrac{m_0 v}{\sqrt{1 - \dfrac{v^2}{c^2}}} = \gamma m_0 v$

The classical equation for momentum is $p = mv$.

(a) Use these equations to determine the relationship between classical momentum and relativistic momentum by calculating values for the γ factor, also known as the Lorentz factor, for a proton moving at various speeds as given in the table. The mass of a proton is 1.673×10^{-27} kg.

Speed (*c*)	Classical momentum ($\times 10^{-22}$)	Relativistic momentum ($\times 10^{-22}$)	Relativistic momentum compared to classical momentum (γ)
0.10			
0.25			
0.50			
0.75			
0.99			
0.999			
0.9999			
0.99999			
0.999999			

(b) Comment on the difference between the relativistic momentum and the classical momentum for the first four calculations and the last five calculations.

....

(c) Comment on the implication of these calculations for rockets being able to be propelled to the speed of light and perhaps beyond.

....

7.17.3.2 A spacecraft is travelling at 0.235 the speed of light. By what factor would its relativistic momentum increase if its speed doubled?

....

....

7.17.3.3

(a) Particle A has twice the mass but half the speed of particle B. Do they have the same momentum or does one have a higher momentum than the other? Justify your answer.

....

....

....

....

(b) Check your answer by imagining A with mass 2 and speed 0.2 c, and B with mass 1 and speed 0.4 c.

....

....

(c) Recheck your answer for A having mass 40 and speed 0.4 c, and B having mass 20 and speed 0.8 c.

....

....

7.17.3.4 At what speed is a particle's relativistic momentum twice its classical momentum? ....

7.17.3.5

(a) A neutron (mass 1.675×10^{-27} kg) is travelling at 0.866 c. What is the value of its relativistic momentum?

....

....

....

....

(b) Considering your answer to (a) above, and Question 7.17.3.3, estimate its classical momentum.

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(c) Calculate its classical momentum to check your answer.

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Science Press

7.18 Use Einstein's mass-energy equivalence relationship: $E = mc^2$ to calculate the energy released by processes in which mass is converted to energy, including production of energy by the Sun, particle-antiparticle interactions, e.g. positron-electron annihilation, and combustion of conventional fuel.

7.18.1 Mass-energy equivalence.

7.18.1.1 Explain qualitatively the consequence of special relativity in relation to the equivalence between mass and energy.

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7.18.1.2 A neutron has a rest mass of 1.675×10^{-27} kg. Calculate its rest energy. ....

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7.18.1.3 Einstein derived the equation $E = mc^2$ to show the relationship between mass and energy. What observation do we make in support of this idea?

(A) The mass of moving particles decreases as their speed increases.
(B) An object which is stationary has zero energy.
(C) The mass defect during a nuclear reaction provides the nuclear energy.
(D) The rest mass of an object can never be zero.

7.18.1.4

(a) Einstein's famous equation states that $E = mc^2$. This indicates that:

(A) Mass and time both change according to the speed of the object.
(B) Mass and energy are directly related to each other.
(C) Mass approaches infinity as the speed of the object approaches the speed of light.
(D) Time dilation occurs at high speeds.

(b) If an object is moving, what is its total energy? ....

....

7.18.1.5

(a) An electron has a mass of 9.11×10^{-31} kg when it is at rest. What is its rest energy?

(A) 8.2×10^{-11} J (B) 8.2×10^{-14} J (C) 2.7×10^{-19} J (D) 2.7×10^{-22} J

(b) When will the rest energy of the electron be zero? Explain. ....

....

7.18.1.6

(a) The rest energy of a particle is 1.8×10^{-14} joules. What is the mass of the particle?

(A) 2.0×10^{-31} kg (B) 3.0×10^{-32} kg (C) 3.0×10^{-24} kg (D) 5.0×10^{23} kg

(b) Is a particle of this mass possible? Explain. ....

....

....

7.18.1.7 What mass needs to be converted into energy to produce 1.8×10^{16} joules?

(A) 6.0×10^{7} kg (B) 6.0×10^{4} kg (C) 2.0×10^{-1} kg (D) 2.0×10^{-4} kg

7.18.1.8

(a) How much energy would be released if 1 kg of uranium (mass number = 238) was converted into pure energy during a nuclear reaction?

(A) 2.5×10^{15} kg (B) 4.5×10^{16} kg (C) 9.0×10^{19} kg (D) 9.0×10^{22} kg

(b) Would more or less energy be released from 1 kg of plutonium (mass number 239)? Explain your answer.

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7.18.1.9

(a) Clarify the ideas of the 'equivalence between mass and energy'.

(A) Mass and energy are interchangeable.
(B) Mass is simply another form of energy.
(C) Mass and energy are the same type of quantity.
(D) Rest mass and energy are equivalent quantities.

(b) Imagine an experiment in which various masses were converted to energy and the results graphed. Describe the gradient of the graph.

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7.18.1.10

(a) What is a consequence of the equivalence between mass and energy?

(A) The speed of light cannot be exceeded. (B) Masses become heavier at light speeds.
(C) The mass of an object can never change. (D) Mass cannot convert into pure energy.

(b) Explain your answer. ....

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7.18.1.11

(a) What is the rest mass of an object?

(A) The total mass of the object when its velocity is considered.
(B) The mass of the object in an inertial frame of reference.
(C) The increase in mass of an object as its speed increases.
(D) The mass of an object when it is stationary.

(b) Is it possible for the rest mass of a particle to be zero? Explain. ....

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7.18.1.12

(a) Why do we need the concept of a rest mass?

(A) Because the mass of an object changes as its position changes.
(B) Because the mass of an object changes as its speed changes.
(C) Because the faster an object moves, the more its rest mass increases.
(D) Because part of the energy used to accelerate an object is converted to rest mass.

(b) Is it possible for the mass of a particle to be less than its rest mass? Explain. ....

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DOT POINT

MODULE 8

From the Universe To the Atom

In this module you will:

- Solve scientific problems using primary and secondary data, critical thinking skills and scientific processes.
- Further your understanding of the limitations of theories and models by studying the development of atomic models.
- Explain and analyse the evidence supporting the relationship between astronomical events and the nucleosynthesis of atoms and relate these to the development of the current model of the atom.
- Appreciate that the fundamental particle model is forever being updated and that our understanding of the nature of matter remains incomplete.
- Engage with all the Working Scientifically skills for practical investigations involving the focus content to examine trends in data and to solve problems and communicate scientific understanding about the development of the atomic model and the origins of the Universe.

Notes

Science Press

Origins Of the Elements

8.1 Investigate the processes that led to the transformation of radiation into matter that followed the 'Big Bang'.

INQUIRY QUESTION

What evidence is there for the origins of the elements?

8.1.1 The Big Bang theory.

8.1.1.1 Choose the correct second half for each sentence and write it in the first column of the table to summarise the formation of matter following the Big Bang event.

	Your completed sentences	Second halves (not in order)
(a)	The Big Bang produced an enormous amount of energy	the leptons, neutrinos and quarks.
(b)	As the Universe cooled, the energy condensed to simple particles	were deuterium, helium and lithium.
(c)	The first particles formed were the fundamental particles,	force to come into play.
(d)	The formation of mass particles allowed the gravitational	first, then to more complex particles.
(e)	Gravity collected the newly forming particles together to	hadrons and antihadrons as they combined.
(f)	As the temperature fell, quarks combined to form	collections of molecules of hydrogen.
(g)	The initial hadrons were mainly protons and	the electromagnetic force.
(h)	This explains the huge amounts of	in the form of gamma rays.
(i)	The formation of these hadrons required the strong nuclear	which expanded outwards.
(j)	The charged leptons resulted in	to form stars and galaxies.
(k)	The next phase is thought to have been the annihilation of	form 'lumps' within the developing Universe.
(l)	This annhilation released leptons and energy	force to take effect on them.
(m)	However, due to an excess of matter over antimatter,	hydrogen into heavier nuclei.
(n)	These hadrons gravitated towards each other forming dense	hydrogen in the Universe.
(o)	The energy produced by the annihilation was enough to allow fusion of some	it started to form.
(p)	The main nuclei formed initially by this fusion	matter hadrons and antimatter hadrons.
(q)	Over the next few hundred thousand years enough matter accumulated	some matter hadrons remained.
(r)	The Universe as we know	neutrons, as isolated particles.

8.1.1.2 What is the currently most accepted theory for the beginning of the Universe and the subsequent birth of stars and galaxies?

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8.1.1.3 Use the information in your completed sentences above to answer these questions.

(a) What do astronomers mean when they refer to a 'lumpy' Universe? ....

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(b) Explain how the 'lumps' came about. ....

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(c) As time passed, the lumps became even lumpier with smaller lumps forming within them. What caused this?

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(d) What was the final result of this process? ....

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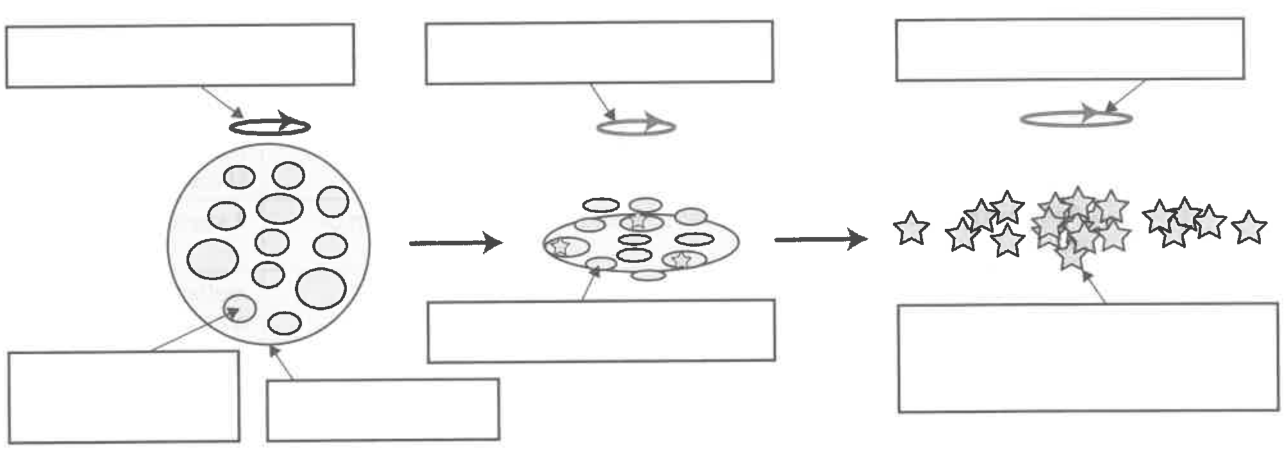
8.1.1.4 The diagram below represents part of the process described by the completed sentences in the table. It is missing labels. Complete the diagram by placing these labels in appropriate positions.

- Cloud flattens due to spin
- Fusion forms stars within galaxy
- Lumps within the cloud
- Matter cloud
- Rotation of galaxy
- Rotation of matter cloud
- Rotation of protogalaxy



8.1.1.5

(a) Why is the Big Bang theory for the development of the Universe accepted over other proposed theories?

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(b) What did scientists think the source of energy was in stars before knowledge of nuclear fusion was known?

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(c) Explain why the fusion reactions occurring in the Sun are vital for life on Earth. ....

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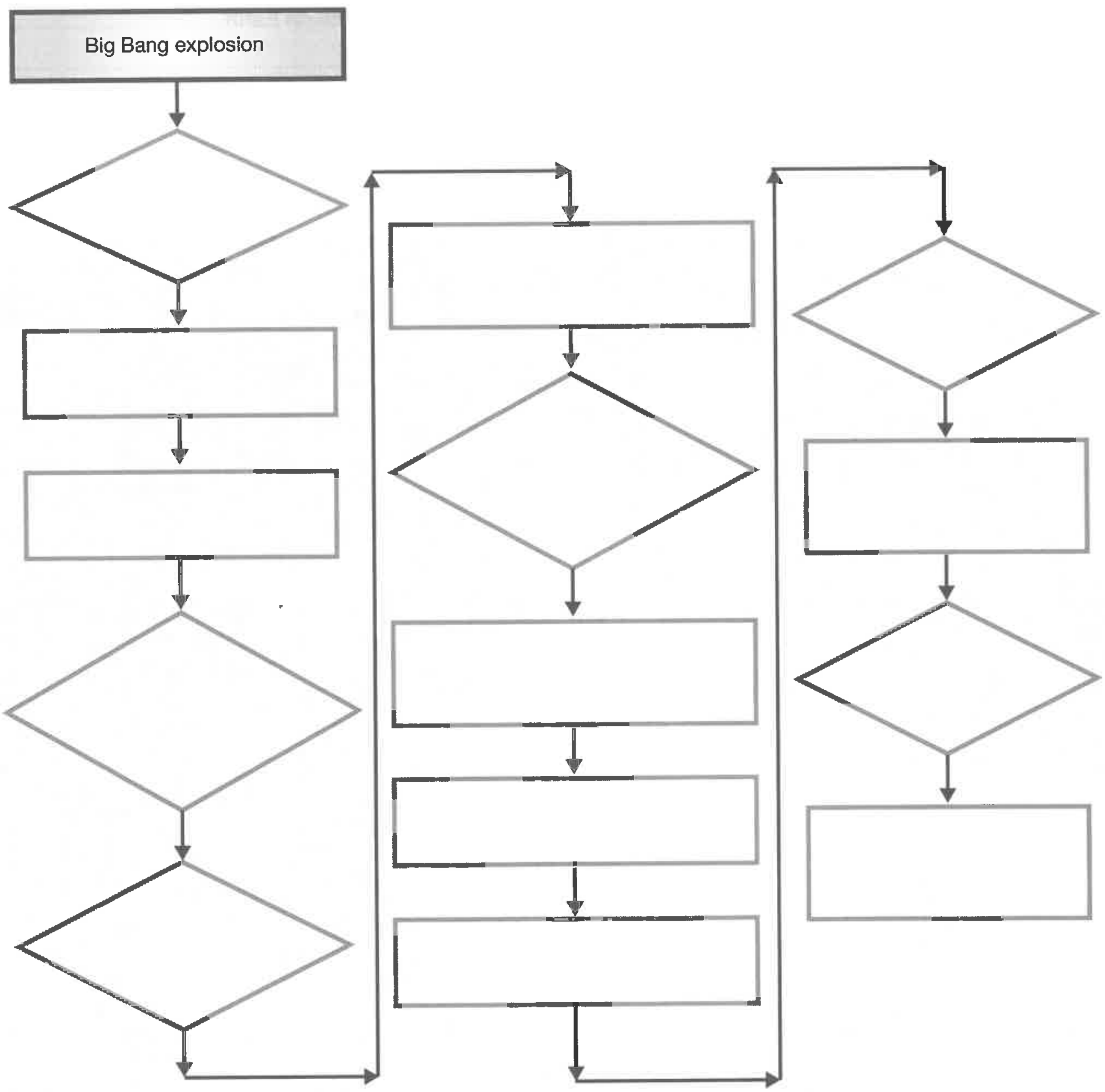
8.1.1.6 The flow diagram below shows a simpler, diagrammatic version of the information in Question 8.1.1.1. In this flow diagram, the diamond shapes contain statements that identify products of processes. The rectangles show processes. Complete the diagram by placing the flowing statements in the appropriate places on it.

Statements

Matter lumps in gas clouds become very dense
Lumps form within gas clouds
Galaxies form
Formation of hydrogen and helium atoms
Expansion of the Universe continues
Hydrogen fusion begins
Stars form
Expansion of energy
Gravitational forces attract atoms together
Gas clouds form
Universe starts cooling
Temperature within lumps rises
Stars grouped by gravitational forces
Energy produced



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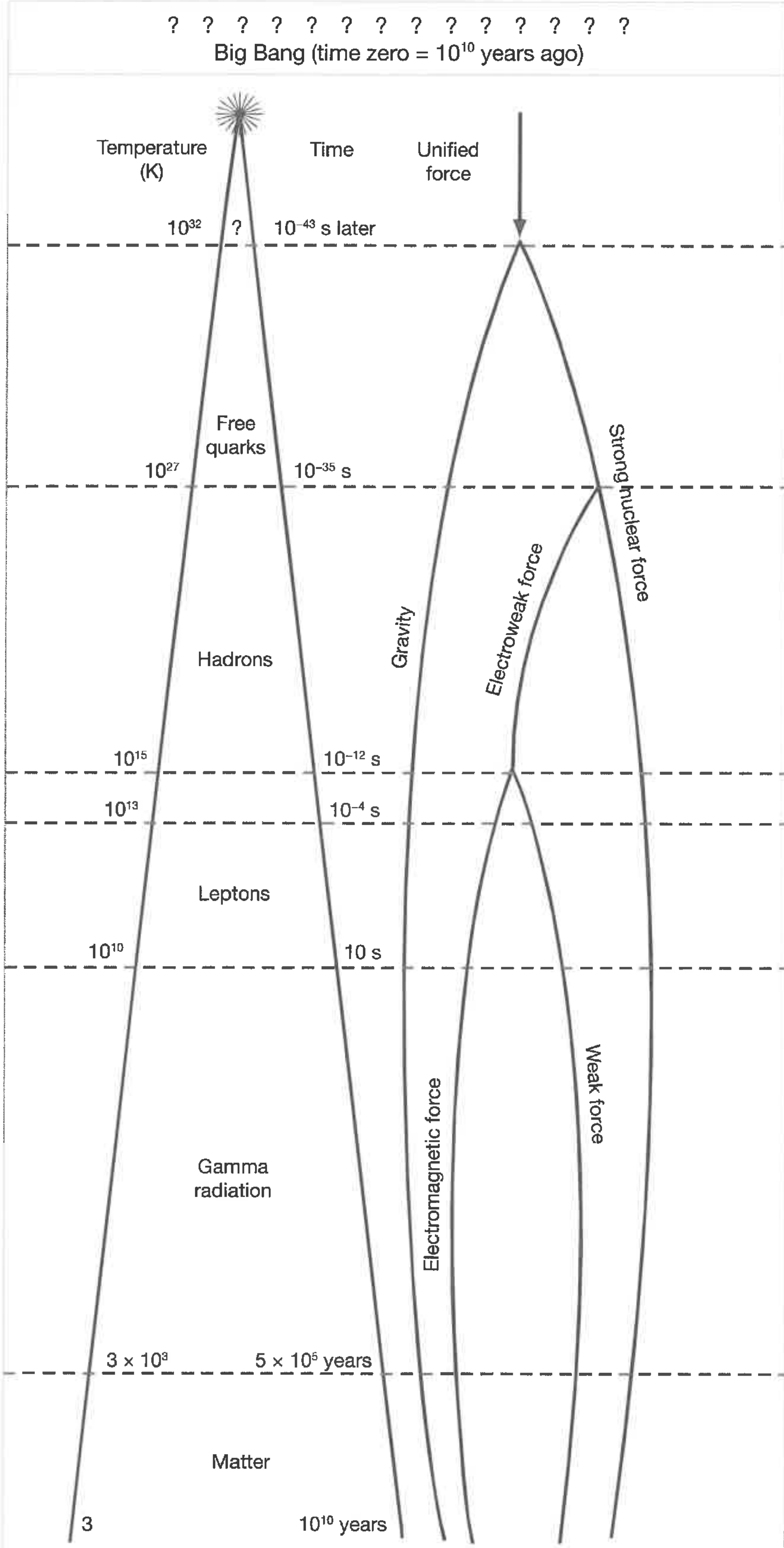
8.1.2 The changing Universe over time.

Use the following diagram to answer the questions on the next page.



- Only one force exists – the *unified force.*
- The state of matter is unknown.
- The Universe starts expanding.

- The Universe starts to cool.
- Energy levels of matter fall, allowing …
- fundamental particles and …
- gluons and gravitons to appear.
- Universe continues to expand.

- As Universe temperatures falls,
- energy levels fall, enabling …
- quarks to combine to form hadrons (including protons and neutrons).
- Photons form.
- The electromagnetic force takes effect as charged particles form.

- The electroweak force separates into electromagnetic and weak nuclear forces.

- Hadrons and antihadrons react to form leptons and gamma radiation.
- Hydrogen and helium form from excess hadrons.

- The Universe is dominated by radiation.
- Expansion of the Universe continues.
- The temperature of the Universe continues to fall.
- More and more hydrogen and helium forms.

- The temperature eventually falls low enough for hydrogen fusion to start.
- Matter as we know it forms.

8.1.2.1

(a) Explain what this diagram shows us about the relationship between time and the formation of matter.

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(b) What assumption (or perhaps a statement of fact) is the diagram making about time?

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8.1.2.2 Explain what this diagram shows us about the relationship between the formation of matter and the appearance of the four fundamental forces in nature.

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8.1.2.3 What is the relationship between time and the size of the Universe shown by this diagram?

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8.1.2.4 What is the relationship between time and the temperature of the Universe? ....

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8.1.2.5

(a) At what point in time is it proposed that matter first appeared in the Universe? ....

(b) What was this matter? ....

....

....

8.1.2.6

(a) When did the matter/antimatter annihilation occur? ....

(b) What was formed as a result of this matter/antimatter annihilation? ....

....

(c) What did this product of matter/antimatter annihilation enable? ....

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8.1.2.7 What had to happen before the fusion of matter and the formation of stars commenced?

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8.1.3 Evidence for the Big Bang.

8.1.3.1 Outline the support given to the Big Bang theory by each of the following.

(a) The spectrum shift of light from distant galaxies.

(b) The helium-hydrogen ratio.

(c) Not enough hot stars.

(d) The presence of radio galaxies and blue stars in deep space.

(e) The connection between particle physics and cosmology.

(f) Cosmic background radiation. ....

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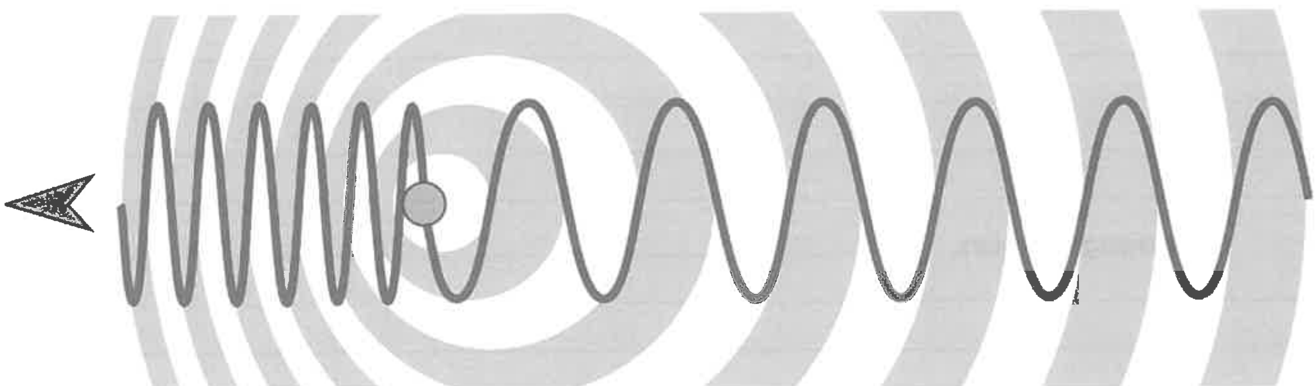
8.1.3.2 Use appropriate labels on the diagram to show how it illustrates the Doppler effect.



8.1.3.3 Many people associate the Big Bang theory with an explosion which resulted in matter and energy expanding at different rates into space. Comment on the incorrect aspects of this interpretation.

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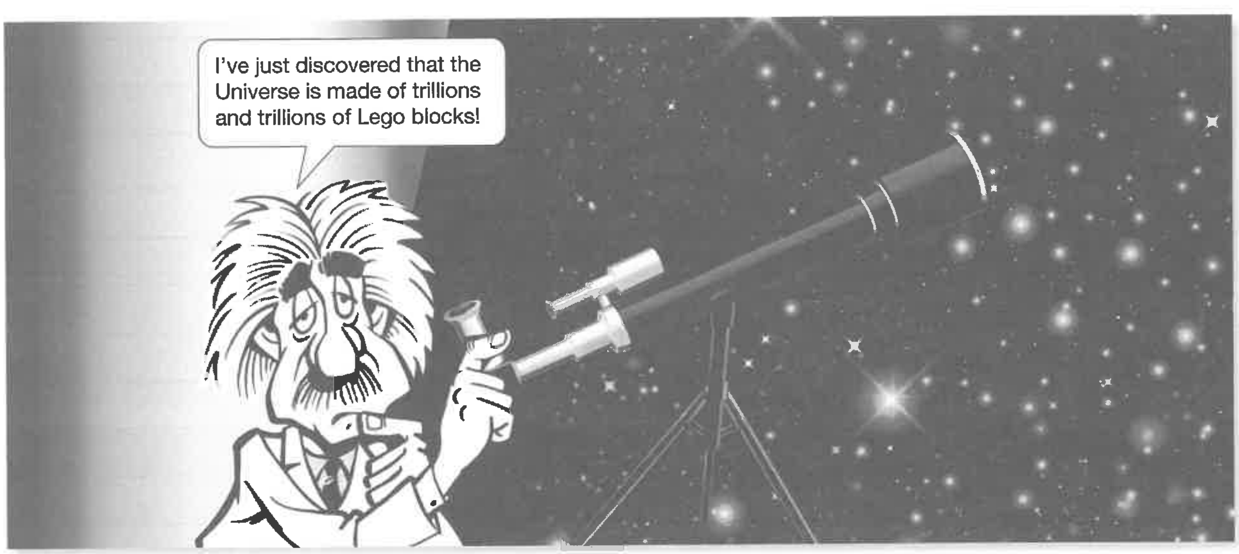

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8.2 Investigate the evidence that led to the discovery of the expansion of the Universe by Hubble.

8.2.1 Ideas leading to the Big Bang theory.

8.2.1.1 What changes occurred at the start of the 20th century that enabled developments in the models of the Universe, previously proposed by Kepler, Galileo and Newton hundreds of years earlier?

8.2.1.2

(a) What was Einstein's earliest contribution to the nature of the Universe?

(b) Einstein's ideas here could be considered to be 'bad science'. In what way?

8.2.1.3 Vestro Slipher, in 1912, was the first to observe the optical Doppler effect.

(a) What is the optical Doppler effect?

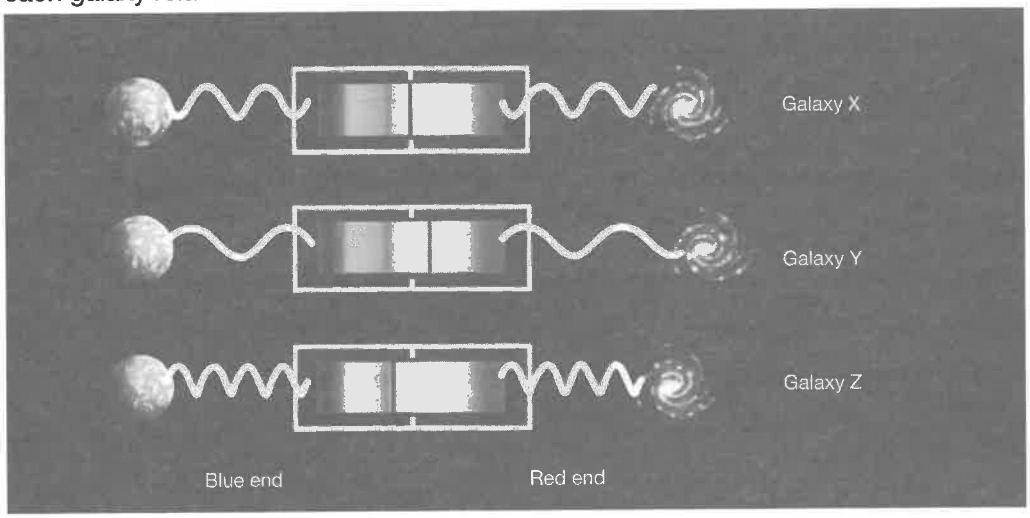
(b) Who was Vestro Slipher and how did he discover this effect?

(c) How is the optical Doppler effect explained?

(d) What other Doppler effect(s) are there?

(e) Outline an example of a Doppler effect that you observe quite often.

(f) Explain what the following diagram is showing, being sure to identify the direction of movement of each galaxy relative to the Earth as shown.



8.2.1.4 Research Friedmann's role in the developing ideas of the Universe.

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8.2.1.5 Vestro Slipher discovered the Doppler effect in 1912, Friedmann proposed the expanding Universe in 1922, and yet Hubble is given more attention on these matters than the original scientists. Why?

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8.2.1.6 Consider the graph.

(a) Whose original data is responsible for this type of graph?

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(b) Show how this graph can be used to calculate an age for the Universe.

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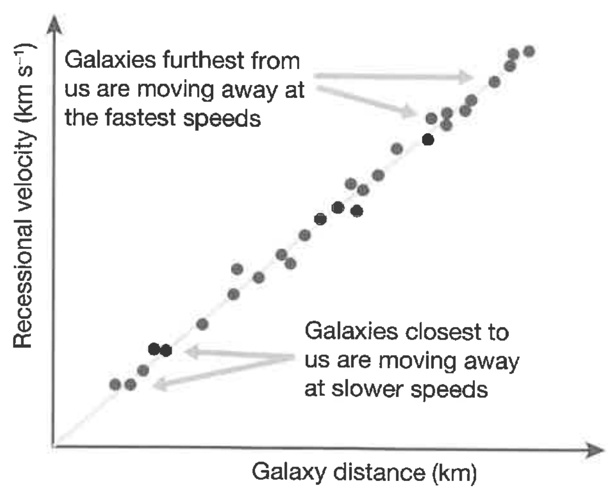

8.2.1.7 Georges Lemaître, a Roman Catholic priest, physicist and teacher, was the first person to propose the idea of a Big Bang explosion to account for observations of an expanding Universe in 1927. He likened Hubble's expanding Universe model to an exploding bomb, with pieces moving outwards in all directions.

How did he rationalise this idea with the belief he held that God created the Universe?

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8.3 Analyse and apply Einstein's description of the equivalence of energy and mass and relate this to the nuclear reactions that occur in stars.

8.3.1 The mass-energy equivalence.

8.3.1.1 Explain qualitatively the consequence of special relativity in relation to the equivalence between mass and energy.

8.3.1.2 A neutron has a mass of 1.675×10^{-27} kg. Calculate its energy equivalence.

8.3.1.3

(a) Clarify the ideas of the 'equivalence between mass and energy'.

(A) Mass and energy are interchangeable.
(B) Mass is simply another form of energy.
(C) Mass and energy are the same type of quantity.
(D) Mass and energy are equivalent quantities.

(b) Imagine an experiment in which various masses were converted to energy and the results graphed. Describe the gradient of the graph.

8.3.1.4

(a) What is meant by the term 'rest mass'? (Research this concept if needed.)

(b) Why is the concept of rest mass needed?

(c) What is rest energy?

8.3.1.5 Einstein derived the equation $E = mc^2$ to show the relationship between mass and energy. What observation do we make in support of this idea?

(A) The mass of moving particles decreases as their speed increases.
(B) An object which is stationary has zero energy.
(C) The mass defect during a nuclear reaction provides the nuclear energy.
(D) The rest mass of an object can never be zero.

8.3.1.6

(a) Einstein's famous equation states that $E = mc^2$. This indicates that:

(A) Mass and time both change according to the speed of the object.
(B) Mass and energy are directly related to each other.
(C) Mass approaches infinity as the speed of the object approaches the speed of light.
(D) Time dilation occurs at high speeds.

(b) If an object is moving, what is its total energy? ....

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8.3.1.7

(a) An electron has a mass of 9.11×10^{-31} kg when it is at rest. What is its rest energy?

(A) 8.2×10^{-11} J (B) 8.2×10^{-14} J (C) 2.7×10^{-19} J (D) 2.7×10^{-22} J

(b) When will the rest energy of the electron be zero? Explain. ....

....

8.3.1.8

(a) The rest energy of a particle is 1.8×10^{-14} joules. What is the mass of the particle?

(A) 2.0×10^{-31} kg (B) 3.0×10^{-32} kg (C) 3.0×10^{-24} kg (D) 5.0×10^{23} kg

(b) Is a particle of this mass possible? Explain. ....

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8.3.1.9 What mass needs to be converted into energy to produce 1.8×10^{16} joules? What is the mass of the particle?

(A) 6.0×10^{7} kg (B) 6.0×10^{4} kg (C) 2.0×10^{-1} kg (D) 2.0×10^{-4} kg

8.3.1.10

(a) How much energy would be released if 1 kg of uranium (mass number = 238) was converted into pure energy during a nuclear reaction?

(A) 2.5×10^{15} kg (B) 4.5×10^{16} kg (C) 9.0×10^{19} kg (D) 9.0×10^{22} kg

(b) Would more or less energy be released from 1 kg of plutonium (mass number 239)? Explain your answer.

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8.3.1.11

(a) What is the rest mass of an object?

(A) The total mass of the object when its velocity is considered.
(B) The mass of the object in an inertial frame of reference.
(C) The increase in mass of an object as its speed increases.
(D) The mass of an object when it is stationary.

(b) Is it possible for the rest mass of a particle to be zero? Explain. ....

....

8.3.1.12

(a) Why do we need the concept of a rest mass?

(A) Because the mass of an object changes as its position changes.

(B) Because the mass of an object changes as its speed changes.

(C) Because the faster an object moves, the more its rest mass increases.

(D) Because part of the energy used to accelerate an object is converted to rest mass.

(b) Is it possible for the mass of a particle to be less than its rest mass? Explain. ....

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8.3.1.13 Explain the relationship between the mass-energy equivalence and the energy released during a nuclear reaction.

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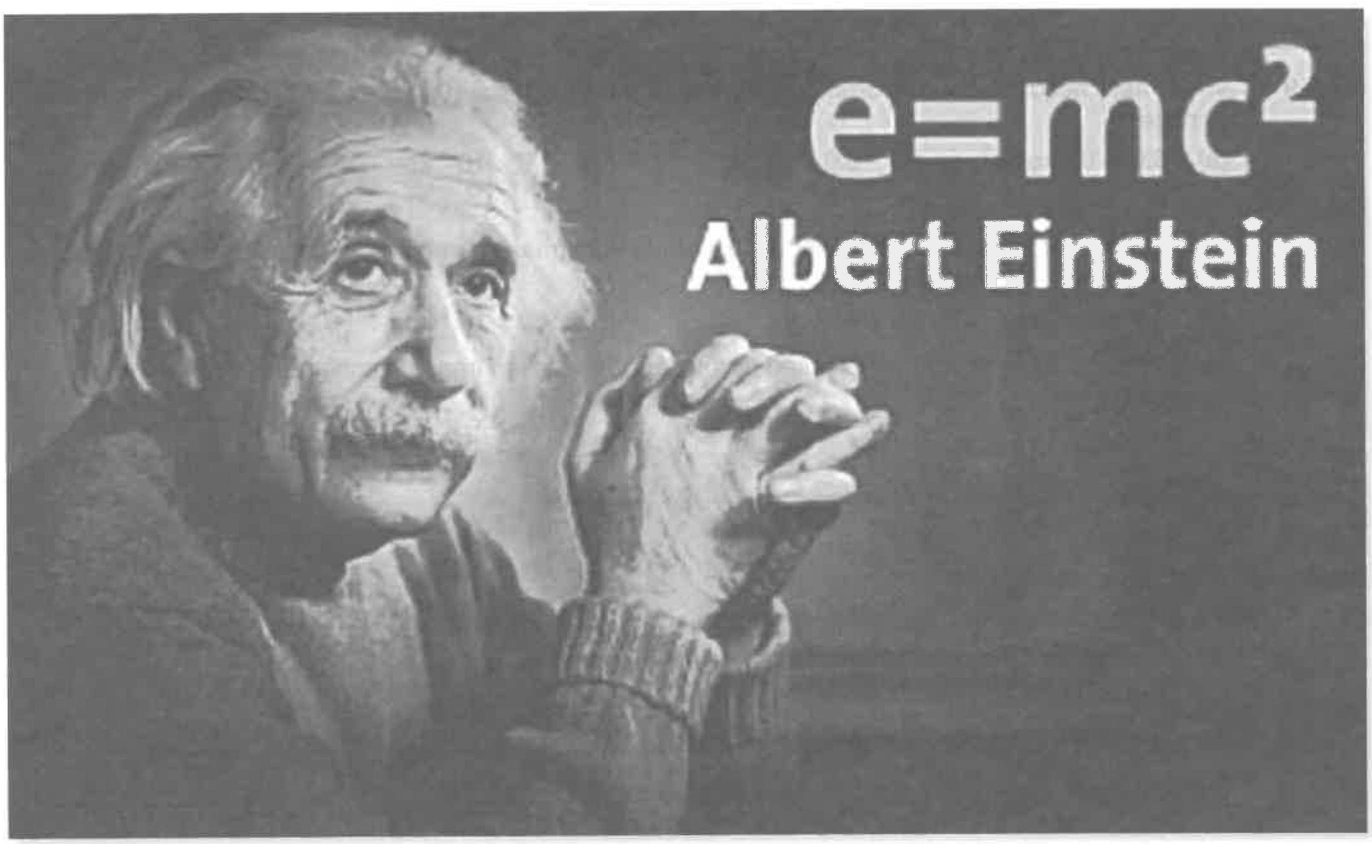

8.3.2 Energy from the Sun.

8.3.2.1 The energy produced by stars comes from the conversion of mass to energy in nuclear fusion reactions (see later). In our Sun, the overall nuclear fusion reaction that occurs can be summarised by the following equation.

$$4{}_{1}^{1}H \rightarrow {}_{2}^{4}He + \gamma$$

The product of this reaction (${}_{2}^{4}He$) will have a mass slightly less than the mass of the reactants ($4{}_{1}^{1}H$) and it is the difference in these two masses, known as the mass defect, which is converted into the energy the Sun emits.

Using the following data: ${}_{1}^{1}H = 1.67325 \times 10^{-27}$ kg and ${}_{2}^{4}He = 6.645 \times 10^{-27}$ kg, find:

(a) The mass of the reactants in the reaction. ....

....

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(b) The mass of the products of the reaction. ....

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....

(c) The mass defect for the overall reaction in the energy producing process given in kg. ....

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(d) The energy released per nucleus of ${}_{2}^{4}He$ produced. ....

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8.3.2.2 If the total energy released by the Sun is approximately 4.0×10^{26} J s^{-1}, find, according to the data you obtained in Question 8.3.2.1:

(a) The number of fusions that must occur every second to produce this energy. ....

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(b) The mass of hydrogen fused per second. ....

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(c) The mass of ${}_{2}^{4}He$ produced each second. ....

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(d) The loss in mass of the Sun each second. ....

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(e) The mass lost by the Sun each year. ....

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(f) If the mass of the Sun is 2.0×10^{30} kg, find the percentage mass lost each year. ....

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(g) Assuming energy is produced at the same rate, how much longer will the Sun last? ....

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(h) The Sun is predicted to last in its current stage about another 5 billion years, a much smaller time than your answer to (g). How do scientists account for this difference? (You may need to research the answer to this question.)

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(i) Assuming the rate of fusion has been constant, find the loss in mass of the Sun since its formation, 4.5 billion years ago.

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(j) The percentage of its original mass the Sun has lost in the last 4.5 billion years. ....

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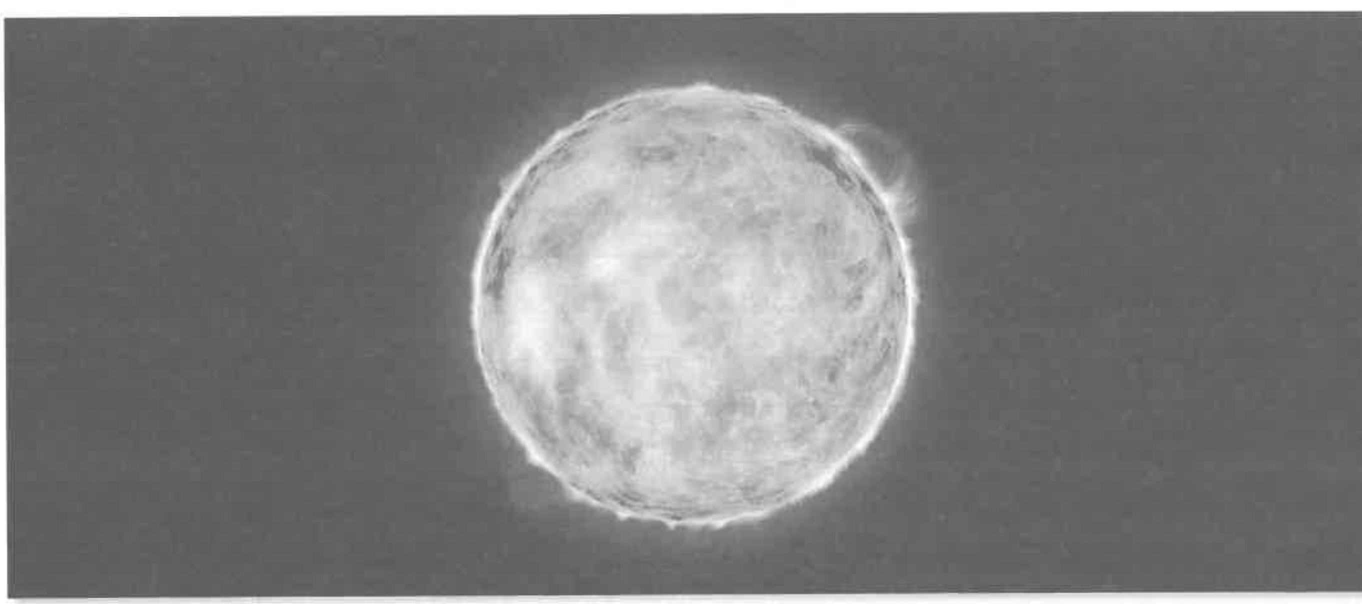

8.4 Account for the production of emission and absorption spectra and compare these with a continuous black body spectrum.

8.4.1 Atomic spectra.

8.4.1.1 What is an atomic spectrum?

8.4.1.2

(a) What are the three different types of atomic spectra?

(b) Briefly describe the appearance of each.

8.4.1.3 Describe the relationship between the emission and absorption spectrum of the same element.

8.4.1.4

(a) What is the most common example of a continuous spectrum?

(b) Briefly describe how each of the other two types of spectra can be produced from a continuous spectrum.

8.4.1.5 Describe the production of each type of spectrum in terms of electron behaviour.

(a) Continuous spectrum.

(b) Emission spectrum. ....

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(c) Absorption spectrum. ....

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8.4.1.6

(a) Who first discovered atomic spectra? And when? ....

(b) What branch of science developed as a result of scientists trying to explain how atomic spectra formed?

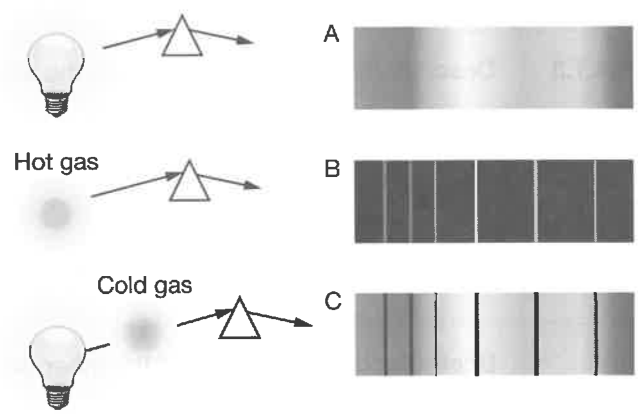
....

8.4.1.7 Which diagram shows how each type of spectrum is formed?

A = ...

B = ...

C = ...



8.4.1.8 The diagrams show three different atomic spectra.

(a) Identify the short wavelength end of each spectrum.

....

(b) Identify the high frequency end of each spectrum.

....

(c) Which end of each spectrum is produced by electron transfers with the highest energy?

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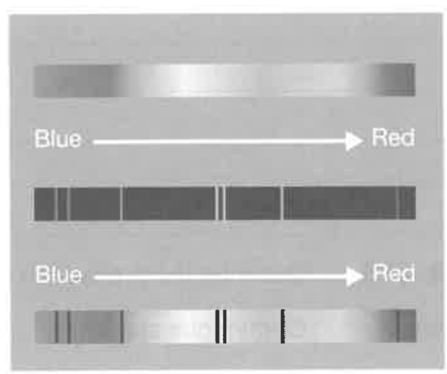

8.4.1.9

(a) What is a black body? ....

....

(b) What would a continuous spectrum from a black body look like? ....

....

8.5 Investigate the key features of stellar spectra and describe how these are used to classify stars.

8.5.1 Black body radiation and star colours.

8.5.1.1 Explain the science behind using black body radiation curves to deduce the colours of stars.

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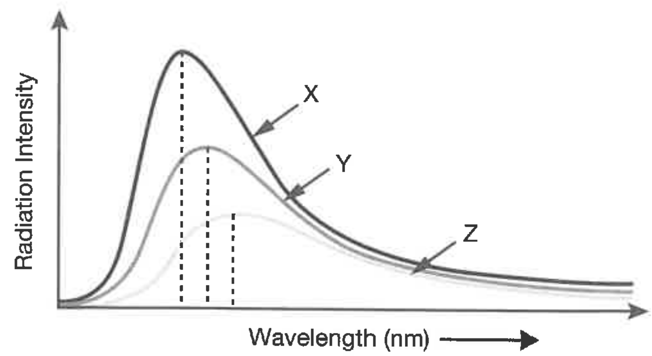
8.5.1.2 The diagram shows the hot body radiation curves for three stars, X, Y and Z.



(a) List the stars in order of increasing wavelength of their peak radiation.

....

(b) List the stars in order of increasing frequency of their peak radiation.

....

(c) List the stars in order of increasing temperature.

....

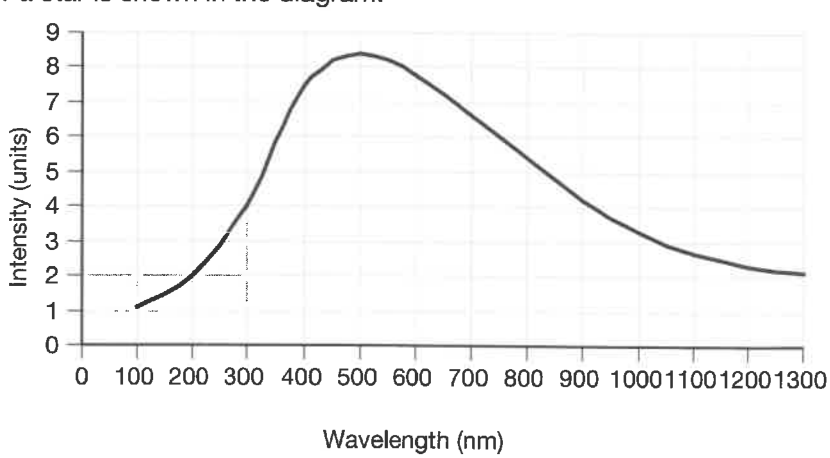
(d) Suggest a colour for:

(i) Star X ....

(ii) Star Y ....

(iii) Star Z ....

8.5.1.3 The black body radiation curve for a star is shown in the diagram.



(a) Use this graph to determine the surface temperature of the star.

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(b) What is its most probable colour? Justify your answer.

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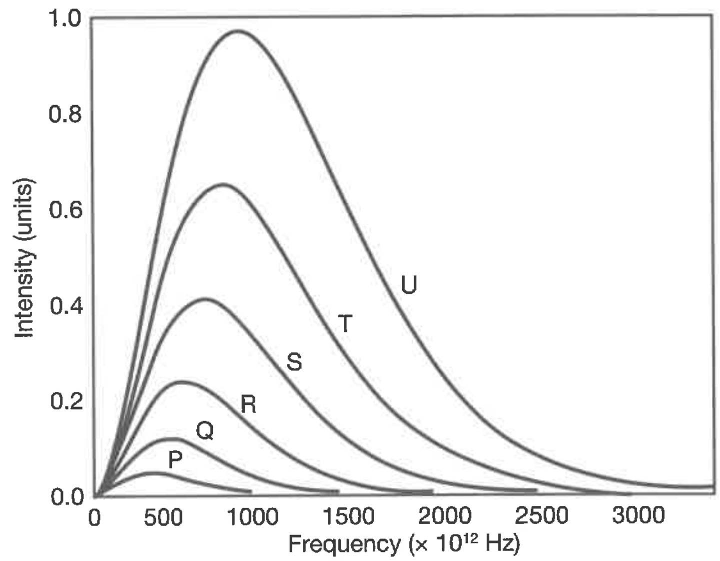
8.5.1.4 Consider the black body radiation curves of six stars.

(a) Explain why the shapes of these graphs are different to those shown in the graph in Question 8.5.1.2 above.



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(b) Which of the stars would have the highest surface temperature? Justify your answer.

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(c) Which star is most likely to be red in colour? Justify your answer. ....

....

(d) Which star is most likely to be yellow? Justify your answer. ....

....

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(e) A student analysing this diagram said that star S would be hotter than star T. Is she correct? Justify your answer.

....

8.5.2 Wien's displacement law.

8.5.2.1

(a) State Wien's displacement law. ....

....

....

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(b) Recall the equation used to calculate the surface temperature of a star from its Planck curve.

....

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(c) What temperature scale is used in this equation? ....

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8.5.2.2 Use Wien's displacement law, along with an appropriate diagram, to explain the connection between the colour and temperature of stars. Draw your diagram in the space provided.

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8.5.2.3 The radius of the Sun is 6.96×10^5 km and the peak wavelength of the radiation it emits is about 500 nm. Use Wien's law to calculate the surface temperature of the Sun in kelvins and degrees Celsius.

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8.5.2.4 Outline how the surface temperature of a star is determined. ....

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8.5.2.5 The temperature of space as indicated by remnant radiation from the Big Bang event is estimated at 2.7 K. What is the wavelength of the background radiation which scientists make this conclusion from?

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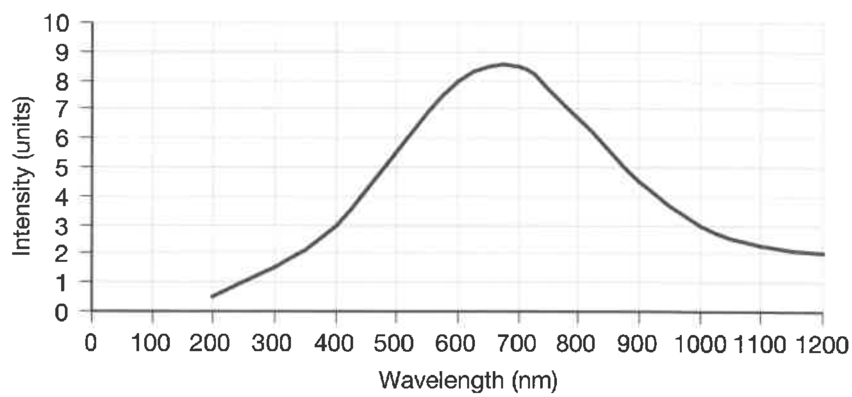
8.5.2.6 The graph shows the radiation emitted by a star.



Determine the surface temperature of this star. ....

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8.5.2.7 Hot object X has a peak radiation wavelength of 6×10^{-6} m. Hot object Y has a peak radiation wavelength of 7×10^{-6} m.

(a) Without making any calculations, predict which object is the hotter. Explain your reasoning.

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(b) Find the surface temperatures of X and Y. ....

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8.5.2.8 What would be the surface temperature of a black body with a peak radiation intensity of 4.5 mm?

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8.5.2.9 A black body is at a temperature of 4500 K. What will be its peak radiation wavelength? ....

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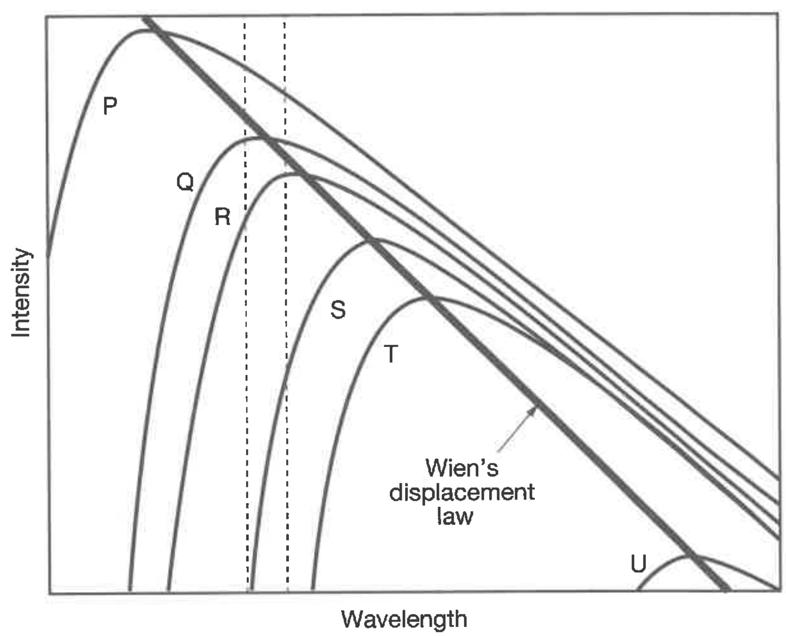
8.5.2.10 The diagram shows the radiation curves for several stars P, Q, R, S. T and U.



(a) Explain how the solid labelled line represents Wien's displacement law.

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(b) Which of the start shown on the diagram could be our Sun? Justify your answer, indicating any assumptions you make.

....

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(c) Which star is most likely to be red in colour? ....

(d) Which star is most likely to be blue in colour? ....

(e) Explain why star U is not a red star. ....

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8.6 Investigate the Hertzsprung-Russell diagram and how it can be used to determine the following about a star: its characteristics and evolutionary stage, its surface temperature, its colour and its luminosity.

8.6.1 The Hertzsprung-Russell diagram.

8.6.1.1 What is an H-R diagram?

8.6.1.2 What new information did the first H-R diagram show astronomers?

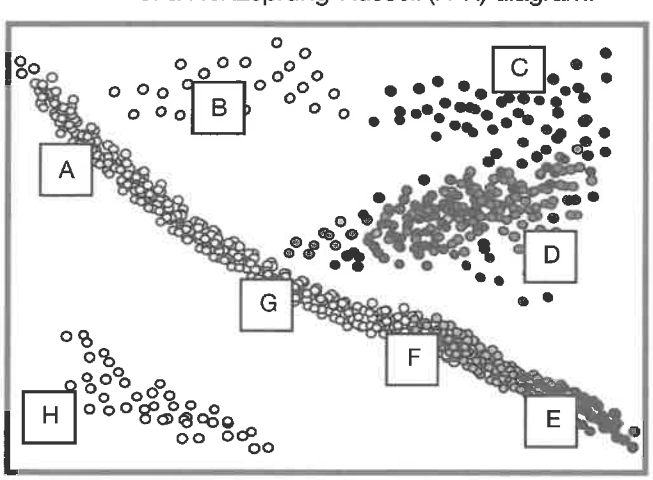
8.6.1.3 The *x*-axis on H-R diagrams can show, either individually, or at the same time, the colours, spectral classes and temperatures of stars. Explain why.

8.6.1.4 What are main sequence stars and where do we find them on an H-R diagram?

8.6.1.5 Explain how the H-R diagram indicates that not all stars are the same type.

8.6.1.6 What mass relationship of stars does the H-R diagram show?

8.6.1.7 The diagram shows a very simplified version of a Hertzsprung-Russell (H-R) diagram.



Identify the types of stars found in these positions on the diagram.

(a) Along the line AGFE.

(b) At B

(c) At C

(d) At D

(e) At H

(f) At E

(g) Referring to the labelled positions on the H-R diagram, at which position would you find:

(i) The coolest stars?

(ii) The hottest stars?

(iii) The smallest stars?

(iv) The largest stars?

(v) The brightest stars?

(vi) The dullest stars?

(h) At what position would the Sun be?

8.6.1.8 On the diagram below draw in trend lines to show the following trends.

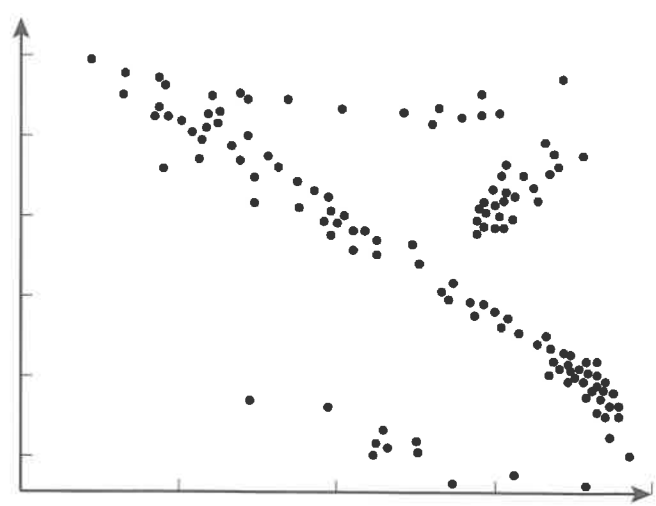
A Increasing mass

B Increasing luminosity

C Colour from blue to red

D Increasing temperature

E Increasing size



8.6.2 Types of stars.

8.6.2.1 What type of star is our Sun? ....

8.6.2.2 How do we know that red giants are larger than our Sun? ....

....

8.6.2.3 Complete the table.

Star type	Energy producing process(es)
Main sequence	
Red giant	
Red supergiant	
Blue supergiant	
Red dwarf	
White dwarf	

8.6.2.4 Describe the main energy source of main sequence stars with core temperatures lower than 10^7 K. Justify your answer.

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8.6.2.5 Describe the main energy sources of main sequence stars.

(a) Main sequence stars with core temperatures greater than 10^7 K. ....

....

(b) Red giants with masses greater than 5 solar masses. ....

....

(c) Main sequence stars with masses greater than 5 solar masses. ....

....

(d) Non main sequence stars with masses greater than 5 solar masses. ....

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8.6.2.6 Explain the concept of the equilibrium between radiation pressure and gravitational force in stars.

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8.6.2.7 Explain why larger, hotter main sequence stars have a shorter life on the main sequence than smaller cooler main sequence stars.

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8.6.2.8 Outline the proposals astronomers have put forward to explain why red dwarf stars will have a much longer life span on the main sequence than other stars.

8.6.2.9 In the process of transitioning from a main sequence star to, say, a red giant, a 'helium flash' occurs. Research the nature and reason for this 'helium flash'.

8.6.3 The evolution of stars.

8.6.3.1 What are the two conditions necessary for a gas cloud to collapse and for nuclear reactions to start thus forming a star?

8.6.3.2 What is thought to be the initial stage for a future star?

8.6.3.3 Describe the 'birth' of a star.

8.6.3.4 What determines a star's starting position on the main sequence?

8.6.3.5 Describe how the mass of matter in a protostar affects the formation, or not, of a star.

8.6.3.6 What property of a star determines whether it leaves the main sequence as a red giant or a red supergiant. Be specific in your answer.

8.6.3.7 Compare the changes in nuclear reactions that occur in a red giant and a red supergiant.

8.6.3.8 Identify and outline the late stages in the evolution of a high mass star that leads it to end its life as a neutron star.

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8.6.3.9 Outline why neutron stars can be detected from Earth.

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8.6.3.10 Explain the idea behind the Chandrasekhar limit.

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8.6.3.11 Explain why stars with solar masses less than 8 solar masses will become white dwarfs after their red giant stage rather than forming a smaller, second generation main sequence star.

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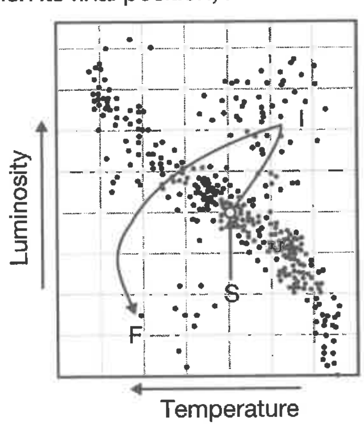
8.6.3.12 The diagram shows the predicted evolutionary path of our Sun on a H-R diagram from its present position, S to an intermediate position, I and then its final position, F.



(a) Identify the type of star the Sun will be at position:

(i) I = ...

(ii) F = ...

(b) What changes would have to occur in the Sun for it to move from S to I?

....

....

....

(c) Identify and explain the change in luminosity of the Sun as it goes from S to I.

....

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(d) Use the Chandrasekhar limit to explain why the final evolutionary stage of the Sun is at F.

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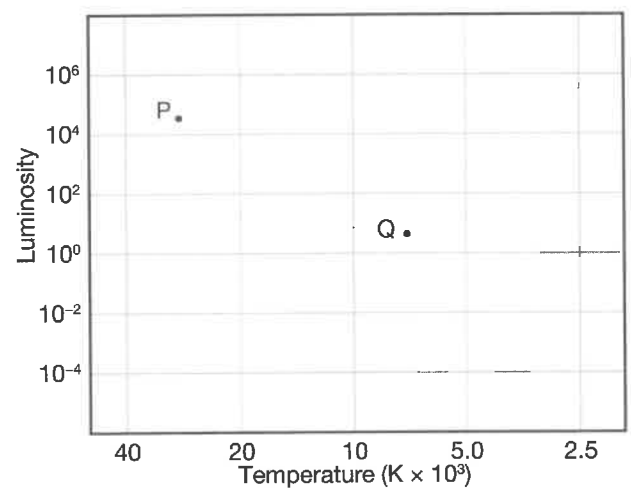
8.6.3.13 The diagram shows an incomplete H-R diagram with two main sequence stars P and Q indicated.



(a) State the likely difference of the fate of star P compared to star Q.

....

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(b) With reference to the Chandrasekhar limit, explain how stars P and Q could have the same fate.

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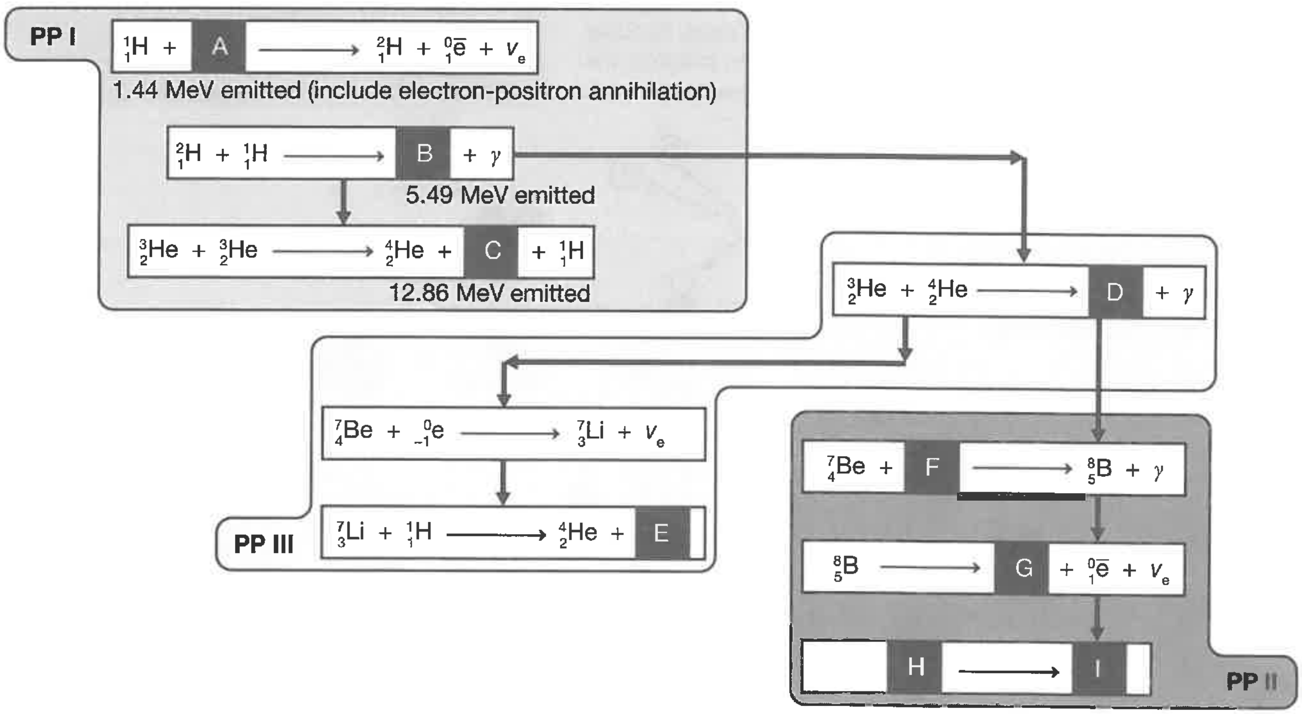
8.7 Investigate the types of nucleosynthesis reactions involved in main sequence and post main sequence stars, including the proton-proton chain and the CNO (carbon-nitrogen-oxygen) cycle.

8.7.1 The proton-proton chain.

8.7.1.1 The diagram below shows the nuclear reactions that occur in the PP I, PP II and PP III chains in the Sun. These are the main reactions that produce the Sun's energy. Some of the information in each reaction is missing (indicated by the letters in the square boxes). Identify each of the missing parts of the equations.



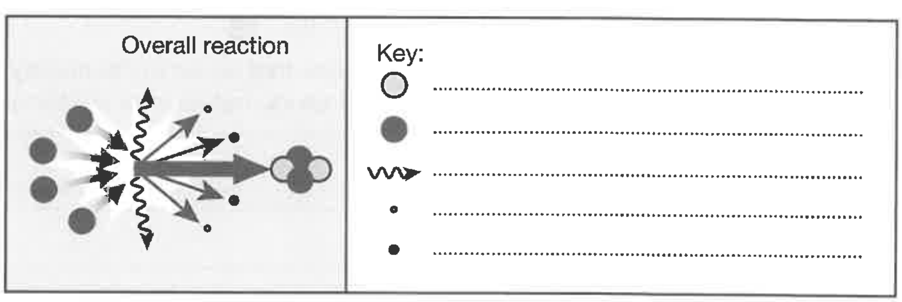
8.7.1.2

(a) Write the nuclear equation for the electron-positron annihilation. ....

(b) What is an alternate name for the positron? ....

8.7.1.3 The diagram represents the overall process that occurs in the Sun via the PP chain to produce its energy.

(a) Complete the diagram by identifying each of the components in it.



(b) Use the information in the diagram to write a nuclear equation for this overall reaction.

....

(c) What do the gamma rays in this reaction represent? ....

....

8.7.1.4 The PP reactions occur mainly in main sequence stars about the size of the Sun or smaller. Explain why.

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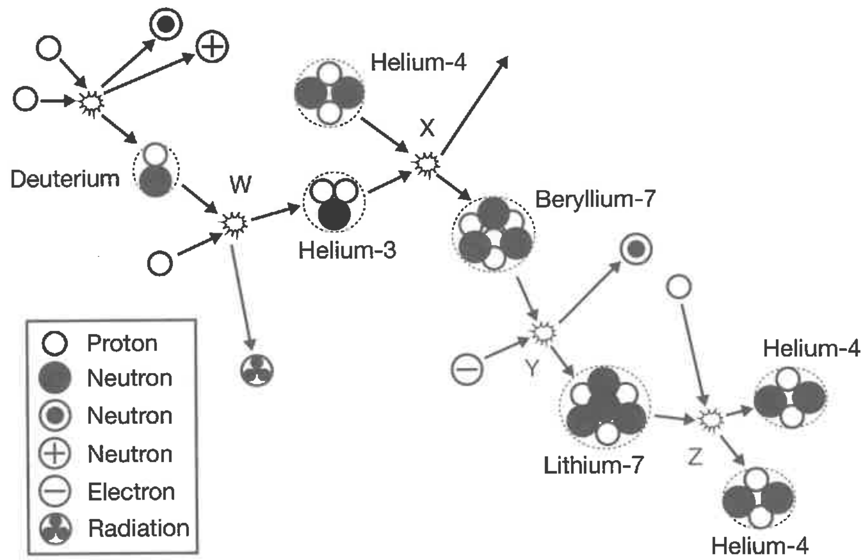
The Sun also loses mass as it emits its Solar wind of charged particles into space at the rate of about 1.5 million tonnes per second.

Use the following information to answer the next FOUR questions.

The diagram shows the five steps in the PP II chain of reactions that produces helium-4 particles and solar energy in the core of the Sun.



8.7.1.5 What nucleons does an atom of helium-4 contain?

(A) One proton and two neutrons.
(B) One proton and three neutrons.
(C) Two protons and two neutrons.
(D) Three protons and four neutrons.

8.7.1.6 Which of these four steps in the process shows nuclear fission?

(A) Step W
(B) Step X
(C) Step W
(D) Step Z

8.7.1.7 Energy from the Sun results from the fusion of hydrogen nuclei to form helium. Which symbol represents a hydrogen nucleus?

(A) ○
(B) ●
(C) ◉
(D) ⊕

8.7.1.8 Write nuclear equations for each of the five reactions that occur in the energy production process in the Sun as shown by the diagram above. Do not include radiation or neutrinos in your equations.

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8.7.1.9 For this question remember that the mass defect of a nuclear reaction is the difference in mass between the reactants and the products. This mass defect, via Einstein's equation: $E = mc^2$ is responsible for the energy released by the Sun.

Particle	Mass (u)
^1_1H	1.007825
^2_1H	2.014102
^3_2H	3.016029
^4_2H	4.002603
^7_4Be	7.016929
^7_3Li	7.016003
$^0_{-1}e$	0.0005486
$^0_{+1}e$	0.0005486

(a) Use the information in the table to calculate the mass defect in each of the five reactions. Note that the masses of the nuclides are given in atomic mass units (u) and that:

1 amu = 1.660×10^{-27} kg = 931.494 MeV

Reaction 1: ....

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Reaction 2: ....

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Reaction 3: ....

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Reaction 4: ....

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Reaction 5: ....

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(b) Calculate the total mass defect (in atomic mass units) for the five reaction process. ....

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(c) Calculate the total mass defect (in MeV) for the five reaction process. ....

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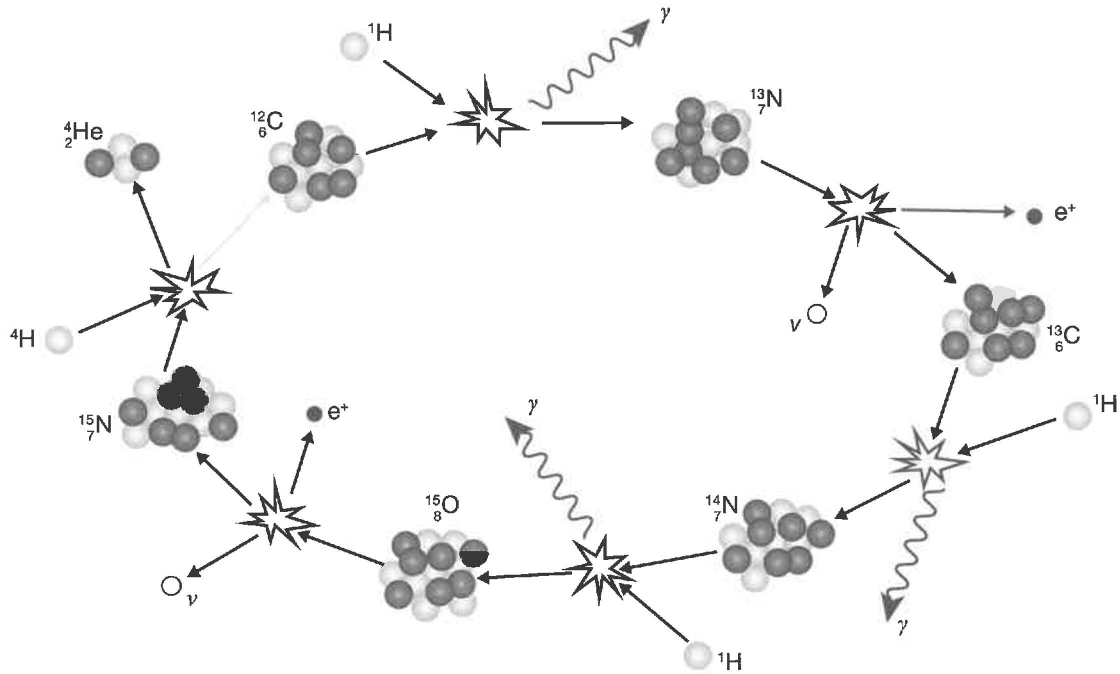
8.7.2 The CNO cycle.

The diagram shows the CNO cycle. Use it to answer the questions which follow it.



8.7.2.1

(a) On the diagram label the starting position as 'Start'.

(b) On the diagram label the steps in the cycle, step 1 to step 6.

(c) On the diagram label the catalyst for the reaction.

8.7.2.2 In the boxes provided on the next page, write the equation for each step of the cycle and then use the mass data given in the table to calculate the mass defect and energy released by each step. Note that the masses of the nuclides are given in atomic mass units (*u*) and that:

$$1 \text{ amu} = 1.660 \times 10^{-27} \text{ kg} = 931.494 \text{ MeV}$$

(Note that your answers may vary slightly from the text answers mainly due, in steps 2 and 5, to the fact that we have not considered the energy involved in the production of the neutrinos. These carry some of the nuclear energy away with them and so the net energy is lower.)

Particle	Mass (*u*)
$^{1}_{1}H$	1.007825
$^{4}_{2}H$	4.002603
$^{12}_{6}C$	12.000000
$^{13}_{6}C$	13.003355
$^{13}_{7}N$	13.005738
$^{14}_{7}N$	14.003074
$^{15}_{7}O$	15.000109
$^{15}_{8}N$	15.003056
$^{0}_{+1}e$	0.0005486
$^{0}_{-1}e$	0.0005486

Step 1: Nuclear equation Mass defect Energy released (MeV and J)	Step 2: Nuclear equation Mass defect Energy released (MeV and J)
Step 3: Nuclear equation Mass defect Energy released (MeV and J)	Step 4: Nuclear equation Mass defect Energy released (MeV and J)
Step 5: Nuclear equation Mass defect Energy released (MeV and J)	Step 6: Nuclear equation Mass defect Energy released (MeV and J)

Structure Of the Atom

8.8 Investigate, assess and model the experimental evidence supporting the existence and properties of the electron, from early experiments examining the nature of cathode rays.

INQUIRY QUESTION

How is it known that atoms are made up of protons, neutrons and electrons?

8.8.1 Cathode rays and discharge tubes 1.

8.8.1.1

(a) What technological advance was needed before scientists could study cathode rays closely?

(A) How to produce electrical potential difference.

(B) How to produce electromagnetism.

(C) The photoelectric effect.

(D) How to produce a vacuum.

(b) How did this new technology assist the scientists of the time?

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8.8.1.2

(a) The invention of cathode ray tubes led to the discovery of which particles?

(A) Anions. (B) Electrons.

(C) Nuclei. (D) Protons.

(b) What are two other names for these?

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8.8.1.3

(a) Which property of cathode rays suggest that they are not waves?

(A) They are charged.

(B) They move in straight lines.

(C) They can be reflected.

(D) They are stopped by solid objects.

(b) Explain your answer.

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8.8.1.4

(a) What observation confused scientists in the 1800s about the nature of cathode rays?

(A) They did not observe their deflection by magnetic fields.

(B) They did not observe their deflection by electric fields.

(C) They formed a shadow in the Maltese cross tube.

(D) They caused the paddle wheel to move in the paddle wheel tube.

(b) How did this confuse the scientists of the time?

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8.8.1.5

(a) What were the two main conflicting ideas about cathode rays that existed before Thomson's experiment?

(A) They were charged and therefore could not be waves.

(B) They were not charged and were therefore waves.

(C) They were either charged or not charged.

(D) They were either particles or waves.

(b) How did Thomson's experiment resolve this?

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8.8.1.6

(a) Who did the experiment that resolved the issue as to whether cathode rays were particles or electromagnetic radiation?

(A) Crookes. (B) Hertz.

(C) Planck. (D) Thomson.

(b) What aspect of his experiment resolved the issue?

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8.8.1.7

(a) In the early days in the study of cathode rays, British scientists proposed that they were charged particles. German scientists disagreed and stated that they were electromagnetic radiation. What evidence did the Germans have to support their view?

(A) Cathode rays travelled at the speed of light.

(B) Heinrich Hertz was able to transmit them through the air using spark generators.

(C) Cathode rays were not deflected by electric fields in the tubes they used.

(D) Cathode rays were known to be uncharged and therefore were waves not particles.

(b) Who eventually resolved this issue and how?

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8.8.1.8 What does the deflection of cathode rays by magnetic fields suggest about their nature?

(A) They are charged particles because moving charged particles produce a magnetic field that interacts with the applied field.

(B) They are charged particles because the charges are attracted or repelled by the magnetic field to cause the deflection.

(C) They are electromagnetic waves because electromagnetic waves produce magnetic fields that interact with the applied magnetic field.

(D) They are electromagnetic waves because electromagnetic waves carry a charge that can be attracted or repelled by the applied magnetic field.

8.8.1.9 What property of cathode rays does the paddle wheel tube demonstrate?

(A) They are charged.

(B) They travel in straight lies.

(C) They have momentum.

(D) They can be reflected.

8.8.1.10

(a) Why were scientists of the 1880s confused about the nature of cathode rays?

(A) Because they were deflected by magnetic fields but not by electric fields.

(B) Because they were deflected by electric fields but not by magnetic fields.

(C) Because they were deflected by both magnetic fields and electric fields.

(D) Because they were not deflected by magnetic fields or electric fields.

(b) Explain why this caused confusion as to the nature of the cathode rays.

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8.8.1.11 What was the reason for the confusion about the nature of cathode rays in the 1880s?

(A) The cathode rays were not deflected by electric fields.

(B) The deflection of cathode rays by electric fields was too small to be detected.

(C) Scientists could not produce electric fields in the 1880s.

(D) The vacuum scientists used in the 1880s was too great.

8.8.1.12

(a) What property of cathode rays is demonstrated in the Maltese cross tube?

(A) Their wave nature.

(B) They carry energy.

(C) They have a negative charge.

(D) They travel in straight lines.

(b) Identify another property of cathode rays this tube demonstrates?

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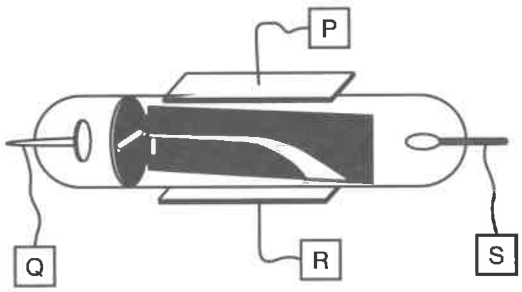
8.8.1.13



(a) The diagram shows an experiment done with cathode rays. Which choice correctly identifies the polarities P, Q, R and S?

	P	Q	R	S
(A)	Positive	Positive	Negative	Negative
(B)	Negative	Positive	Negative	Positive
(C)	Positive	Negative	Positive	Negative
(D)	Negative	Negative	Positive	Positive

(b) What property of cathode rays does this experiment demonstrate?

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8.8.1.14 What property of cathode rays is *incorrect*?

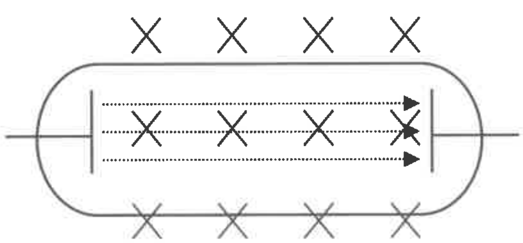
(A) They are formed at the cathode and travel to the anode.

(B) They are deflected by magnetic but not electric fields.

(C) They have momentum.

(D) They travel in straight lines.

8.8.1.15 A beam of cathode rays is generated in a cathode ray tube as shown. A magnetic field is applied to the tube directed into the page. Which way will the cathode rays be deflected?



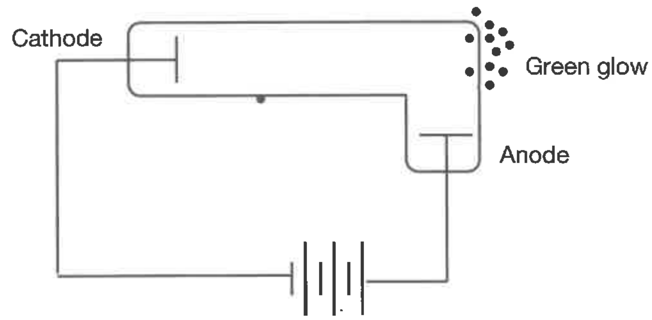
(A) Out of the page.

(B) Into the page.

(C) Up the page.

(D) Down the page.

8.8.1.16 In an early experiment Crookes used the cathode ray tube shown (among others) to study the behaviour of cathode rays.



What could Crookes conclude from this experiment?

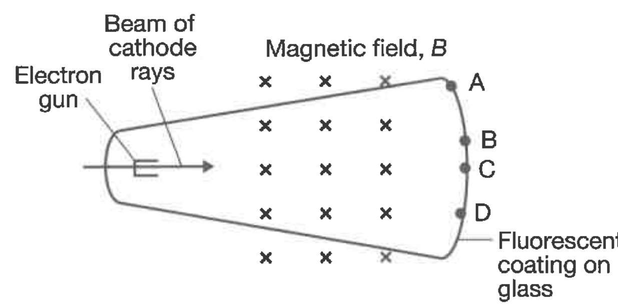
(A) Cathode rays are particles.

(B) Cathode rays travel in straight lines.

(C) Cathode rays were formed at the cathode.

(D) Cathode rays were a form of electromagnetic radiation.

8.8.1.17 A cathode ray tube has a magnetic field applied to it into the page as shown in the diagram.



Where will the cathode rays hit the fluorescent screen?

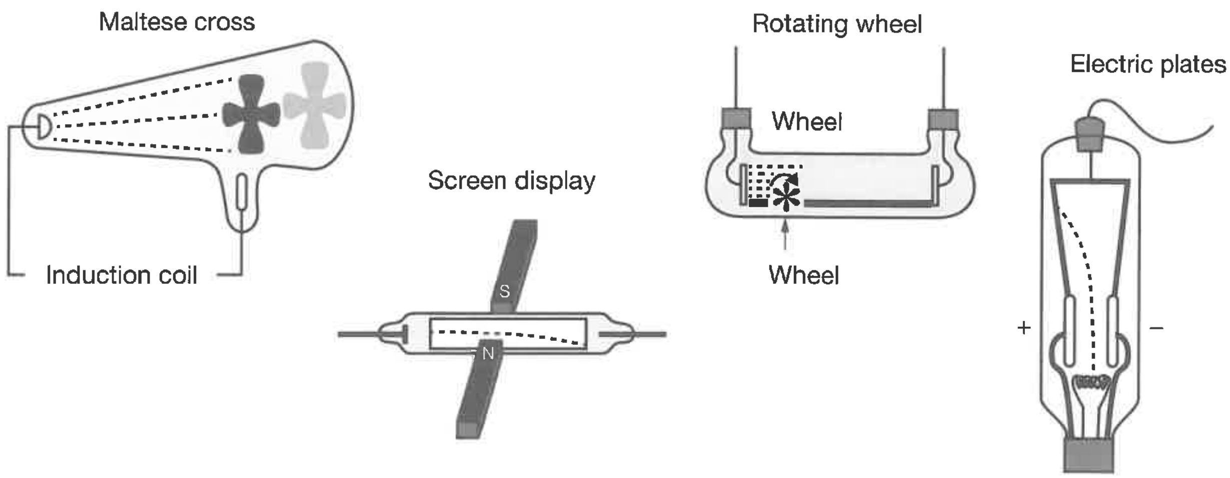
(A) A

(B) B

(C) C

(D) D

8.8.1.18 The diagrams show some of the tubes used to study the properties of cathode rays.



(a) Which choice correctly shows properties demonstrated by these tubes?

(A) They travel in straight lines, are negatively charged, have momentum and carry energy.

(B) They are negatively charged, electromagnetic, and are deflected by electric and magnetic fields.

(C) They are electrons, blocked by solids, cause fluorescence, and produce high voltage electric fields.

(D) They have energy but no mass, are not affected by gravitational fields, can be reflected and refracted.

(b) Which properties listed in the choices are incorrect? ....

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8.8.1.19

(a) Which choice best shows a property of cathode rays deduced by the scientists of the 1800s from each of the cathode ray tubes indicated.

	Maltese cross tube	Paddle wheel tube	Fluorescent screen tube and electric field	Fluorescent screen tube and magnetic field
(A)	Produce a shadow	Transfer energy	Straight line travel	Can be reflected
(B)	Straight line travel	Have momentum	Straight line travel	Negatively charged
(C)	Absorbed by solids	Have mass	Negatively charged	Straight line travel
(D)	Reflected by solids	Have mass	Negatively charged	Can be deflected

(b) If we were considering these experiments repeated today, which choice(s) would be correct? Explain your answer.

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8.8.2 Cathode rays and discharge tubes 2.

8.8.2.1 Outline the structure of a cathode ray tube. ....

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8.8.2.2

(a) What technology was needed before cathode rays could be studied seriously? ....

(b) What was essential about this technology in terms of studying cathode rays? ....

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8.8.2.3 Describe an experiment done by scientists in the 1800s which indicated that cathode rays were particles.

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8.8.2.4 Describe an experiment done by scientists in the 1800s which indicated that cathode rays were waves.

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8.8.2.5 Describe how the results of the experiment you have outlined in Question 8.8.2.3 were misleading.

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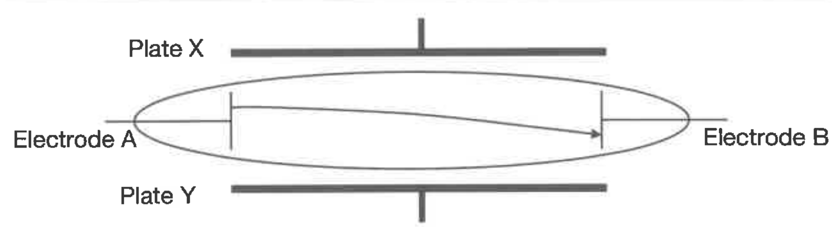
8.8.2.6 Complete the table to summarise the observations made by scientists in the 1860s and conclusions drawn from those observations about cathode rays using various discharge tubes.

Discharge tube	Observations	Conclusions drawn from each observation
Maltese cross	1. 2.	
Fluorescent display	1. 2. 3.	
Paddle wheel	1.	
Electric plates	1. 2.	

8.8.2.7 The diagram shows a cathode ray beam inside a cathode ray tube. The beam has been deflected by an electric field.



(a) Identify the positive plate.

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(b) Predict the direction of an external magnetic field which would cause the cathode ray beam to pass through the tube undeflected.

....

(c) Identify the cathode. ....

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8.9 Investigate, assess and model the experimental evidence supporting the existence and properties of the electron, from Thomson's charge-to-mass experiment.

8.9.1 Thomson's experiment.

8.9.1.1 Explain how we determine the direction of the force on a charge moving in a magnetic field (use a diagram to assist your answer).

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8.9.1.2 Describe the motion of a charged particle in a magnetic field. ....

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8.9.1.3 Justify the equality of these two equations when studying the motion of a charged particle moving in a magnetic field.

$F = Bqv \sin\theta = \frac{mv^2}{r}$

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8.9.1.4 Explain the significance of the ratio for $\frac{q}{m}$ obtained by Thomson. ....

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8.9.1.5 With the aid of a diagram, explain how Thomson was able to determine the $\frac{q}{m}$ ratio for cathode rays. You need to show the mathematical equations he used as well as the experimental method.

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8.9.1.6 The electric deflecting plates in a cathode ray tube are 15 mm apart and have a potential difference of 1200 V across them. A beam of charged particles moving at 2×10^4 m s^{-1} travel through the plates undeflected. Calculate:

(a) The electric field between the plates. ....

....

(b) The strength of the magnetic field which causes the beam to travel straight through the electric plates.

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(c) In a separate experiment using the same cathode ray tube, the beam again travels through the plates undeflected, but this time the gravitational force on the particles in the beam counters the electric field. Calculate the mass of each particle.

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8.9.1.7

(a) What was the critical technique Thomson used in his cathode ray experiment?

(A) He adjusted the magnetic and electric fields so that they were parallel to each other.
(B) He adjusted the magnetic and electric fields so that they deflected the cathode rays in opposite directions.
(C) He adjusted the magnetic and electric fields so that they deflected the cathode rays in the same directions.
(D) He adjusted the magnetic and electric fields so that they cancelled each other out.

(b) What was Thomson able to calculate as a result of doing this? Explain how he did this.

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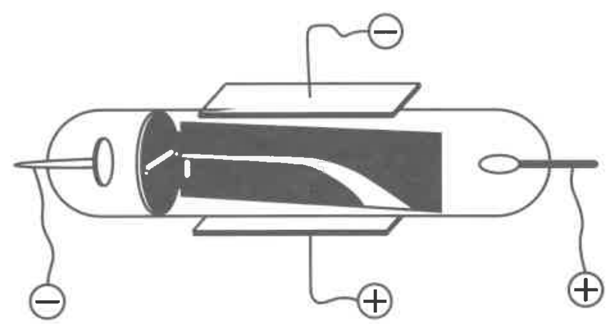
8.9.1.8 Which choice correctly classifies the variables in Thomson's experiment? The coding used in the table is as follows.

Variables: E = strength of electric field
B = strength of magnetic field
q = charge on the electron
m = mass of the electron
r = radius of curvature of path
v = velocity of electron

	Independent variable(s)	Dependent variables
(A)	B	E, r
(B)	E, B, r	q, m
(C)	E, B	q, m, r
(D)	E, r	B, q, m

8.9.1.9 The diagram shows a cathode ray tube used to study cathode rays.



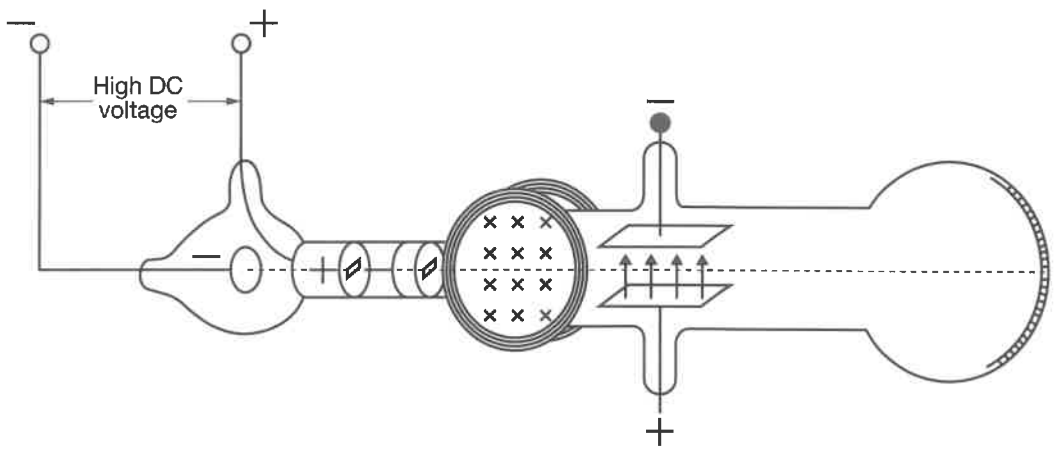
How did Thomson modify this tube to do his experiment?

(A) He added another pair of electric plates at right angles to the ones shown.
(B) He added a pair of electromagnetic coils parallel to the electric plates shown.
(C) He added a pair of electromagnetic coils at right angles to the electric plates shown.
(D) He reversed the polarity of the plates shown.

8.9.1.10 Under what condition will a charged particle travel undeflected through a region which contains both an electric and a magnetic field?

(A) If it enters the electric field after it enters the magnetic field.
(B) If it enters the electric field before it enters the magnetic field.
(C) If the electric and magnetic fields are parallel to each other.
(D) If the electric field and magnetic field are perpendicular to each other.

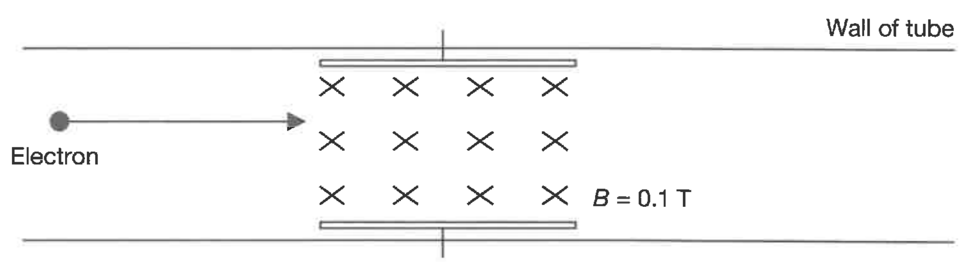
8.9.1.11 The diagram shows a cathode ray tube.



Which statement is correct if the cathode rays travel through this tube undeflected?

(A) They must leave the electron gun at very high speeds.
(B) They must be moving at a specific speed depending on the relative strengths of the electric and magnetic fields.
(C) The magnetic field must be zero.
(D) The magnitudes of the electric field must equal the value of the magnetic field.

8.9.1.12 An electron moving at 2×10^4 m s^{-1} inside a cathode ray tube enters a magnetic field of strength 0.1 T directed into the page as shown in the diagram. The magnetic field is confined to the space between two charged parallel plates which are 10 cm apart.



What electrical potential difference needs to be applied across the plates so that the electron passes between them undeflected?

(A) 2000 V directed down the page.
(B) 2000 V directed up the page.
(C) 200 V directed down the page.
(D) 200 V directed up the page.

Science Press

8.9.1.13 Although scientists had been experimenting with electrons for some 40 years before Thomson's experiment, Thomson is credited with their discovery. Why?

(A) He was the first scientist to prove they were a different particle from those already known.

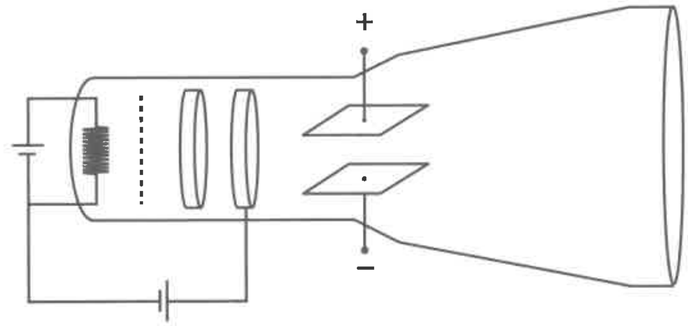
(B) He was the first scientist to measure their charge and mass.

(C) He was the first scientist to show that they were the particles involved in electrical conductivity.

(D) He was the first scientist to calculate the charge on cathode rays and gave them their name: electrons.

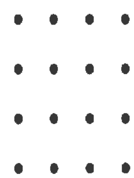
8.9.1.14 The diagram shows apparatus similar to that used by Thomson.

Which choice shows the correct direction for an applied magnetic field which would allow cathode rays to pass through this tube undeflected?

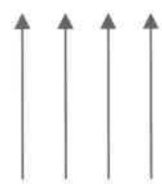


(A)

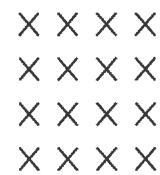
(B)



(C)



(D)



8.9.1.15 Why was the measurement of the radius of curvature of a cathode ray which was deflected by a magnetic field important in Thomson's experiment?

(A) It enabled him to calculate the velocity of the cathode rays through the tube.

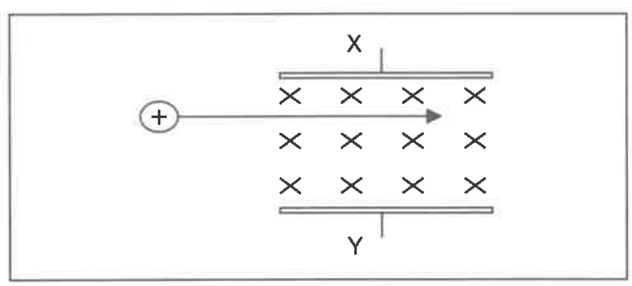
(B) It enabled him to calculate the strength of the electric field needed to balance the magnetic field.

(C) He had three unknowns, q, m and r and needed a value for r to calculate his ratio of $\frac{q}{m}$.

(D) It enabled him to calculate the value of the centripetal force acting on the cathode ray.

8.9.1.16 A positively charged ion moving at 300 m s^{-1} travels straight through two parallel plates X and Y, and a magnetic field as shown. The plates are 2.0 cm apart and the field between them is 400 V m^{-1}.

Which choice correctly shows the strength of the magnetic field and the polarity of plate X?



	Magnetic field strength (T)	Polarity of X
(A)	0.67	Negative
(B)	1.33	Positive
(C)	13.3	Negative
(D)	66.7	Positive

Science Press

8.10 Investigate, assess and model the experimental evidence supporting the existence and properties of the electron, from Millikan's oil drop experiment.

8.10.1 Millikan's oil drop experiment.

8.10.1.1

(a) What was the purpose of the Millikan oil drop experiment?

Part of Millikan's apparatus.

(b) Briefly describe how this experiment was carried out.

(c) Show the mathematics used to determine the charge on the oil drops.

8.10.1.2 Explain how Millikan arrived at his result for the charge on the electron from the results of his experiment.

8.11 Investigate, assess and model the experimental evidence supporting the nuclear model of the atom from the Geiger-Marsden experiment.

8.11.1 The Geiger-Marsden experiment.

8.11.1.1 What experiment are Geiger and Marsden famous for?

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Hans Geiger (1882-1945).

8.11.1.2 Briefly describe this experiment. ....

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8.11.1.3

(a) What was surprising about the results? ....

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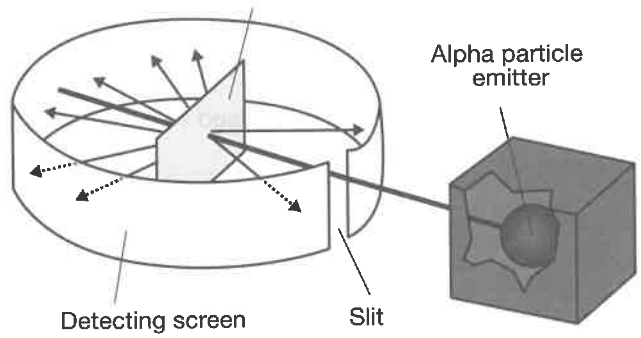
(b) The diagram shows a version of the apparatus used by Geiger and Marsden and their results. On the diagram indicate the 'surprising' results.



8.11.1.4 What were the two conclusions about the structure of atoms that Rutherford made as a result of this experiment?

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8.12 Investigate, assess and model the experimental evidence supporting the nuclear model of the atom from Rutherford's atomic model.

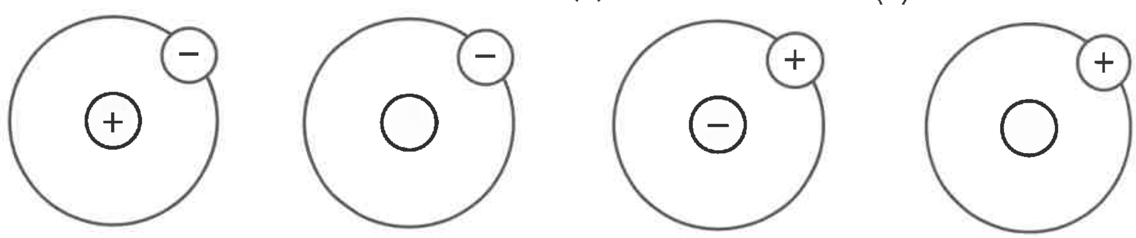
8.12.1 Rutherford's model of the atom.

8.12.1.1 Summarise the main ideas in the Rutherford model of the atom.

8.12.1.2 Outline the main experiment that led Rutherford to his atomic model.

8.12.1.3 Which diagram best illustrates Rutherford's model of the atom?

(A) (B) (C) (D)



8.12.1.4

(a) What was a major weakness of the Rutherford model of the atom?

(A) It did not explain spectral lines.
(B) It did not identify the nucleus.
(C) It only applied to the hydrogen atom.
(D) Electron orbits are not quite circular.

(b) Explain why this was considered to be a weakness.

8.12.1.5

(a) What are alpha particles?

(A) Helium nuclei.
(B) Helium atoms.
(C) Helium nuclei carrying a double positive charge.
(D) Positively charged electrons.

(b) Write the chemical symbol we use for an alpha particle, and the common symbol used when we write nuclear equations.

8.12.1.6

(a) Why was gold foil used in alpha particle scattering experiments?

(A) Being a conductor, it does not carry an electrostatic charge.
(B) Its surface does not corrode in a vacuum.
(C) Its nuclei are heavy and it can be beaten into very thin sheets.
(D) It does not oxidise when exposed to air.

(b) Explain why this was important. ....

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8.12.1.7 The diagram shows typical results from alpha particle experiments.

Identify each of the labelled parts of the diagram.

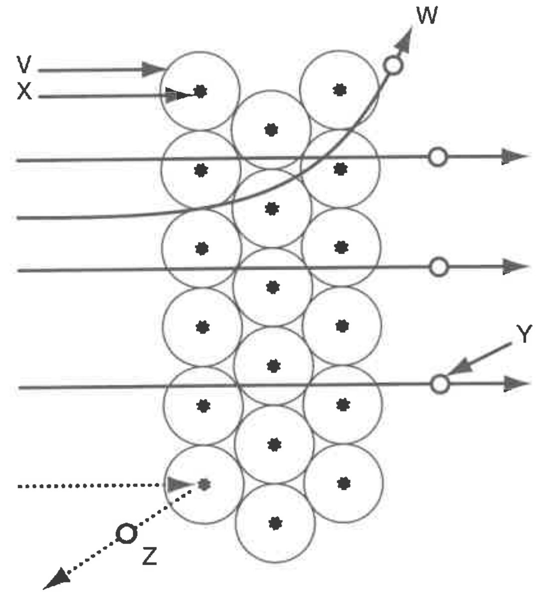
V = ...

W = ...

X = ...

Y = ...

Z = ...



8.12.1.8 What was Rutherford's explanation for most alpha particles passing through the gold foil undeflected?

(A) The alpha particles were not affected by the gold nuclei.
(B) The forces on the alpha particle were in equilibrium.
(C) Most of the atom was empty space.
(D) The nucleus of the atom contained most of its mass.

8.12.1.9 Which observation led Rutherford to suggest that atoms had a small nucleus?

(A) Most alpha particles passed through the gold foil undeflected.
(B) Only a few alpha particles were deflected through large angles.
(C) No alpha particles were reflected backwards.
(D) Alpha particles which hit the nucleus were reflected backwards.

8.12.1.10 Explain why this experiment cold not have been done before 1897.

(A) Technology to produce the golf foil thin enough was unknown.
(B) Radioactivity and alpha particles were not discovered before then.
(C) Devices to detect alpha particles had not been invented.
(D) Alpha particles with sufficient energy had not been produced.

8.13 Assess the limitations of the Rutherford atomic model.

8.13.1 Limitations of the Rutherford model of the atom.

8.13.1.1 Describe the three main imitations with the Rutherford model of the atom and explain why they were limitations.

Ernest Rutherford (1871-1937).

8.13.1.2 Assess each of these limitations.

Science Press

8.14 Investigate, assess and model the experimental evidence supporting the nuclear model of the atom from Chadwick's discovery of the neutron.

8.14.1 The discovery of the neutron.

8.14.1.1 What observations were made by Rutherford in 1919 to cause him to propose that there must be another particle in atoms apart from the proton and the electron?

8.14.1.2

(a) What suggestion did Rutherford make in 1920 about the existence of the neutron?

(b) What were the two reasons this suggestion was discounted by 1930?

8.14.1.3

(a) Whose experiment prompted the search for the neutron that eventually led to its discovery?

(b) Briefly describe this experiment.

(c) Who built on this experiment and what did they observe?

(d) What did Chadwick do in 1932 that resulted in the acceptance of the neutron as a new, fundamental particle?

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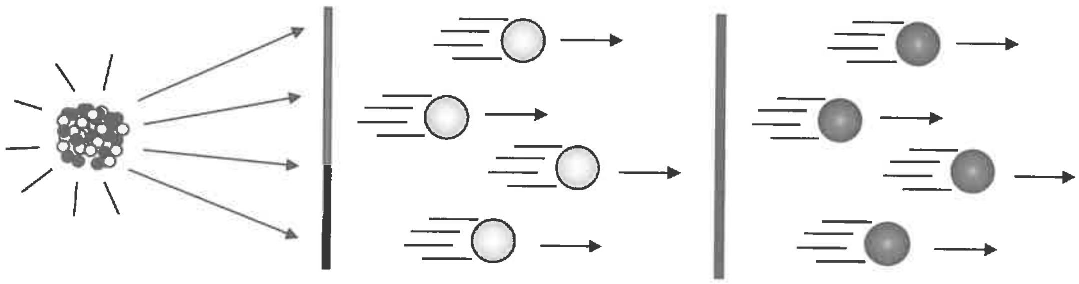
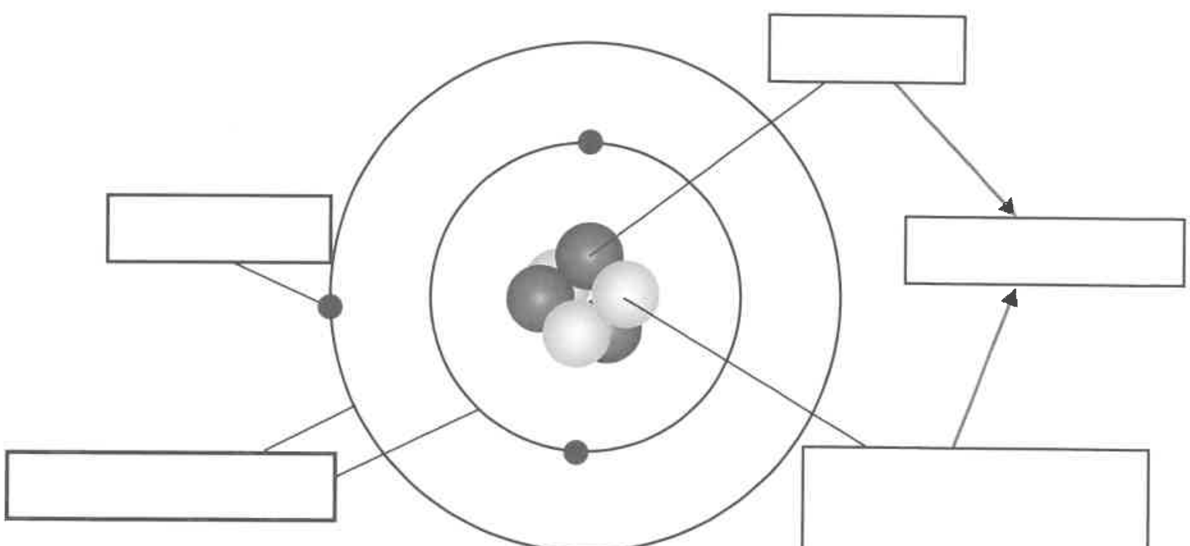
8.14.1.4 The diagram represents the experiment done by Curie and Joliot in 1932. Place the following labels on this diagram to clarify the nature of the experiment.

Alpha particles, Parrafin wax sheet, Polonium-210, Protons, Test metal, Unknown radiation



8.14.1.5 The diagram represents an atom of an element according to Rutherford's 1919 proposals for its structure. With this in mind, complete the labels so that it includes all the features of Rutherford's model at this time.



Quantum Mechanical Nature Of the Atom

8.15 Investigate the line emission spectra to examine the Balmer series in hydrogen.

INQUIRY QUESTION

How is it known that classical physics cannot explain the properties of the atom?

8.15.1 The Bohr atom.

8.15.1.1 Identify the two scientists and the specific work they did that most stimulated Bohr to attempt to develop his model of the atom.

8.15.1.2 The work of a third scientist 'made everything clear' to Bohr, and provided the essential idea for his model.

(a) Recall the name of this scientist.

(b) Outline what this scientist did that helped Bohr.

8.15.1.3 Outline Bohr's model of the atom.

8.15.1.4

(a) Bohr's postulates are sometimes listed as two postulates, sometimes as three (in which case the second postulate has been divided into two separate ones). Recall Bohr's postulates as three statements.

Postulate 1:

Postulate 2:

Postulate 3:

(b) What are postulates?

(c) Explain why Bohr needed these postulates. Give an example to support your answer.

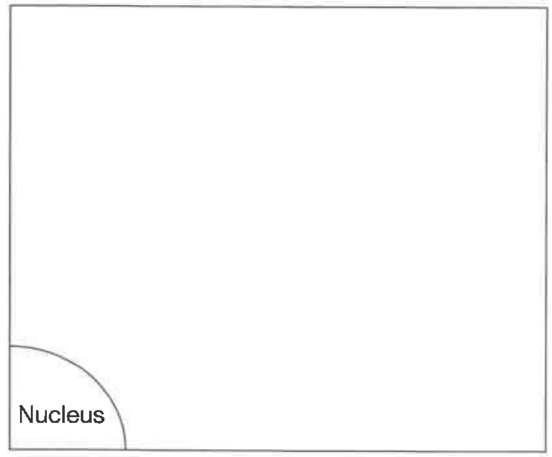
8.15.1.5 Bohr also proposed another idea, usually referred to as his 'quantisation condition', but sometimes referred to as another postulate. Recall this idea.

8.15.1.6 Assess the significance of the Bohr model of the atom in terms of the relationship between classical and quantum physics.

8.15.1.7

(a) Complete the diagram to represent a hydrogen atom, and show on this diagram the electron transitions which represent the first four lines in the Balmer series of the hydrogen spectrum (H_α to H_δ).

(b) Label each transition.



8.15.1.8

(a) What is regarded as the greatest success of the Bohr model?

(A) It was the first scientific idea to combine both classical and quantum physics.

(B) It was able to explain the hydrogen spectrum.

(C) It led to the development of an equation for predicting previously undiscovered spectral lines.

(D) It showed that quantum physics and classical physics could be used together.

(b) Explain your answer. ....

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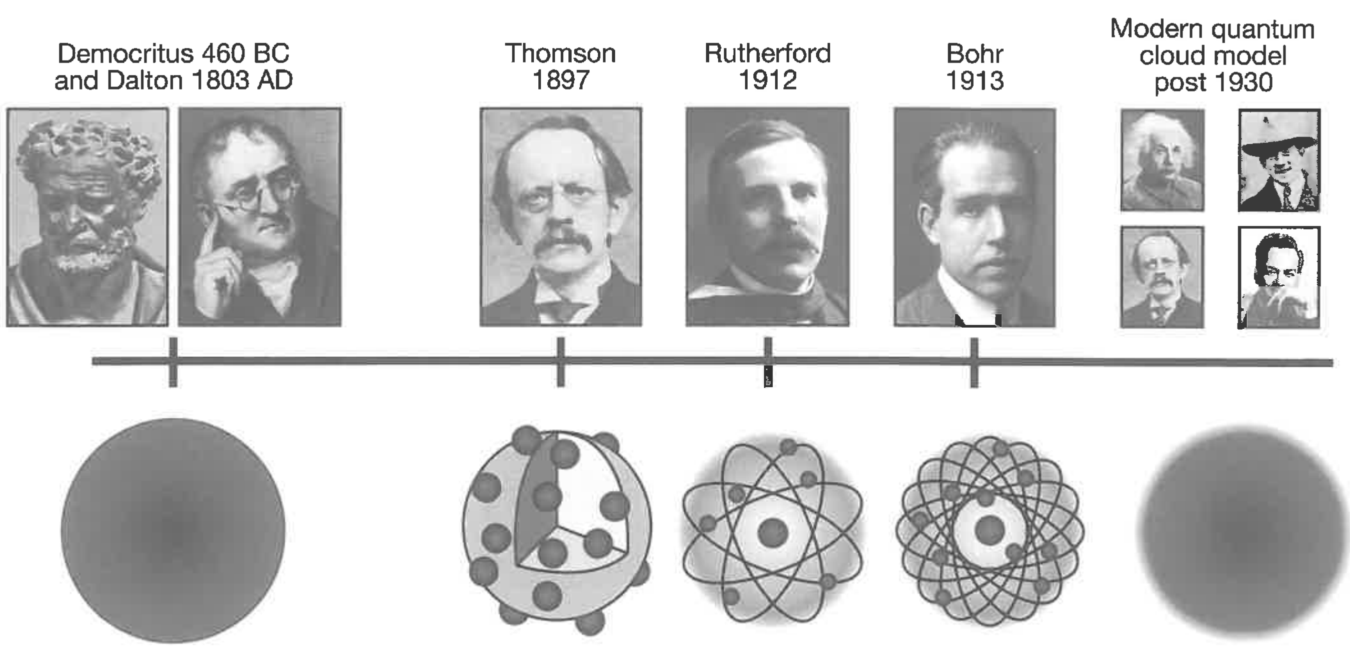
History of the atom timeline



Science Press

8.16 Relate qualitatively and quantitatively the quantised energy levels of the hydrogen atom and the law of conservation of energy to the line emission spectrum of hydrogen using $E = hf$, $E = \frac{hc}{\lambda}$, and $\frac{1}{\lambda} = R\left[\frac{1}{n_f^2} - \frac{1}{n_i^2}\right]$.

8.16.1 The atomic spectrum of hydrogen.

8.16.1.1 What was the importance of the hydrogen spectrum in the study of the structure of matter?

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8.16.1.2 What is meant by the 'convergence limit' of a spectrum of an element and what does it signify?

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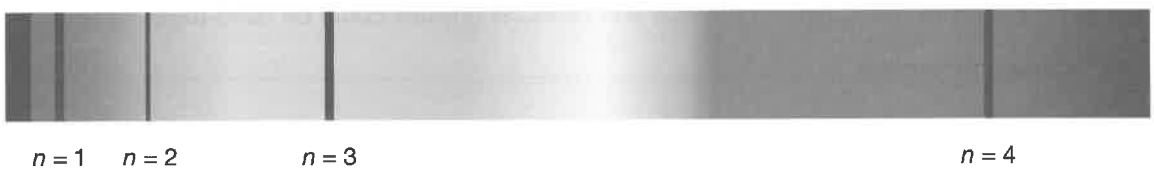
8.16.1.3 The diagram shows part of an uncoloured spectrum of hydrogen. Some of the spectral lines are numbered according to Balmer's notation.



(a) The table shows the actual wavelengths of these four lines in the hydrogen spectrum. Using the Balmer equation:

$$\lambda = b\left(\frac{n^2}{n^2 - 2^2}\right)$$

Calculate the wavelengths that he would have predicted for the light resulting in these spectral lines. (b = 364.5 nm)

(b) Research and calculate the values for the $n = 7$ line in the hydrogen spectrum.

(c) Comment on the validity of using the Balmer equation to predict the wavelengths of the hydrogen spectrum lines.

Line	Actual λ (nm)	Balmer λ (nm)
$n = 3$	656.3	
$n = 4$	486.1	
$n = 5$	434.0	
$n = 6$	410.2	
$n = 7$		

....

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8.16.1.4 The diagram represents the spectrum of hydrogen.

(a) Which of these lines would you see as blue?

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(b) Which of the lines would have the highest frequency? Justify your answer.

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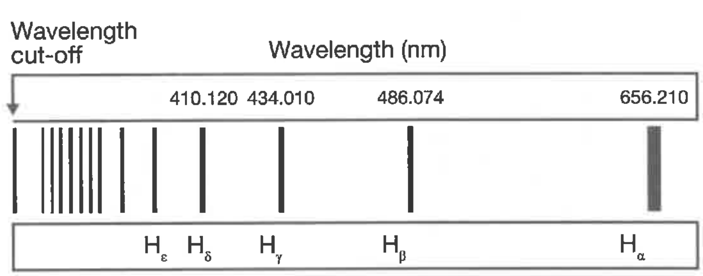

The hydrogen spectrum

(c) Which line represents an electron transfer with the most energy? ....

8.16.1.5

(a) Explain the concept of a 'series' in the hydrogen spectrum.

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(b) Suggest a reason the Balmer series was the first to be discovered.

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(c) Which of the five series shown in the diagram would emit electromagnetic radiations with the shortest wavelengths (on average)? Justify your answer.

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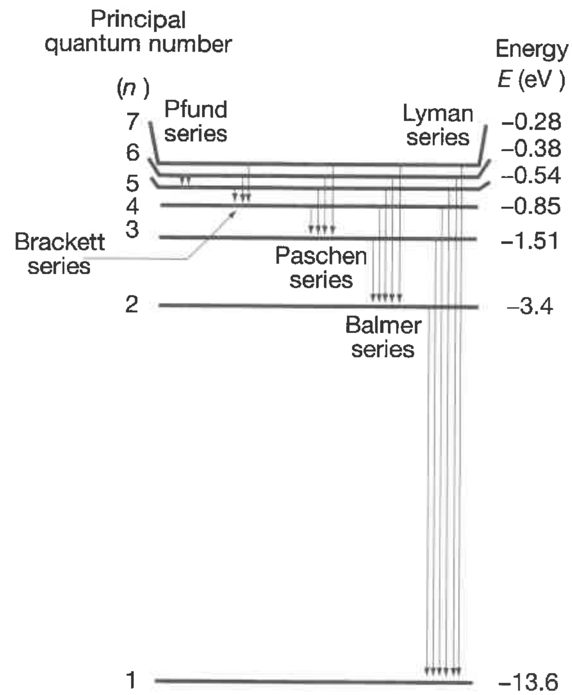

Emission spectrum of the hydrogen atom

8.16.2 Analysing spectra.

8.16.2.1 The diagrams show the spectra of five different elements and an unknown mixture of some of those elements.

(a) Which of the identified elements is contained in the unknown mixture? Justify your answer.

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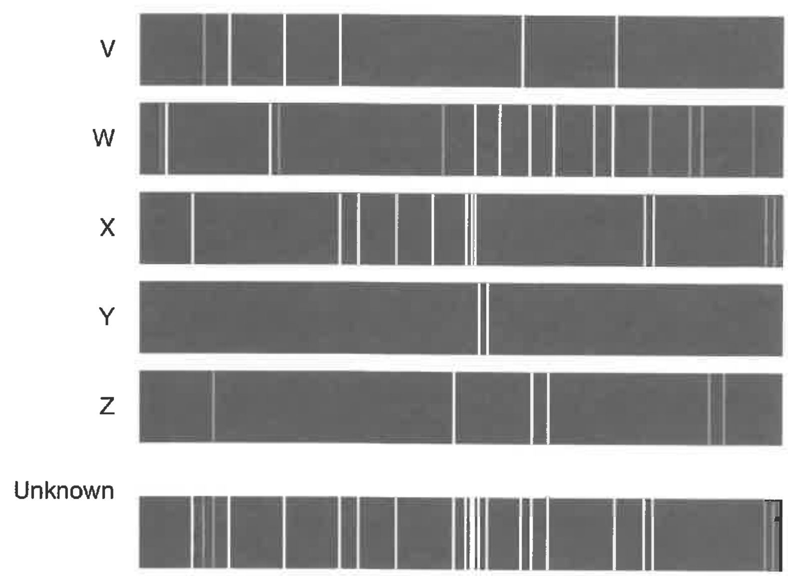
(b) There is a problem with including element Z in the unknown mixture. What is this problem and propose an explanation for this.



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(c) How do we know that the top two spectra represent different elements? ....

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(d) The spectra of elements are sometimes referred to as the 'fingerprints' for the elements. Why is this analogy made?

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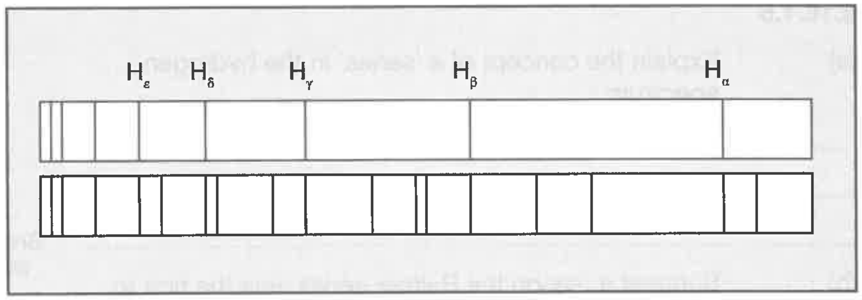
8.16.2.2 The diagrams show the spectrum of hydrogen and that from a star. The first five lines in the hydrogen spectrum have been labelled.



(a) Can we conclude from this information that the star contains hydrogen? Justify your answer.

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(b) What evidence is there that elements other than hydrogen are in this star? ....

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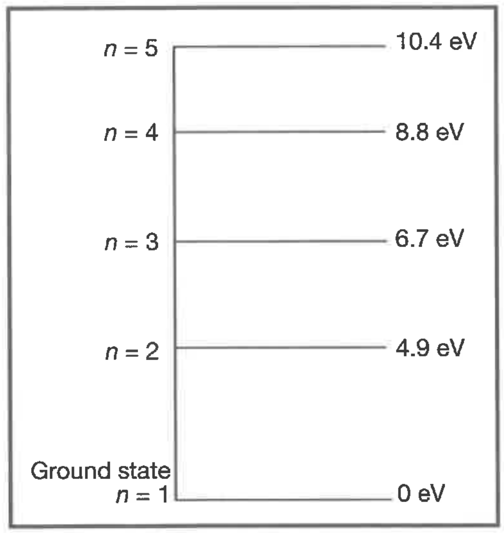
8.16.2.3 The diagram shows the energy levels for a mercury atom.



(a) An electron is in the third excited state ($n = 3$). How much energy will be emitted when it falls to $n = 2$?

..........?

(b) What additional energy is needed to excite this electron to $n = 5$?

....

(c) If an electron falls from $n = 4$ to $n = 2$, what energy is emitted/absorbed?

....

(d) An electron in the second excited state is hit by a photon with frequency 1.207×10^{15} Hz. What will happen to this electron?

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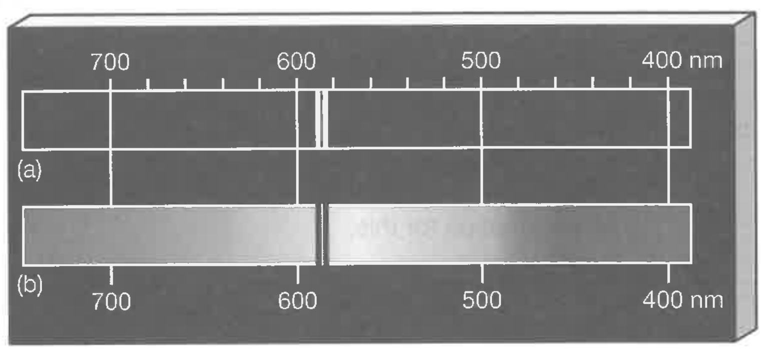
8.16.2.4 When heated to high temperatures, a sample of sodium vapour emits visible light strongly at just two wavelengths – 589.9 nm and 589.6 nm – lying in the yellow part of the spectrum. The emission and absorption spectra of sodium are compared in the diagram below, clearly showing the relation between emission and absorption features.



(a) State and explain the relationship between emission and absorption spectra. ....

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(b) Find the frequency and energy (in eV and joules) of the two main sodium vapour spectrum lines.

(i) 589.9 nm ....

(ii) 589.6 nm ....

8.16.2.5 The line spectrum for mercury has over 500 lines representing over 500 energy transformations between energy levels. The table shows a few of these energy levels.

Energy levels for mercury	
n	Energy (eV)
1	–10.38
2	–5.74
3	–5.52
4	–4.95
5	–3.71
6	–2.68
7	–2.48
8	–1.57
9	–1.56
10	0.00

(a) Which listed energy level represents the ground state? Justify your answer.

(b) Why are the values in this table all negative?

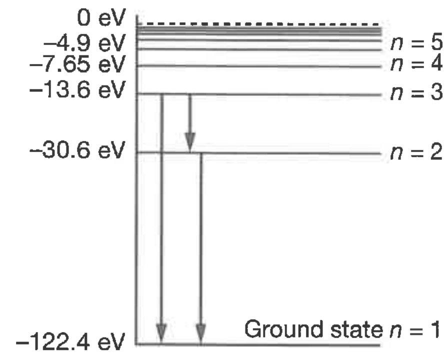
(c) In moving from level $n = 8$ to $n = 3$ would an electron absorb or emit energy? Justify your answer.

(d) What would be the frequency of the photon emitted or absorbed when an electron moves between levels $n = 8$ and $n = 3$?

(e) What is the ionisation energy of mercury according to this data?

(f) What wavelength photon would have to hit an electron in the ground state in order to cause ionisation?

8.16.2.6 The diagram shows the energy diagram for an element. Use it to answer this question.



(a) An electron in an atom of this element is excited to $n = 3$. State the energy values of three possible photons which could be emitted as this electron falls back to the ground state. And identify the transition in each case.

(b) Calculate the wavelength and frequency of each of these three photons.

(c) Another excited electron emits a photon with wavelength 143 nm when it falls back to $n = 3$. What level did it fall from?

(d) An electron in the atom is hit by a photon with frequency 5.54×10^{15} Hz. All its energy transfers and the electron is excited to a higher level. What transition does this photon cause?

(e) A photon is emitted from the atom with a frequency of 2.21×10^{15} Hz. What happens to cause this?

8.17 Assess the limitations of the Bohr atomic model.

8.17.1 Limitations of the Bohr atom.

8.17.1.1 Recall five limitations of the Bohr model of the hydrogen atom. ....

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8.17.1.2 Suggest possible reasons why the Bohr model was unable to predict the spectral lines of atoms other than hydrogen with the same degree of accuracy as it could for hydrogen.

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8.17.1.3

(a) Explain what is meant by the relative intensity of spectral lines. ....

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(b) Recall the proposed reason for the relative intensity of spectral lines. ....

....

8.17.1.4

(a) Define the Zeeman effect. ....

....

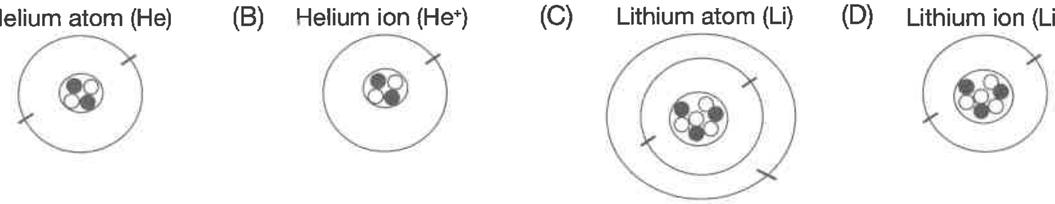
(b) Clarify the anomalous Zeeman effect. ....

....

8.17.1.5

(a) The line spectrum of which chemical entity below would be best predicted by the Bohr model?

(A) Helium atom (He) (B) Helium ion (He^+) (C) Lithium atom (Li) (D) Lithium ion (Li^+)



(b) Explain why. ....

8.17.1.6 Which of the following is *not* one of the postulates Bohr put forward in developing his model of the atom?

(A) Two electrons cannot occupy the same orbital position at the same time.
(B) Electrons occupy stable, circular orbits.
(C) Electrons in stable orbits do not emit electromagnetic radiation.
(D) Electrons absorb or emit energy when they move from one orbit to another.

8.17.1.7

(a) Which of Bohr's postulates explains Planck's idea of quanta of energy?

(A) Two electrons cannot occupy the same orbital position at the same time.
(B) Electrons occupy stable, circular orbits.
(C) Electrons in stable orbits do not emit electromagnetic radiation.
(D) Electrons absorb or emit energy when they move from one stable orbit to another.

(b) Explain your answer. ....

....

8.17.1.8 What other idea(s) are explained by the idea that electron orbit transfers involve quanta of energy?

(A) The frequency differences in electromagnetic radiations.
(B) The wave nature of light.
(C) The photoelectric effect and the spectra of elements.
(D) The stability of electron orbits.

8.17.1.9 Why did Bohr state that electrons in stable orbits did not emit electromagnetic radiation?

(A) Because this did not fit in with idea of quanta.
(B) Because the orbits were assumed to be circular.
(C) Because normal atoms did not emit electromagnetic radiation.
(D) Because energy was emitted when electrons changed energy levels.

8.17.1.10 Why did Bohr state his three postulates?

(A) To identify the controls needed for his model to work.
(B) To identify things which had to be true if his model was to work.
(C) To define the terms he used in developing his model.
(D) To propose new problems which needed to be researched further.

8.17.1.11

(a) Which of the postulates Bohr put forward in developing his model of the atom is sometimes referred to as his 'quantisation condition'?

(A) Two electrons cannot occupy the same orbital position at the same time.
(B) Electrons occupy stable, circular orbits.
(C) Electrons in stable orbits do not emit electromagnetic radiation.
(D) Electrons absorb or emit energy when they move from one orbit to another.

(b) Explain the term 'quantisation condition'. ....

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8.17.1.12

(a) What was the significance of the Bohr model in terms of the relationship between classical and quantum physics.

(A) It was the first scientific idea to combine both classical and quantum physics.
(B) It was the first model to use quantum physics instead of classical physics to explain observations.
(C) It proved that classical physics did not apply to all ideas in physics.
(D) It showed that quantum physics and classical physics could not be used together.

(b) In what specific way did the Bohr model do this? ....

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8.17.1.13

(a) What weakness did the Rutherford and Bohr models both have?

(A) Neither could account for stable electron orbits.

(B) The both only worked for hydrogen.

(C) Neither could explain atomic spectra.

(D) Neither could explain how quanta applied to the model.

(b) What was unique to the Rutherford model compared to models before it? ....

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8.17.1.14

(a) The Bohr model only works well for the hydrogen atom, predicting the wavelength and frequency of hydrogen's spectrum fully. Which is a reason it does not work for other atoms?

(A) Electrons are attracted more strongly to larger nuclei.

(B) Orbits may not be exactly circular.

(C) Outer electrons are shielded from the nucleus by inner electrons.

(D) All of the above.

(b) Does this mean that the Bohr model is incorrect? ....

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8.17.1.15

(a) Which of the following is inconsistent with the Bohr model of the atom?

(A) The continuous spectrum produced by hot solids.

(B) Spectrum lines either side of the visible spectrum.

(C) Spectral lines in the visible spectrum.

(D) The difference between emission and absorption spectra.

(b) Explain your answer. ....

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8.17.1.16 Which choice correctly identifies an aspect of the Bohr model which is classical and quantum physics?

	Classical physics	Quantum physics
(A)	Electrons are particles.	Energy levels have discrete values.
(B)	Electrostatic forces hold electrons to the nucleus.	Orbiting electrons radiate electromagnetic energy.
(C)	A strong nuclear force is needed to hold nuclei together.	The nucleus holds most of the mass of an atom.
(D)	Energy levels have discrete values.	Electrons can be considered as waves.

8.18 Investigate de Broglie's matter waves, and the experimental evidence that developed the formula: $\lambda = \frac{h}{mv}$.

8.18.1 De Broglie's matter waves.

8.18.1.1

(a) What was the idea that Prince Louis Victor Pierre Raymond, the seventh duc de Broglie had about matter in 1924 that resulted in his Nobel Prize in Physics in 1929?

Louis de Broglie (1892-1987).

(b) How did this idea account for the stable electron orbits in atoms?

(c) In what way was de Broglie's idea consistent with the scientific process?

(d) How did the scientific world react to de Broglie's proposal?

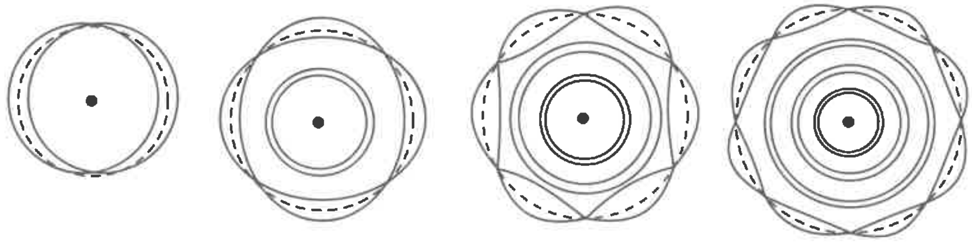
(e) In what way did de Broglie's idea link classical and quantum physics?

8.18.1.2 Explain how de Broglie's idea was able to account for the stability of electron orbits.

8.18.1.3 How did de Broglie's idea support Bohr's model of the atom?

(A) It supported the idea that electrons were quantised.
(B) It enabled the wavelength of the electrons to be calculated.
(C) It explained 'allowed' electron orbits.
(D) It stated that all moving objects have a wavelength.

8.18.1.4 The diagrams show how de Broglie's idea can be applied to the Bohr model of the atom.



(a) What are the diagrams trying to show?

(A) Electron orbits as standing waves.

(B) Interference patterns in electron orbits.

(C) Diffraction of electron orbits.

(D) The shape of each electron orbit.

(b) Explain this aspect of de Broglie's proposal. ....

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8.18.2 Applying de Broglie's ideas.

8.18.2.1

(a) Using Planck's quantum equation, $E = hf$, and Einstein's mass equivalence equation, $E = mc^2$, derive de Brogie's equation, $\lambda = \frac{h}{p}$.

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(b) Using de Broglie's equation from (a), show that for an electron in a stable orbit that $mvr = \frac{n\lambda}{2\pi}$.

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8.18.2.2 Calculate the de Broglie wavelength of an electron moving at 0.006 c. ....

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Science Press

8.18.2.3

(a) What is the de Broglie wavelength of a 200 g ball moving at 25 m s^{-1}?

(A) 9.939×10^{-25} m

(B) 1.325×10^{-34} m

(C) 7.546×10^{-35} m

(D) 5.301×10^{-36} m

(b) Explain why this is not a sensible concept for this ball.

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8.18.2.4 Find the de Broglie wavelength of a 20 kg ball moving at 25 m s^{-1}.

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8.18.2.5 What is the wavelength of an electron (mass 9.11×10^{-31} kg) travelling at 7.5×10^{5} m s^{-1}?

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8.18.2.6 What is the wavelength of a proton traveling at 60% of the speed of light? Take the mass of the proton as 1.673×10^{-27} kg.

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8.18.2.7 Find the wavelength of a hydrogen atom (mass 1.674×10^{-27} kg) moving at 25 m s^{-1}.

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8.18.2.8 Find the velocity of an atom of helium, mass 6.649×10^{-27} kg, with a de Broglie wavelength of 2800 nm.

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8.18.2.9 Find the wavelength of an object weighing 10 kg and moving at 160 km h^{-1}.

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8.18.2.10 A bullet of mass 15 g travels at 1600 m s^{-1}. Find the de Broglie wavelength of the bullet at that speed.

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8.18.2.11 Find the velocity of an electron having a de Broglie wavelength of 5.4×10^{-10} m.

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8.18.2.12 Find the velocity of a neutron, mass 1.675×10^{-27} kg with a wavelength of 4.2×10^{-11} m.

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8.18.2.13 Find the de Broglie wavelength of a neutron (mass 1.675×10^{-27} kg) moving at 0.01 *c*.

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8.18.2.14 A bird of mass 150 g flies at 12 m s^{-1}. Find the de Broglie wavelength of the bird .

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8.18.2.15 Calculate the velocity of an insect of mass 0.5 g having a de Broglie wavelength of 1.06×10^{-29} m.

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8.18.2.16 Compare the de Broglie wavelength of a proton and an electron moving at the same speed.

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8.18.2.17 Proton X is travelling at 0.005 *c*. Proton Y is travelling at 0.0025 *c*. Compare their de Broglie wavelengths.

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8.18.2.18

(a) Find the de Broglie wavelength of a neutron, mass 1.67×10^{-27} kg moving at 2.0×10^8 m s^{-1}.

(A) 5.922×10^{-7} m

(B) 5.041×10^{-14} m

(C) 1.984×10^{-15} m

(D) 71.8 m

(b) Would the wavelength of a proton, mass 1.66×10^{-27} be larger or smaller than this? Explain.

8.18.2.19

(a) Which statement about the de Broglie wavelength of a proton and an electron moving at the same speed is correct?

(A) They would be equal because they are travelling at the same speed.

(B) The wavelength of the proton would be larger because it has more mass.

(C) The wavelength of the electron would be larger because it has less mass.

(D) The wavelength of the proton would be smaller because it has a positive charge.

(b) Justify your answer.

8.18.2.20

(a) Particle X is travelling at four times the speed of particle Y. Particle Y has twice the mass of particle X. What is the ratio of their de Broglie wavelengths?

(A) 1 : 2 (B) 1 : 4

(C) 1 : 8 (D) 4 : 1

(b) Justify your answer.

8.18.2.21 Proton X is travelling at 0.02 *c*. Proton Y is travelling at 0.04 *c*. Which statement correctly compares their de Broglie wavelengths?

(A) Wavelength X = twice wavelength Y.

(B) Wavelength X = half wavelength Y.

(C) Wavelength X = wavelength Y.

(D) Unable to be determined without additional data.

8.18.2.22

(a) Calculate the de Broglie wavelength of a neutron, mass 1.675×10^{-27} kg moving at 2.0×10^8 m s^{-1}.

(b) Compare this with the de Broglie wavelength of a proton at the same speed, mass 1.673×10^{-27} kg. Explain your answer.

8.18.2.23 Proton X is travelling at 0.02 *c*. Proton Y is travelling at 0.04 *c*. Compare their de Broglie wavelengths.

8.18.2.24 Particle X, mass $2M$ is travelling at four times the speed of particle Y, mass M. What is the ratio of their de Broglie wavelengths?

8.18.2.25

(a) A proton and a neutron are moving at the same speed. Find the ratio of their de Broglie wavelengths.

(b) A proton and a neutron have the same de Broglie wavelength. Find the ratio of their momenta.

8.19 Analyse the contribution of Schrödinger to the current model of the atom.

8.19.1 Schrödinger and Heisenberg.

Note: Heisenberg is not mentioned in the syllabus, but his contribution is considered important and is instrinsically linked to Schrödinger's work and so is included herein. You may have to do some research to answer questions on Heisenberg, or you can ignore them.

Erwin Schrödinger (1887-1961).

8.19.1.1 Outline Schrödinger's contribution to the development of atomic theory.

8.19.1.2 How did this differ from Heisenberg's model?

8.19.1.3 Whose model was better accepted by other scientists at the time, and why?

8.19.1.4 Comment on the validity of the decision of these scientists (see answer to above).

Optional questions

8.19.1.5 Outline Heisenberg's contribution to the development of atomic theory.

8.19.1.6 Heisenberg's uncertainty principle is often confused with what is known as the observer effect. Clarify the difference between the uncertainty principle and the observer effect.

8.19.1.7

(a) In what way did Heisenberg contribute to atomic theory?

(A) He was able to measure the momentum of electrons in orbit.
(B) He defined electrons in terms of four different quantum numbers.
(C) He was able to explain the shape of the different electron orbits.
(D) He derived the same equations as Bohr and de Broglie from a different perspective.

(b) Why was this important?

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Properties Of the Nucleus

8.20 Analyse the spontaneous decay of unstable nuclei, and the properties of the alpha, beta and gamma radiation emitted.

INQUIRY QUESTION

How can the energy of the atomic nucleus be harnessed?

8.20.1 The strong nuclear force 1.

8.20.1.1

(a) Identify the four forces in the nucleus that cause interactions between nucleons. ....

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(b) Which of these four forces is the stronger? Which is the weakest? ....

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(c) What is the nature of each force and which nucleons do each of these four forces involve?

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8.20.1.2

(a) Give the formulas we use to calculate the two common forces along with a description of what each symbol in the formulas stands for.

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(b) Calculate the gravitational force between two protons in a nucleus. ....

(c) Calculate the electrostatic force between two protons in a nucleus. ....

(d) Use your answers to (b) and (c) to find the relative strength of the electrostatic force compared to the gravitational force.

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(e) What is the implication of your answers to (d) for atoms of stable elements that have many protons in their nuclei?

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(f) Explain how your answer to (e) accounts for the necessity of a strong nuclear force.

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8.20.1.3

(a) Explain, in terms of the forces acting inside a nucleus, why the nuclei of very large atoms are unstable and spontaneously decay into smaller nuclei.

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(b) Consider a hydrogen atom. Is there a need for the strong nuclear force in its nucleus? Justify your answer.

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8.20.1.4 Predict the relative stability of a nucleus of an atom with atomic number 20 to that of the nucleus of an atom with atomic number 30. Justify your answer.

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8.20.1.5 Elements with high atomic numbers (greater than 90) have few stable isotopes. Most exist only for very short periods of time after being produced in a nuclear reactor, then undergo spontaneous decay to form atoms of elements higher up on the periodic table until a stable isotope is eventually formed. Explain why.

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Use the diagram below to answer the next TWO questions.

8.20.1.6 What does this diagram show?

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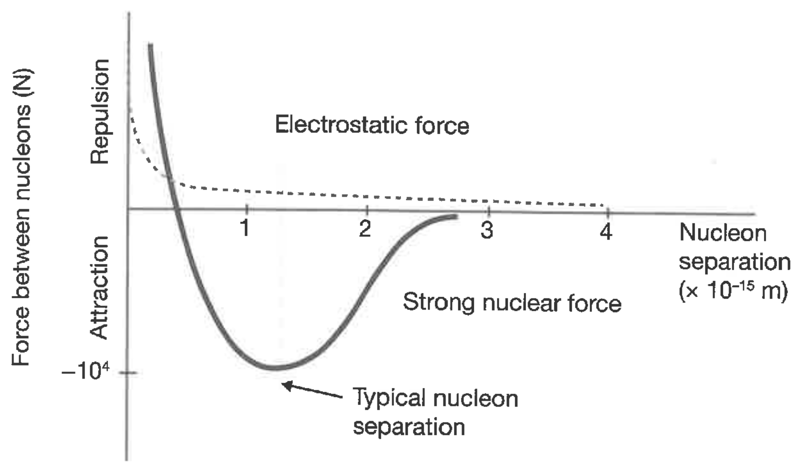

8.20.1.7 Predict if the nuclear force will be repulsive or attractive if two nucleons are, on average:

(a) 1.8×10^{-15} m apart.

....

(b) 3.0×10^{-15} m apart.

....

(c) 2.0×10^{-16} m apart. ....

8.20.1.8

(a) Who was the scientist who proposed the existence of the weak nuclear force? ....

(b) Explain the rationale behind the existence of the weak nuclear force. ....

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8.20.2 The strong nuclear force 2.

8.20.2.1

(a) What is the strong nuclear force? ....

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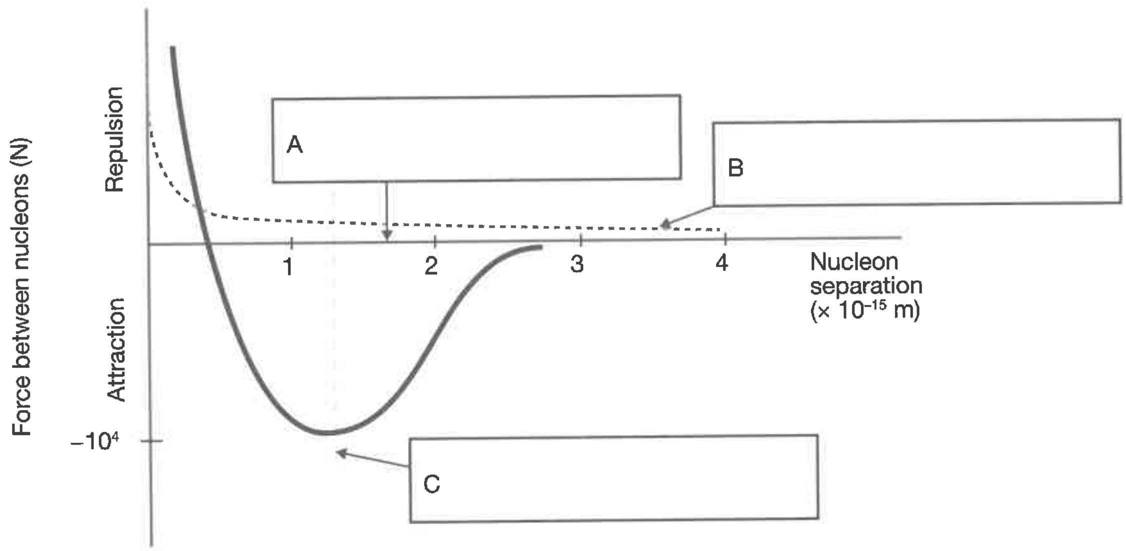
(b) Label the following graph.



(c) List the four main properties of the strong nuclear force. ....

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8.20.2.2 Explain why large nuclei are less stable than small nuclei. ....

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8.20.3 Nuclear decay.

8.20.3.1 Describe the following types of nuclear decay, indicating what happens to the nucleus as a result of each decay process.

(a) Alpha decay. ....

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(b) Beta decay. ....

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(c) Neutron decay. ....

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(d) Positron decay. ....

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(e) Proton emission. ....

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(f) Outline the situation with gamma emission. ....

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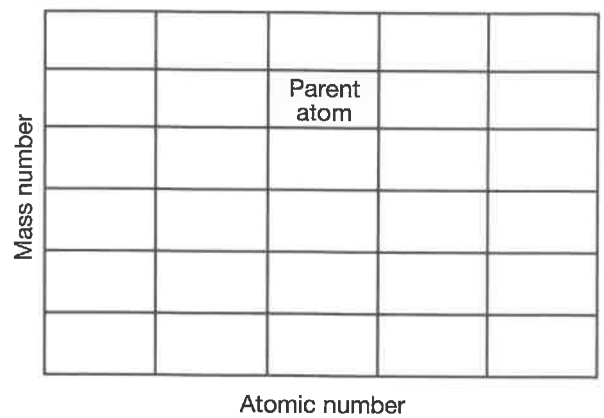
8.20.3.2 On the following periodic table grid, indicate what happens to the atomic number (Z) and mass number (A) of an atom when it undergoes each type of nuclear decay (alpha, beta, positron, proton and neutron).

Identify the position of the new nucleus by drawing an arrow from the parent atom in the grid square which holds the new nucleus. Identify each nuclear decay by labelling each arrow.



8.20.3.3

(a) Using the format of the equation shown for alpha decay in the table, write a general equation for each of the other four types of nuclear decay.

Decay reaction	General equation for reaction
Alpha	${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}X + {}^{4}_{2}He$
Beta	
Positron	
Proton	
Neutron	

(b) Explain why gamma decay has not been included in the table above. ....

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8.20.3.4 Because energy is released during a radioactive emission, what change occurs in the nucleus?

(A) The nucleus will decrease in mass.
(B) The nucleus will become more stable.
(C) The nucleus will increase in mass.
(D) The nucleus will become unstable.

8.20.3.5 Where does the energy released by a radioactive substance come from?

(A) The breaking of chemical bonds between nucleons.
(B) The breaking of chemical bonds within nucleons.
(C) The breaking of bonds within the nucleus.
(D) The mass defect of the nuclear emissions.

8.20.3.6 Which of the following best describes a nuclear transmutation?

(A) Elements emit radioactive particles to change into other elements.
(B) Elements react with each other to produce new elements.
(C) Reactions which involve the release of enormous amounts of energy.
(D) Reactions in which elements combine to produce unknown elements.

8.20.3.7 Element Y undergoes two beta decays. Which statement about the product is correct?

(A) Atomic number down 2, mass number up 2.
(B) Atomic number up 2, mass number stays the same.
(C) Atomic number up 2, mass number down 2.
(D) Atomic number down 2, mass number stays the same.

8.20.3.8 Element X emits an alpha particle to form element Y. Which statement is true about X and an atom of Y?

(A) Atoms of X have 4 more protons than atoms of Y.
(B) Atoms of X have 2 less neutrons than atoms of Y.
(C) Atoms of X have 2 more neutrons than atoms of Y.
(D) Atoms of X have 2 less protons than atoms of Y.

8.20.3.9 Which particle always accompanies positron emission?

(A) Antineutrino. (B) Beta particle.
(C) Gamma ray. (D) Neutrino.

8.20.3.10 From which part of an atom is energy released during a nuclear reaction?

(A) Electrons. (B) Nucleus.
(C) Neutrons. (D) Protons.

8.20.3.11

(a) Which of the following terms means the same as transmutation as it is used in the phrase 'nuclear transmutation'?

(A) Change. (B) Decay.
(C) Transformation. (D) All of the above.

(b) What was the first practical application of nuclear reactions?

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8.20.3.12

(a) The discovery of nuclear transmutations led scientists to explain why atomic masses were not integral numbers. What is the explanation?

(A) Atomic masses are only approximations of the true mass of an atom.
(B) Most elements have different isotopic forms.
(C) Some atoms have more protons than other atoms.
(D) Atoms of different elements have different numbers of neutrons.

(b) Explain your answer. ....

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8.20.3.13 List three other words which could also be used to describe a nuclear transmutation.

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8.20.3.14 Explain the concept of a nuclear transmutation.

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8.20.4 Why some nuclei decay.

8.20.4.1

(a) What is the strong nuclear force? ....

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(b) List the four main properties of the strong nuclear force. ....

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8.20.4.2 Explain why large nuclei are less stable than small nuclei. ....

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8.20.4.3 Use the concept of entropy to explain why some nuclei are unstable whereas others are stable.

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8.20.4.4 Use the idea of the distance between nucleons and the strong nuclear force to explain the relative stability of atoms.

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8.20.4.5 Explain why all isotopes of elements above lead, atomic number 82, tend to be unstable.

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8.20.4.6 Scientists have observed that atoms with even numbers of both protons and neutrons tend to be most stable while those with odd numbers of both are the least stable. What is the explanation scientists give for this?

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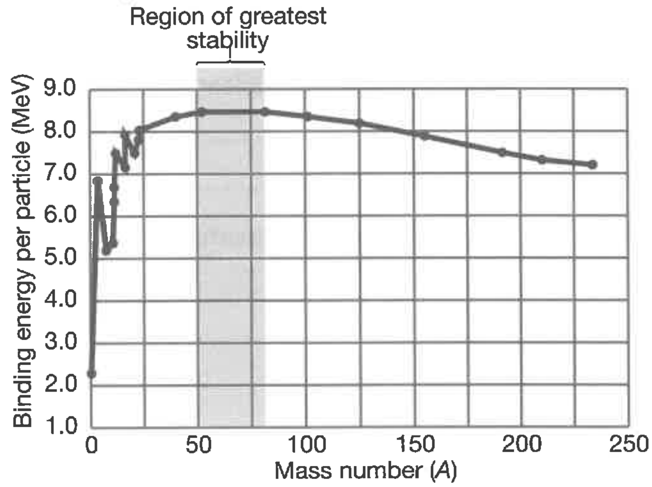
8.20.4.7 Consider the following graph which relates the stability of isotopes to their mass number and binding energy.

(a) What is meant by binding energy?



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(b) What is this graph telling us in terms of stability and binding energy?

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(c) Explain the theory behind the region of greatest stability atoms.

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(d) Does this information tell us that atoms with mass numbers less than 50 or greater than 82 are unstable? Explain your answer.

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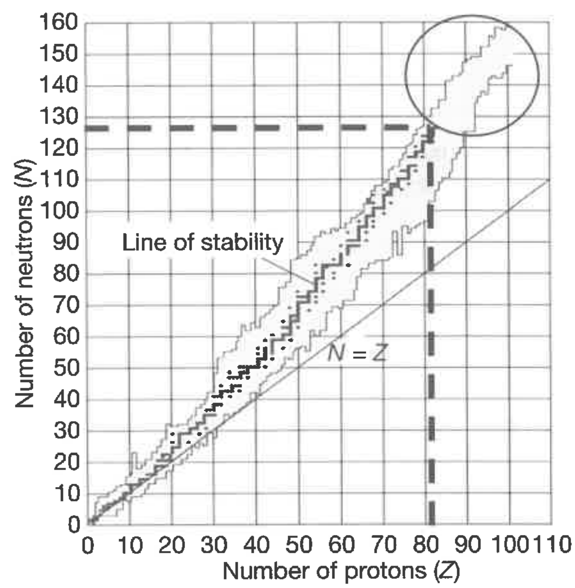
8.20.4.8 Shown is a typical 'band of stability' diagram. Use it to answer this question.

(a) What is the 'line of stability' shown on the diagram?



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(b) Atoms of isotopes above the line of stability tend to be unstable by beta decay. Explain, in terms of proton/neutron ratios why this is so.

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(c) Atoms of isotopes below the line of stability tend to be unstable by positron decay. Explain, in terms of proton/neutron ratios why this is so.

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(d) Atoms of isotopes beyond the line of stability (circled area) tend to be unstable by alpha decay. Explain, in terms of proton/neutron ratios why this is so.

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(e) What must we keep in mind when using this data to predict the decay of particular isotopes?

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8.20.5 Properties of alpha, beta and gamma rays.

8.20.5.1 Complete the table to summarise the properties of alpha, beta and gamma radiations.

Radiation	Charge	Mass (amu)	Penetrating power	Ionising power	Path through electric field	Path through magnetic field	What is it?
Alpha							
Beta							
Gamma							

8.20.5.2

(a) What are alpha particles?

(A) Helium nuclei with no charge.

(B) Helium atoms.

(C) Helium nuclei carrying a double positive charge.

(D) Positively charged electrons.

(b) Write the chemical symbol we use for an alpha particle, and the common symbol used when we write nuclear equations.

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8.20.5.3 Which has the highest penetrating power?

(A) Alpha particles. (B) Beta particles. (C) Gamma rays. (D) Protons.

8.20.5.4 Which has the highest ionising power?

(A) Alpha particles. (B) Beta particles. (C) Gamma rays. (D) Protons.

8.20.5.5

(a) What is a correct symbol for an alpha particle?

(A) ${}^{0}_{-1}e$ (B) ${}^{1}_{1}H$ (C) ${}^{4}He$ (D) ${}^{4}_{2}He$

(b) Why are alpha particles more penetrating than beta particles?

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8.20.5.6 Why do gamma rays have low ionising power?

(A) They have no mass. (B) They have no charge.

(C) They have no charge or mass. (D) They travel too fast.

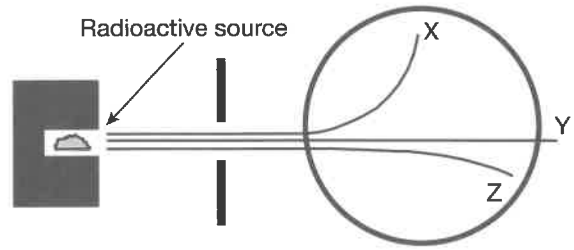
8.20.5.7 Which choice correctly identifies the nature of each radiation?

	Alpha	Beta	Gamma
(A)	Helium nuclei	Electrons	Electromagnetic radiation
(B)	Electrons	Helium nuclei	Helium nuclei
(C)	Electromagnetic radiation	Electrons	Electrons
(D)	Helium nuclei	Electromagnetic radiation	Electromagnetic radiation

8.20.5.8 Which statement is correct?

(A) Alpha radiation is the most penetrating radiation.
(B) Beta radiation penetrates further than gamma radiation.
(C) Gamma radiation is the least penetrating radiation.
(D) Alpha radiation only travels a few centimetres in air.

8.20.5.9 The diagram shows the path of alpha, beta and gamma rays through a magnetic field. Note that the direction of the magnetic field is not shown.



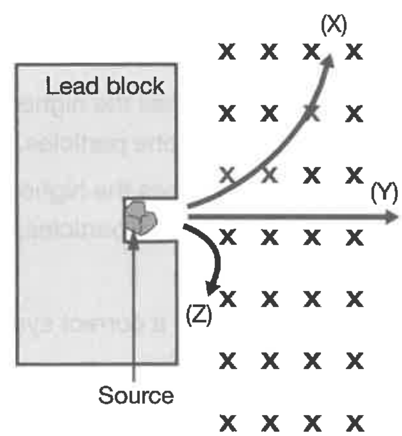
Which choice correctly identifies each?

	Alpha	Beta	Gamma
(A)	X	Y	Z
(B)	X	Z	Y
(C)	Z	X	Y
(D)	Z	Y	X

8.20.5.10 The path of an alpha particle through a magnetic field compared to a beta particle at the same speed through the same field has:

(A) Greater radius due to greater mass.
(B) Greater radius due to lesser mass.
(C) Smaller radius due to greater mass.
(D) Smaller radius due to lesser mass.

8.20.5.11 The diagram shows the path of alpha and beta particles and gamma rays through a magnetic field. Identify each.



(a) Identify each particle.

X = ...

Y = ...

Z = ...

(b) Account for the difference in the *curvature* of the paths of the radiations.

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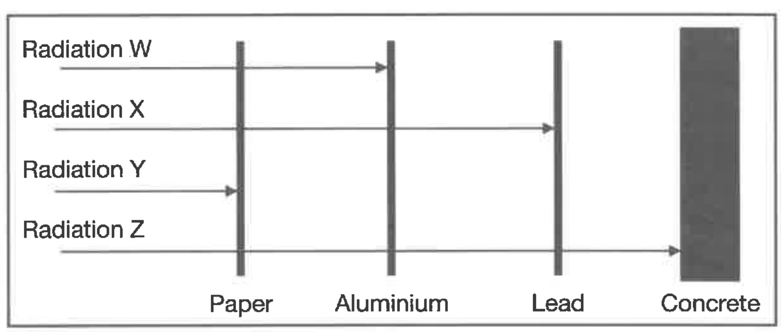
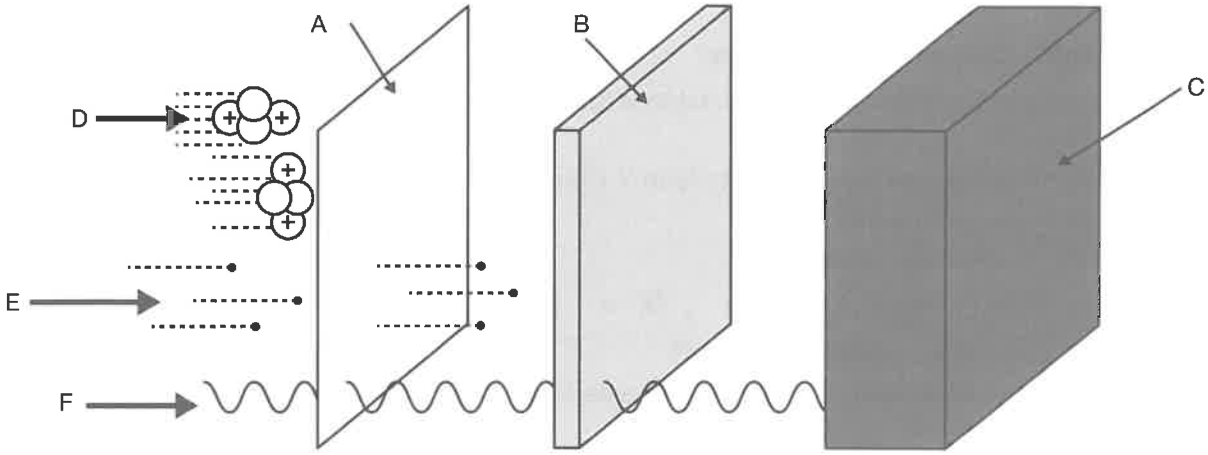
8.20.5.12 The diagram shows four types of nuclear radiations and their ability to penetrate several substances.



Knowing that neutrons are more penetrating than gamma radiation which is stopped by a thin sheet of lead, and that alpha radiation is the least penetrating, which choice correctly identifies each type of radiation?

	W	X	Y	Z
(A)	Alpha	Beta	Gamma	Neutrons
(B)	Beta	Neutrons	Alpha	Gamma
(C)	Alpha	Neutrons	Beta	Gamma
(D)	Beta	Gamma	Alpha	Neutrons

8.20.5.13 Identify the labels on the diagram which shows the three types of nuclear radioactivity and the minimum substances needed to stop them.



A = ...

B = ...

C = ...

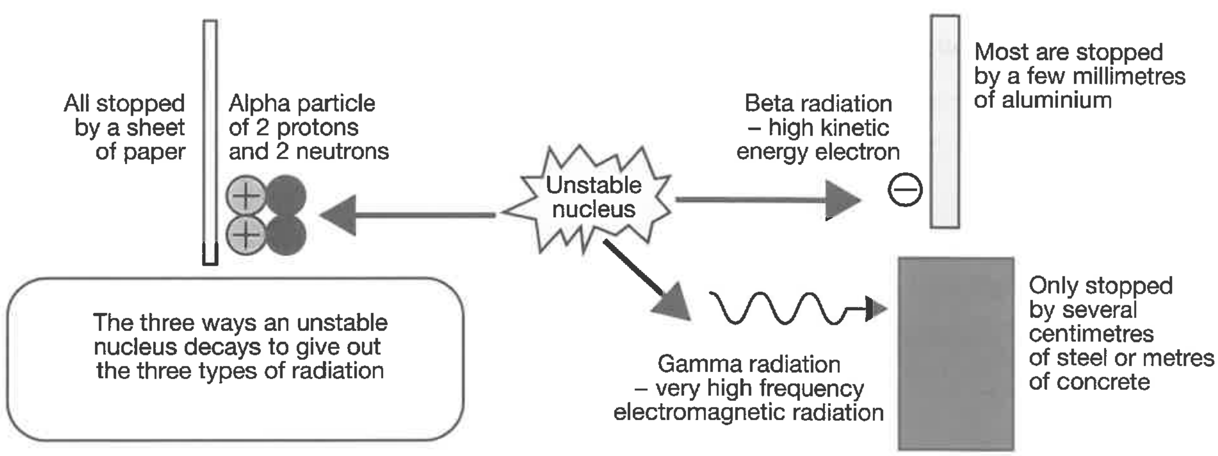
D = ...

E = ...

F = ...

8.20.5.14 Complete the table, identifying the three nuclear radiations X, Y and Z and their properties.

Radiation	Charge	Penetrating power	Ionising power	Path through electric field	Path through magnetic field	What is it?
X		Very high				
Y	Positive					
Z						



8.21 Analyse relationships that represent conservation of mass-energy in alpha decay and beta decay.

8.21.1 Aplha, beta and gamma decay.

Note: You may need to refer to the periodic table of the elements at the back of this book to answer some of these questions.

8.21.1.1 X-212 undergoes alpha decay to form Y. Compared to X, an atom of Y will have:

(A) Two protons less.
(B) Two protons and two neutrons less.
(C) Four protons less.
(D) Four protons and two neutrons less.

8.21.1.2 Consider the reaction: ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}X + {}^{0}_{-1}e + Z.$

Which choice correctly identifies Z?

(A) An antineutrino. (B) An alpha particle. (C) A beta particle. (D) A neutrino.

8.21.1.3

(a) Which choice correctly gives the nuclear equation for the reaction between beryllium and alpha particles to produce a neutron?

(A) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + \gamma$
(B) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}N + {}^{1}_{0}n$
(C) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}O + {}^{1}_{0}n$
(D) ${}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n$

(b) What do the numbers used in these equations represent? ....

....

8.21.1.4

(a) Element X undergoes alpha particle emission to form element Y. Which statement about X and an atom of Y is correct?

(A) Atoms of X have four more protons than Y.
(B) Atoms of X have four more neutrons than Y.
(C) Y will be listed before X on the periodic table.
(D) Y could be listed either before or after X on the periodic table.

(b) Explain your answer. ....

....

8.21.1.5

(a) If an atom of polonium emits an alpha particle, what element will be formed?

(A) Bismuth. (B) Lead. (C) Mercury. (D) Radon.

(b) Justify your answer. ....

....

8.21.1.6

(a) If an atom of bismuth emits a beta particle, what element will be formed?

(A) Thallium. (B) Lead. (C) Polonium. (D) Radon.

(b) Justify your answer. ....

....

8.21.1.7

(a) What is the correct identification for element Y in the reaction below?

$^{A}_{Z}Y \rightarrow {}^{222}_{86}N + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$

(A) $^{222}_{85}At$ (B) $^{210}_{85}At$ (C) $^{223}_{87}Fr$ (D) $^{222}_{87}Fr$

(b) Justify your answer. ....

....

8.21.1.8

(a) What is the correct identification for element X in the reaction below?

$^{211}_{83}Bi \rightarrow X + {}^{4}_{2}He$

(A) $^{215}_{85}At$ (B) $^{207}_{85}At$ (C) $^{215}_{81}Tl$ (D) $^{207}_{81}Tl$

(b) Justify your answer. ....

....

8.21.1.9

(a) What is the $^{0}_{0}\overline{v}$ shown in the reaction below?

$Y \rightarrow Z + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$

(A) Antineutrino. (B) Gamma ray. (C) Neutrino. (D) Positron.

(b) When do we come across these? ....

....

8.21.1.10

(a) Thorium-235 undergoes two successive beta decays. What element is formed?

(A) Actinium. (B) Protactinium. (C) Radium. (D) Uranium.

(b) Justify your answer. ....

....

8.21.1.11

(a) U-238 undergoes a series of decays to form Pb-210. How many of each decay occur?

(A) 14 alphas and 4 betas. (B) 8 alphas and 6 betas.
(C) 7 alphas and 4 betas. (D) 7 alphas and 2 betas.

(b) Justify your answer. ....

....

8.21.1.12

(a) Y undergoes beta decay then alpha decay. Which statement about the product is correct?

(A) Atomic number down 2, mass number down 4. (B) Atomic number down 1, mass number down 4.
(C) Atomic number down 3, mass number down 4. (D) Atomic number down 2, mass number down 3.

(b) Justify your answer. ....

....

8.21.1.13 What element would be formed if thorium decayed by releasing an alpha particle?

(A) Actinium. (B) Francium. (C) Lutetium. (D) Radium.

Use the following information to answer the next FIVE questions. The table shows successive steps in the decay of an atom of U-238 to lead-206.

Element	Symbol	Atomic number	Mass number
Uranium	U	92	238
Thorium	Th	90	234
Protactinium	Pa	91	234
Uranium	U	92	234
Thorium	Th	90	230
Radium	Ra	88	226
Radon	Rn	86	222
Polonium	Po	84	218
Lead	Pb	82	214
Bismuth	Bi	83	214
Thallium	Tl	81	210
Lead	Pb	82	21
Bismuth	Bi	83	210
Polonium	Po	84	210
Lead	Pb	82	206

8.21.1.14 What radioactive particles are emitted when thallium-210 decays to form polonium-210?

(A) One alpha particle.
(B) One alpha and two beta particles.
(C) Two beta particles.
(D) Four beta particles.

8.21.1.15 What is the total number of alpha particles emitted in this decay sequence?

(A) 6 (B) 7
(C) 8 (D) 9

8.21.1.16 What is the total number of beta particles emitted in this decay sequence?

(A) 6 (B) 7
(C) 8 (D) 9

8.21.1.17 Which equation is a correct equation for one of the steps in this decay sequence?

(A) ${}^{230}_{90}Th \rightarrow {}^{222}_{86}Rn + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$
(B) ${}^{230}_{90}Th \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$
(C) ${}^{210}_{81}Tl \rightarrow {}^{210}_{82}Pb + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$
(D) ${}^{210}_{81}Tl \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$

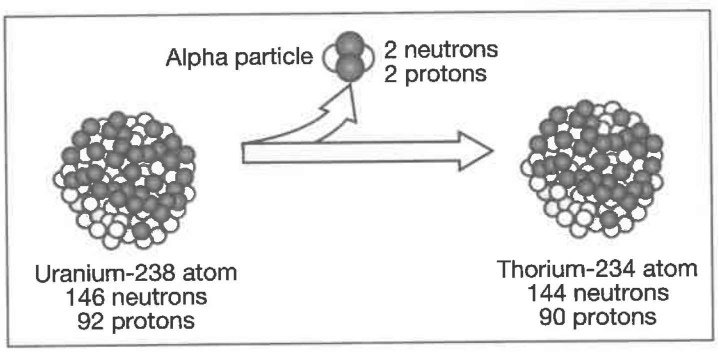
8.21.1.18 Which equation is an incorrect equation for one of the steps in this decay sequence?

(A) ${}^{230}_{90}Th \rightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$
(B) ${}^{230}_{90}Th \rightarrow {}^{226}_{86}Ra + {}^{4}_{2}He$
(C) ${}^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$
(D) ${}^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$

8.21.1.19 Thorium is also radioactive. Suppose an atom of thorium released an alpha particle. How many protons and neutrons would be in the nucleus of the atom formed?

	Number of protons	Number of neutrons
(A)	90	144
(B)	90	142
(C)	88	142
(D)	142	88

8.21.1.20 The diagram shows the nuclear decay of a uranium-238 atom into a thorium-234 atom by releasing an alpha particle. Use it, and the periodic table at the back of the book, to answer the this question.



Which equation best represents this nuclear decay?

(A) U-238 + alpha → Th-234
(B) U-238 → Th-234 + alpha
(C) U-234 → Th-238 + alpha
(D) U-234 – alpha → Th-234

8.22 Examine the model of half-life in radioactive decay and make quantitative predictions about the activity or amount of a radioactive sample using the relationships: $N_t = N_o e^{-\lambda t}$ and $\lambda = \frac{ln\ (2)}{t_{½}}$ where N_t = number of particles at time t, N_o = number of particles present at $t = 0$, λ = decay constant, $t_{½}$ = time for half the radioactive amount to decay.

8.22.1 The half-life of nuclides.

8.22.1.1 Define the term 'half-life' as it applies to radioisotopes. ....

....

....

8.22.1.2 A particular radioactive isotope has a half-life of 4 hours and a 5 g specimen of this isotope in the laboratory has a radioactive count of 200 s^{-1} at 9.00 o'clock when school starts.

(a) What will be the radioactive count for this isotope at 1.00 o'clock? ....

(b) At what time would the count be 25 s^{-1}? ....

(c) How many half-lives would have past if only 1.25 g of the isotope remained in the sample? ....

....

8.22.1.3 Thorium-227 has a half-life of 17.82 days. The half-life of iodine-131 is 8.040 days. A nuclear researcher starts with a mass of each that has an activity of 200 counts per minute.

(a) What would be the activity of the Th-227 after 5 half-lives? ....

(b) How much time is represented by 5 half-lives for I-131? ....

(c) The researcher measured the activity of each sample after the same period of time. Which radioisotope would show the greatest activity? Justify your answer.

....

....

(d) What would be the activity of the thorium compared to the iodine after 50 days? ....

....

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8.22.1.4 After 24.0 days, 2.00 mg of a 128.0 mg sample of an isotope remains. What is its half-life?

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8.22.1.5 100.0 g of an isotope with a half-life of 36.0 hours is present at time zero. How long before only 5.00 g remains?

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....

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8.22.1.6 How much time will be required for a sample of H-3 to lose 75% of its radioactivity? The half-life is 12.26 years.

8.22.1.7 The half-life of iodine-131 is 8.040 days. What percentage remains after 40.2 days?

8.22.1.8 The half-life of thorium-227 is 18.72 days How long for 62.5% of a sample to decay?

8.22.1.9 Rn-222 has a half-life of 3.82 days. How long before only 25% of the sample remains?

8.22.1.10 You have 20.0 grams of P-32 that decays 5% daily. What is its half-life?

8.22.1.11 If you start with 5.32×10^9 atoms of Cs-137, how much time will pass before the amount remaining is 5.20×10^6? The half-life of Cs-137 is 30.17 years.

8.22.1.12 The half-life of the radioactive isotope phosphorus-32 is 14.3 days. How long until a sample loses 99% of its radioactivity?

8.22.1.13 A radioactive sample contains 3.25×10^{18} atoms of a nuclide that decays at a rate of 3.4×10^{13} disintegrations per 26 minutes.

(a) What percentage of the nuclide will have decayed after 159 days?

(b) What is the half-life of the nuclide?

8.22.1.14

(a) The half-life of C-14 is 5730 years. How much of this isotope would remain in a sample which was 63 030 years old?

(b) Explain why this is the limit for dating using C-14.

8.22.1.15 K-40 decays to Ar-40 with a half-life of 1.27×10^9 years. A sample of moon rock has 78 argon-40 atoms for every 22 potassium-40 atoms. Assume the sample was 100% K-40 at the start. Find the age of the moon rock.

8.22.1.16 What is the age of a rock in which the mass ratio of Ar-40 to K-40 is 3.8 : 1? K-40 decays to Ar-40 with a half-life of 1.27×10^9 years.

8.22.1.17 A sample of petrified wood has a C-14 decay rate of 6.00 counts min^{-1}. The decay rate of carbon-14 in fresh wood is 13.6 counts min^{-1}. If the half-life of C-14 is 5730 years, what is the age of the piece of wood?

8.22.1.18 The carbon-14 decay rate of a sample obtained from a young tree is 0.296 s^{-1}. Another sample prepared from an object recovered at an archaeological dig gives a decay rate of 0.109 s^{-1}. What is the age of the object?

8.22.1.19 The C-14 content of an ancient piece of wood was found to have three tenths of that in living trees (indicating 70% of the C-14 had decayed). How old is that piece of wood?

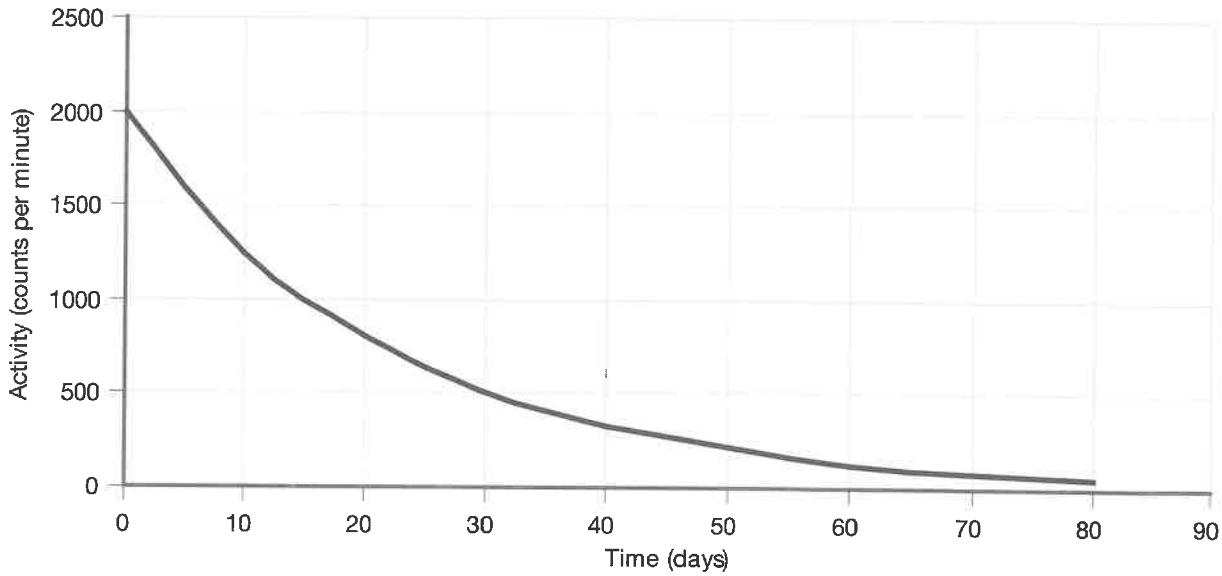
8.22.1.20 Carbon-14 is used to determine the age of ancient objects. If a sample today contains 0.060 mg of carbon-14, how much carbon-14 must have been present in the sample 11 430 years ago?

8.22.1.21 All current plants have a C-14 count of 15.3 counts min^{-1}. How old is a wooden artefact if it has a count of 9.58 counts min^{-1}?

8.22.1.22 A living plant contains approximately the same isotopic abundance of C-14 as does atmospheric carbon dioxide. The observed rate of decay of C-14 from a living plant is 15.3 disintegrations min^{-1}. How many disintegrations min^{-1} will be measured from a 10 000-year-old sample? (The half-life of C-14 is 5730 years.)

8.22.1.23 Using dendrochronology (using tree rings to determine age), tree materials dating back 10 000 years have been identified. Assume you have a sample of such a tree in which the number of C-14 decay events was 15.3 decays per minute before decomposition. What would the decays per minute be in the present day?

8.22.1.24 Use the following half-life graph to answer this question.



(a) Which is the best estimate for the half-life of the radioisotope from which this graph was drawn?

(A) 10 days
(B) 15 days
(C) 20 days
(D) 25 days

(b) What would be the activity of the isotope after 25 days?

(A) About 600 counts per minute.
(B) About 625 counts per minute.
(C) About 650 counts per minute.
(D) About 675 counts per minute.

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8.22.2 Analysing a half-life experiment.

8.22.2.1 A nuclear scientist was investigating the properties of a radioisotope, X. Before starting the experiment she measured the background radiation and gained the results shown in the table.

Time (s)	Number of counts
60	48
60	51
60	53
60	52
60	46
Average count	

(a) Calculate the average background radiation in counts per minute (counts min^{-1}). Use your calculation to complete the table.

....

....

(b) Why is it necessary to measure this background radiation before starting the experiment?

....

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(c) The scientist then placed a sample of X near the counter and measured the radiation each Monday for 7 weeks, counting the first week as week 0, the starting week. Her results are shown in the table. Complete it by writing in the values for the third column.

Time (hours)	Total radiation counts recorded (counts min^{-1})	Radiation due to X (counts min^{-1})
0	1730	
2	1110	
4	715	
6	465	
8	320	
10	215	
12	160	

(d) Plot the results to show the relationship between time and the radiation of X.

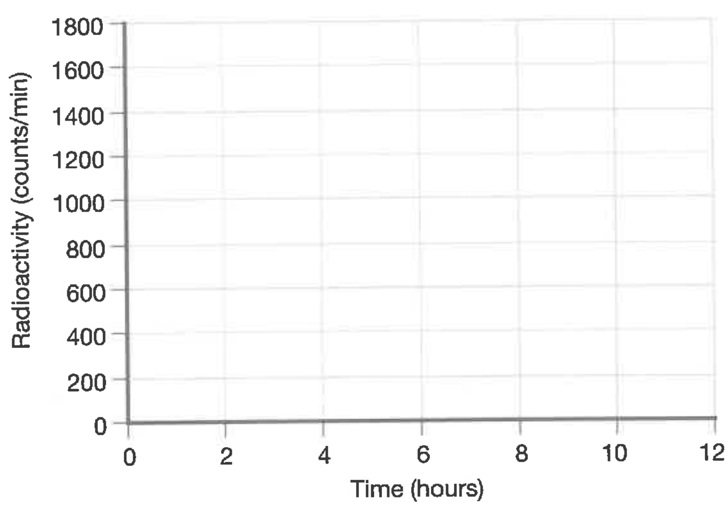
(e) Use your graph to determine the number of days for the radiation count from X to halve, that is, the 'half-life' of X.

....

(f) Predict the radiation in counts min^{-1} of X after 20 hours.

....

(g) Predict the radiation in counts min^{-1} of X after 36 hours.



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8.23 Model and explain controlled and uncontrolled chain reactions.

8.23.1 Fermi's model of a chain reaction.

8.23.1.1

(a) Describe the demonstration of a nuclear chain reaction done by Fermi. ....

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(b) Outline Fermi's observations from this demonstration. ....

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8.23.1.2 Recall the purpose of Fermi's demonstration. ....

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8.23.1.3 In his demonstration of a nuclear chain reaction, Fermi used ping pong balls and mousetraps spread across the floor. Identify the symbolism in this demonstration.

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8.23.1.4 Recall Fermi's conclusion. ....

....

....

8.23.1.5

(a) What was the purpose of Fermi's initial experiment?

(A) To use neutrons to bombard uranium to see if he could produce new elements.
(B) To start a chain reaction by bombarding uranium with neutrons.
(C) To see if he could control the reaction initiated when he bombarded uranium with neutrons.
(D) To observe the radioactive decay of uranium after bombarding it with neutrons.

(b) Why did Fermi use neutrons? ....

....

8.23.1.6

(a) What did Fermi observe?

(A) That the bombarding neutrons were able to split uranium nuclei.
(B) That the uranium became highly radioactive.
(C) That atoms heavier than target atoms were sometimes produced.
(D) Both (A) and (C).

(b) Suggest a reason uranium was used as the main target atoms. ....

....

8.23.1.7

(a) What did Fermi find confusing about his observations?

(A) The amount of energy released during the fission of uranium was enormous.
(B) The products of uranium fission were not always the same.
(C) That not all neutrons caused fission of uranium atoms.
(D) That the fission of uranium sometimes produced atoms with a greater atomic number.

(b) What was the factor that seemed to determine what sort of products were produced? ....

....

8.23.1.8

(a) Which observation caused Fermi to propose the concept of a chain reaction?

(A) The mass defect in the reaction was converted directly into energy.
(B) Uranium nuclei sometimes captured neutrons and formed heavier atoms.
(C) Fission of uranium atoms produced more neutrons.
(D) Fission of uranium involved enormous amounts of energy.

(b) Explain your answer. ....

....

8.23.2 Controlled and uncontrolled chain reactions.

8.23.2.1 Define a controlled nuclear reaction. ....

....

8.23.2.2 Recall the requirements for a controlled nuclear reaction. ....

....

....

8.23.2.3 Define an uncontrolled nuclear reaction. ....

....

8.23.2.4 Recall the requirements for an uncontrolled nuclear reaction. ....

....

....

....

8.23.2.5 Predict possible consequences of an uncontrolled nuclear reaction. ....

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8.23.2.6

(a) Compare the energy released in a controlled reaction with that released in an uncontrolled reaction.

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(b) Assuming the same nuclear fission reaction occurs for both a controlled and an uncontrolled nuclear reaction, what happens in order to control the reaction?

....

....

8.23.2.7

(a) On average, as determined by Fermi, how many neutrons per fission are required to sustain a controlled nuclear reaction?

....

(b) Why this number? Surely only one neutron could initiate the next fission. ....

....

(c) What would happen to the nuclear reaction if, on average, only 0.75 neutrons per fission had sufficient energy to initiate further fission reactions?

....

8.23.2.8

(a) Write two nuclear equations for each of the following reactions (note that you will need to include emitted neutrons and beta particles if appropriate).

(i) Neutron capture by U-235, and then the product's fission to produce Ba-141 and Kr-92.

....

....

(ii) Neutron capture by U-235, and then the product's fission to produce La-139 and Mo-95.

....

....

(iii) Neutron capture by U-235, and then the product's fission to produce Sr-88 and Xe-136.

....

....

(iv) Neutron capture by U-235, and then the product's fission to produce La-147 and Br-87.

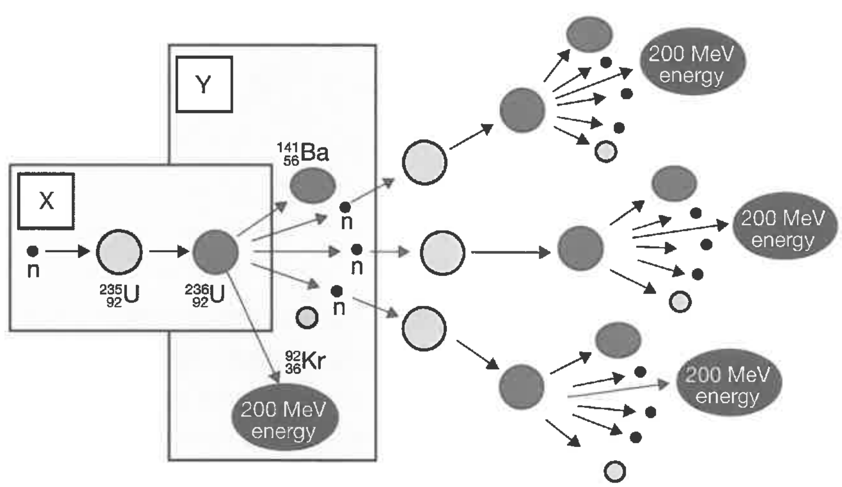
....

....

(b) Assuming emitted neutrons have the appropriate energy, which of these reactions would be able to sustain a nuclear reaction? Justify your answer.

....

8.23.2.9 Consider the diagram.



(a) What is part X of the diagram showing?

....

....

(b) What is Y showing?

....

....

(c) What is the diagram showing overall?

....

....

8.23.2.10

(a) Which choice best describes a controlled nuclear reaction?

(A) One in which the energy input is equal to the energy output.

(B) One in which only a specific amount of energy is produced.

(C) One in which the amount of energy produced is limited.

(D) One which produces more energy output than energy input.

(b) How might more energy be produced in a controlled nuclear reaction? ....

....

8.23.2.11

(a) Which of the following is an essential requirement for a controlled nuclear reaction?

(A) Each fission produces no further neutrons with the energy needed to initiate another fission.

(B) Each fission produces only one neutron with the energy needed to initiate another fission.

(C) Each fission produces 2.5 neutrons with the energy needed to initiate other fissions.

(D) Each fission produces more than 2.5 neutrons with the energy needed to initiate other fissions.

(b) Rationalise your answer in terms of Fermi's statement that 2.5 neutrons per fission are needed to sustain a chain reaction.

....

8.23.2.12

(a) Which statement best describes an uncontrolled nuclear reaction?

(A) One in which more energy is produced than is needed.

(B) One in which too much energy is produced.

(C) One in which energy output exceeds energy input.

(D) One in which energy is produced in ever increasing amounts.

(b) How might an uncontrolled reaction in a reactor be prevented? ....

....

8.23.2.13

(a) Which of these reaction(s) would be most likely to sustain a chain reaction?

(A) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$

(B) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{57}La + ^{95}_{42}Mo + 2^{1}_{0}n + 7^{0}_{-1}e$

(C) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{88}_{38}Sr + ^{136}_{54}Xe + 12^{1}_{0}n$

(D) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{147}_{57}La + ^{87}_{35}Br + 2^{1}_{0}n$

(b) Explain your answer. ....

....

....

8.23.2.14

(a) Which of the following is the minimum requirement for an uncontrolled nuclear reaction?

(A) Each fission produces one neutron with the energy needed to initiate another fission.

(B) Each fission produces more than one neutron with the energy needed to initiate other fissions.

(C) Each fission produces at least 2.5 neutrons with the energy needed to initiate other fissions.

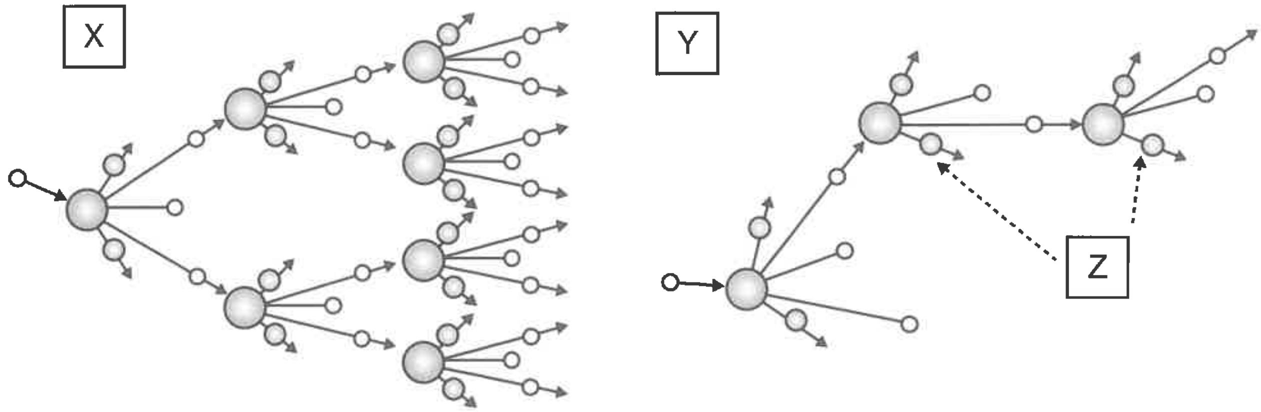
(D) Each fission produces more than 2.5 neutrons with the energy needed to initiate another fission.

(b) Explain why more than one neutron is required to be produced each fission. ....

....

Use the following information to answer the next TWO questions.

Refer to the diagrams shown.



8.23.2.15 Which statement about these diagrams is correct?

(A) Both diagrams represent controlled chain reactions.
(B) Both diagrams represent uncontrolled chain reactions.
(C) X represents a controlled reaction, Y represents an uncontrolled reaction.
(D) X represents an uncontrolled reaction and Y a controlled reaction.

8.23.2.16

(a) What do particles Z represent?

(A) Daughter products of the reaction.
(B) Emitted radioactive particles.
(C) Neutrons which do not hit additional fuel nuclei.
(D) Neutrons with insufficient energy to initiate fission.

(b) What is meant by fission? ....

....

....

8.23.2.17

(a) A nuclear reaction produces 2.5 neutrons per fission, but only 0.75 of them (on average) have sufficient energy to produce further fission reactions. What will happen to the energy production in this reactor?

(A) It will slow down and eventually stop.
(B) It will decrease to a minimum amount and then remain steady.
(C) It will be produced at a steady, but lower level.
(D) There will be no effect on energy production as long as there is enough fuel in the reactor.

(b) Explain your answer. ....

....

....

8.23.2.18 What are the high energy particles released during a nuclear fission reaction that are responsible for nuclear chain reactions?

(A) Alpha particles. (B) Beta particles. (C) Protons. (D) Neutrons.

8.23.2.19

(a) Predict what would happen to the reaction if, out of the average 2.5 neutrons produced by each fission, only 0.8, on average, caused additional fissions.

....

(b) Predict what would happen to the reaction if, out of the average 2.5 neutrons produced by each fission, exactly 1.0, on average, caused additional fissions.

....

(c) Predict what would happen to the reaction if, out of the average 2.5 neutrons produced by each fission, more than 1.0, on average, caused additional fissions.

....

8.23.2.20 The equations show two possible nuclear fissions for U-235. Use them and the information in the table to answer this question.

A: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3(^{1}_{0}n)$

B: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{139}_{57}La + ^{95}_{42}Mo + 2(^{1}_{0}n) + 7(^{0}_{-1}e)$

C: $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{136}_{54}Xe + ^{88}_{38}Sr + 12(^{1}_{0}n)$

Note: 1 amu = 1.661×10^{-27} kg and 1 MeV = 1.6×10^{-13} J

Particle	Mass (amu)
$^{141}_{56}Ba$	140.9139
$^{92}_{36}Kr$	91.8973
$^{139}_{57}La$	138.8061
$^{95}_{42}Mo$	94.9057
$^{235}_{92}U$	235.1170
$^{0}_{-1}e$	0.000549
$^{1}_{0}n$	1.008665

(a) Predict which of these might best sustain a chain reaction. Justify your choice.

....

(b) Identify the additional data needed to confirm your prediction.

....

(c) Calculate the mass defect for each reaction.

A: ....

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B: ....

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C: ....

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(d) Identify from this which reaction will release the most energy per fission. ....

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(e) From this, calculate the amount of energy which would be released by the fission of 1 kg of U-235 by this reaction.

....

8.24 Predict quantitatively the energy released in nuclear decays or transmutations, including nuclear fission and nuclear fusion, by applying the law of conservation of energy, mass defect, binding energy and Einstein's mass-energy equivalence relationship: $E = mc^2$.

8.24.1 Binding energy.

8.24.1.1

(a) What is the binding energy of a nucleus?

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....

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(b) Compare the relative strength of the binding energy in a nucleus to the electrostatic force holding electrons in orbit (ball park answer will suffice).

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(c) How does the binding energy per nucleon in a nucleus relate to the stability of the nucleus?

....

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8.24.1.2 If the binding energy per nucleon of $^{62}_{28}Ni$ is 8.7948 MeV, what is its total binding energy:

(a) In MeV? ....

(b) In joules? ....

8.24.1.3 Consider nuclei of $^{31}_{15}P$ and $^{39}_{19}K$.

(a) Without making any calculations, which nucleus would have the greater total binding energy? Justify your answer.

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(b) Which has the greater binding energy per nucleon?

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(c) On this information alone, which of these two nuclei would be the most stable? Justify your answer.

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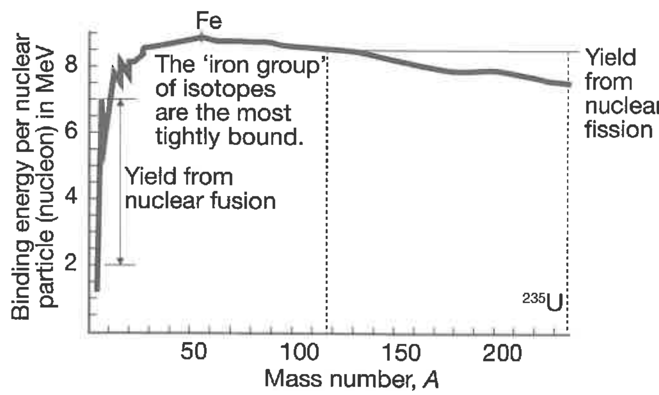
8.24.1.4 Consider the following graph.



(a) According to this graph, which is the most stable nucleus? Justify your answer.

....

....

(b) This graph suggests that elements with a mass number less than 56, the mass number of iron, will, if they undergo a nuclear reaction, undergo nuclear fusion and not nuclear fission. Explain this prediction.

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(c) This graph suggests that elements with a mass number greater than 56, the mass number of iron, will, if they undergo a nuclear reaction, undergo nuclear fission and not nuclear fusion. Explain this prediction.

....

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8.24.1.5 Which is a correct definition of binding energy?

(A) The energy released per nucleon when nucleons combine to form a nuclide.

(B) The energy represented by the mass defect in a nuclide.

(C) The energy released per atom during a nuclear transformation.

(D) The energy required to initiate a nuclear fusion reaction.

8.24.1.6 Which is *not* a correct definition of mass defect?

(A) The difference between the mass of the products and the mass of the reactants of a nuclear transformation.

(B) The difference between the mass of a nucleus and the sum of the masses of its constituent nucleons.

(C) Mass converted to energy and used to bind nucleons together.

(D) Mass released during a nuclear transformation.

8.24.1.7 What is the source of energy in a nuclear fission reaction?

(A) The mass defect between products and reactant nuclei.

(B) The mass defect between product nuclei and their constituent nucleons.

(C) The difference in the binding energy per nucleon in product nuclei.

(D) The difference in the binding energy per nucleon in reactant nuclei.

8.24.1.8 What is the source of energy in a nuclear fusion reaction?

(A) The mass defect between products and reactant nuclei.

(B) The mass defect between product nuclei and their constituent nucleons.

(C) The difference in the binding energy per nucleon in product nuclei.

(D) The difference in the binding energy per nucleon in reactant nuclei.

8.24.1.9 How does mass defect arise in a nuclear transformation?

(A) The total binding energy in the product nuclei is greater than that in the reactant nuclei.

(B) The total binding energy in the reactant nuclei is greater than that in the product nuclei.

(C) Reactant nuclei have a lower binding energy per nucleon than product nuclei.

(D) Product nuclei have a lower binding energy per nucleon than reactant nuclei.

8.24.1.10 Define binding energy. ....

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8.24.1.11 What is mass deficit? ....

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8.24.1.12 Explain the connection between mass defect and binding energy.

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8.24.1.13 The mass of a helium nucleus, $^{4}_{2}He$, is 4.0015 *u*. Calculate the following quantities.

(a) The mass deficit for the helium nucleus.

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(b) The binding energy of the nuclide in MeV.

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(c) The binding energy per nucleon in MeV.

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8.24.1.14 Calculate the binding energy of a tritium atom ($^{3}_{1}H$).

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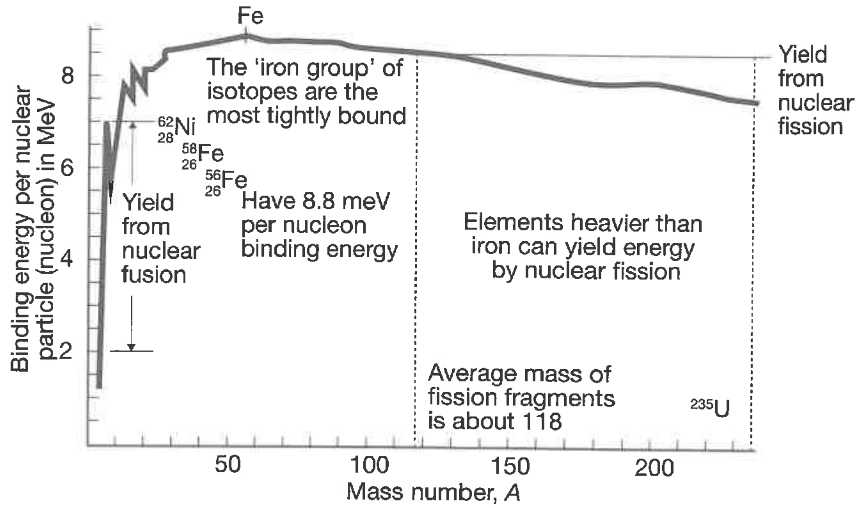
Use the following information to answer the next FOUR questions.

The graph shows how the binding energy per nucleon is related to the total number of nucleons in a nucleus (the mass number of an atom).



8.24.1.15 Consider the two nuclei $^{7}_{3}Li$ and $^{56}_{26}Fe$.

(a) Without making any calculations, which nucleus would have the greater total binding energy? Justify your answer.

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(b) Which has the greater binding energy per nucleon? ....

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(c) On this information alone, which of these two nuclei would be the most stable? Justify your answer.

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8.24.1.16 Use the graph to show that energy must be given off when a Ba-141 nucleus decays.

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8.24.1.17 Consider the following four theoretical nuclear transformations.

A: Breaking a nucleus of mass number 120 into two smaller nuclei of approximately equal mass number.

B: Fusing two nuclei of mass number 60 into one larger nucleus of mass number 120.

C: Breaking a nucleus of mass number 20 into two smaller nuclei of mass number 10 each.

D: Fusing two nuclei of mass number 10 into one larger nucleus of mass number 20.

(a) Which of these transformations would release energy? ....

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(b) Justify your answer. ....

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8.24.1.18 The binding energy per nucleon of uranium-235 is 7.59 MeV. What is its total binding energy?

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8.24.2 Nuclear reactions and mass defect 1.

8.24.2.1 Define mass defect. ....

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8.24.2.2 Explain the connection between binding energy and mass defect. ....

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8.24.2.3 A helium nucleus contains two protons and two neutrons. Which of the following statements is true?

(A) The mass of the nucleus is equal to the mass of the protons plus the mass of the neutrons.

(B) The mass of the nucleus is more than the mass of the protons plus the mass of the neutrons.

(C) The mass of the nucleus is less than the mass of the protons plus the mass of the neutrons.

(D) The mass of the nucleus is equal to the mass of the protons plus the mass of the neutrons plus the binding energy.

8.24.2.4 What is meant by the 'equivalence of mass and energy'?

(A) Mass and energy can be considered to be different forms of matter and are interchangeable.

(B) The laws of conservation of both mass and energy hold in any chemical or nuclear process.

(C) Mass is the same as energy.

(D) Mass can be converted into energy in a nuclear process.

8.24.2.5 The mass defect of a nucleus is 0.004356 *u*. What is its energy equivalent?

(A) 6.5×10^{-13} MeV (B) 4.06 MeV

(C) 4.06 J (D) 6.5×10^{-13} J

8.24.2.6 What, in joules, is the energy equivalent of 0.5 grams of iron?

(A) 4.5×10^{6} J (B) 4.5×10^{7} J

(C) 4.6×10^{14} J (D) 4.5×10^{17} J

8.24.2.7 A nuclear transmutation released 168 MeV of energy. What is the mass defect for this reaction?

(A) 0.018035 *u* (B) 0.001803 g

(C) 2.688×10^{-17} *u* (D) 0.18035 *u*

8.24.2.8 A nuclear transmutation released 5.6×10^{-14} J of energy. What is the mass defect for this reaction?

(A) 3.746×10^{-4} *u*

(B) 5.2165×10^{-11} *u*

(C) 5.83×10^{-28} *u*

(D) 5.994×10^{-31} *u*

8.24.2.9 Use the information about isotopes of some elements in the data table to answer this question.

Particle	Mass (amu)	Particle	Mass (amu)
$^{12}_{6}C$	12.00000	$^{7}_{3}Li$	7.0160
$^{1}_{1}H$	1.007825	$^{1}_{0}n$	1.0087
$^{2}_{1}H$	2.014102	$^{15}_{7}N$	15.000109
$^{4}_{2}He$	4.0026	$^{88}_{38}Sr$	87.9056
$^{92}_{36}Kr$	91.8973	$^{235}_{92}U$	235.0439
		$^{136}_{54}Xe$	135.9072

Find the mass defect in each of the following reactions.

(a) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{88}_{38}Sr + ^{136}_{54}Xe + 12^{1}_{0}n$

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....

....

(b) $^{12}_{6}C + ^{4}_{2}He \rightarrow ^{15}_{7}N + ^{1}_{1}H$

....

....

(c) $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He$

....

....

(d) Calculate the mass defect for a $^{92}_{36}Kr$ nucleus.

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(e) What does your answer to (b) indicate about this reaction?

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8.24.2.10 Explain the source of the energy released by a nuclear fission reaction. ....

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8.24.2.11 Explain the source of the energy released by a nuclear fusion reaction. ....

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8.24.2.12 In a typical fission reaction a neutron collides with a U-235 nucleus producing barium-141 and krypton-92 nuclei as well as a number of neutrons. Given:

Mass U-235 = 235.1170
Mass Ba-141 = 140.9139
Mass Kr-92 = 91.8973
Mass neutron = 1.008665
1 amu = 931.494 MeV

(a) Write a nuclear equation for the reaction. ....

....

(b) Calculate the mass defect for this reaction. ....

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(c) Calculate the energy released per fission. ....

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8.24.2.13

(a) What is meant by the 'equivalence of mass and energy'?

(A) Mass is the same as energy.
(B) Mass can be converted into energy in a nuclear process.
(C) Mass has an energy equivalent and energy has a mass equivalent.
(D) Mass and energy must be conserved in any chemical or nuclear process.

(b) Recall the equation which connects mass and energy. ....

....

8.24.2.14

(a) What is a correct statement for mass defect?

(A) The difference in mass between the products and reactants of a chemical reaction.
(B) The binding energy of the nucleons in a nucleus.
(C) The energy released in a nuclear reaction.
(D) The difference between the mass of a nucleus and the total mass of its component nucleons.

(b) In general, what is the relationship between mass defect and the size of a nucleus? Explain your answer.

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8.24.2.15

(a) A deuterium nucleus contains one proton and one neutron. Which of the following statements is true?

(A) The mass of the nucleus is equal to the mass of the proton plus the mass of the neutron.

(B) The mass of the nucleus is more than the mass of the proton plus the mass of the neutron.

(C) The mass of the nucleus is less than the mass of the proton plus the mass of the neutron.

(D) The mass of the nucleus is equal to the mass of the proton plus the mass of the neutron plus the binding energy.

(b) Explain your answer. ....

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8.24.2.16

(a) What is mass defect as it applies to a nuclear transmutation?

(A) The difference between the total mass of the products and the total mass of the reactants.

(B) The difference between the total mass of product atoms and the total mass of reactant atoms.

(C) The difference between the total mass of the reactants and the total mass of the products.

(D) The difference between the total mass of reactant atoms and the total mass of product atoms.

(b) Explain why the answer similar to the one you chose is incorrect. ....

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8.24.2.17 Calculate the mass defect, in amu, for nuclear reactions which release the following energies.

	Energy released (MeV or J)	Mass defect (amu)
(a)	2.36	
(b)	3.56	
(c)	9.51	
(d)	10.1	
(e)	13.6	
(f)	3.69×10^{-13} J	
(g)	7.72×10^{-13} J	
(h)	7.84×10^{-13} J	
(i)	1.04×10^{-12} J	
(j)	1.50×10^{-12} J	

8.24.2.18 Given the following mass information: ${}^{27}_{13}Al = 26.99008\ u$

${}^{4}_{2}He = 4.00260\ u$

${}^{23}_{11}Na = 22.99705\ u$

Calculate and account for the energy involved in the following nuclear reaction:

$${}^{27}_{13}Al \rightarrow {}^{23}_{11}Na + {}^{4}_{2}He$$

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8.24.3 Nuclear reactions and mass defect 2.

8.24.3.1 What name do we give to the energy equivalent of the mass defect?

(A) Nuclear energy. (B) Energy absorbed during reaction.

(C) Energy released during reaction. (D) Binding energy.

8.24.3.2 The mass defect of a deuterium nucleus is 0.002388 u. What is its energy equivalent?

(A) 3.57×10^{-13} MeV (B) 2.224 MeV (C) 2.224 J (D) 2.15×10^{14} J

8.24.3.3 What, in joules, is the energy equivalent of 1.0 grams of uranium?

(A) 931.5 J (B) 9×10^{6} J (C) 9×10^{13} J (D) 9×10^{16} J

8.24.3.4 A nuclear transmutation released 2.50 MeV of energy. What is the mass defect for this reaction?

(A) 0.0026838 u (B) 0.0026838 g (C) 2.78×10^{-11} u (D) 2328.75 u

8.24.3.5 A nuclear transmutation released 6.3×10^{-14} J of energy. What is the mass defect for this reaction?

(A) 7.0×10^{-31} u (B) 6.763×10^{-17} u (C) 5.868×10^{-11} u (D) 4.214×10^{-4} u

8.24.3.6 A nuclear reactor converts 2.5 kg of uranium fuel pellets to energy every hour. How much energy would be produced by this reactor each hour?

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8.24.3.7 Assuming 100% conversion to energy, which nuclear fuel would release the most energy per kilogram, uranium or hydrogen? Explain your answer.

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Use the following information to answer the next FOUR questions.

Refer to the information about isotopes of some elements in the data table.

Particle	Mass (amu)	Particle	Mass (amu)
$^{12}_{6}C$	12.00000	$^{7}_{3}Li$	7.0160
$^{1}_{1}H$	1.007825	$^{1}_{0}n$	1.0087
$^{2}_{1}H$	2.014102	$^{15}_{7}N$	15.000109
$^{4}_{2}He$	4.0026	$^{88}_{38}Sr$	87.9056
$^{92}_{36}Kr$	91.8973	$^{235}_{92}U$	235.0439
		$^{136}_{54}Xe$	135.9072

8.24.3.8 What is the mass defect in the following reaction?

$$^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He$$

(A) -0.9892 u (B) 0.01862 u

(C) 3.01340 u (D) 4.02128 u

8.24.3.9 What, in joules, is the energy released in the following reaction?

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{88}_{38}Sr + ^{136}_{54}Xe + 12^{1}_{0}n$$

(A) 1.67×10^{-9} J (B) 2.35×10^{-11} J (C) 2.03×10^{-13} J (D) 2.16×10^{-14} J

8.24.3.10 What is the mass defect for a lithium nucleus?

(A) -0.0414 u (B) 0.0422 u (C) 0.9664 u (D) 3.9925 u

8.24.3.11

(a) What is the mass defect for the following reaction?

$$^{12}_{6}C + ^{4}_{2}He \rightarrow ^{15}_{7}N + ^{1}_{1}H$$

(A) -0.005334 u (B) -1.002491 u (C) 0.005334 u (D) 4.007934 u

(b) What does this value indicate? ....

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8.24.4 Nuclear reactions and mass defect 3.

Use the following information to answer the next THREE questions.

Refer to the table to answer the questions.

Particle	Mass (amu)
$^{27}_{13}Al$	26.99008
$^{11}_{5}B$	11.012795
$^{141}_{56}Ba$	140.9139
$^{8}_{4}Be$	8.00785
$^{0}_{-1}e$	0.000549
$^{1}_{1}H$	1.0078825
$^{2}_{1}H$	2.014102
$^{3}_{2}He$	3.016029
$^{4}_{2}He$	4.00260
$^{19}_{9}F$	19.004448
$^{92}_{36}Kr$	91.8973
$^{139}_{57}La$	138.8061
$^{7}_{3}Li$	7.016003
$^{95}_{42}Mo$	94.9057
$^{1}_{0}n$	1.008665
$^{14}_{7}N$	14.003074
$^{15}_{7}N$	15.000108
$^{23}_{11}Na$	22.99705
$^{16}_{8}O$	16.000000
$^{17}_{8}O$	16.999131
$^{226}_{88}Ra$	226.09600
$^{222}_{86}Rn$	222.08690
$^{88}_{38}Sr$	87.9056
$^{235}_{92}U$	235.1170
$^{136}_{54}Xe$	135.9072

8.24.4.1 Calculate the energy released when one atom of U-235 undergoes the following reaction. Give your answer in MeV and joules.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{95}_{42}Mo + ^{139}_{57}La + 2(^{1}_{0}n) + 7(^{0}_{-1}e)$$

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8.24.4.2 Find the energy released in the following reactions in MeV and joules.

(a) $^{14}_{7}N + ^{2}_{1}H \rightarrow ^{15}_{7}N + ^{1}_{1}H$

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(b) $^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$

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(c) $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He$

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(d) $4(^{1}_{1}H) \rightarrow ^{4}_{2}He + 2(^{0}_{-1}e)$

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(e) $${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3({}^{1}_{0}\text{n})$$

(f) $${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{136}_{54}\text{Xe} + {}^{88}_{38}\text{Sr} + 12({}^{1}_{0}\text{n})$$

(g) $${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{3}_{2}\text{He} + {}^{1}_{0}\text{n}$$

(h) $${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

(i) $${}^{11}_{5}\text{B} + {}^{1}_{1}\text{H} \rightarrow {}^{8}_{4}\text{Be} + {}^{4}_{2}\text{He}$$

(j) $${}^{19}_{9}\text{F} + {}^{1}_{1}\text{H} \rightarrow {}^{16}_{8}\text{O} + {}^{4}_{2}\text{He}$$

8.24.4.3 Explain your answer to (b) above.

8.25 Model and explain the process of nuclear fission and nuclear fusion, including the concepts of controlled and uncontrolled chain reactions, and account for the release of energy in the process.

8.25.1 Nuclear fission and fusion.

A Nuclear fission

8.25.1.1

(a) Clarify the concept of nuclear fission.

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(b) What is the source of the energy released during nuclear fission reactions?

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(c) In general, which elements undergo nuclear fission?

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(d) Explain why it is these elements that undergo fission rather than fusion.

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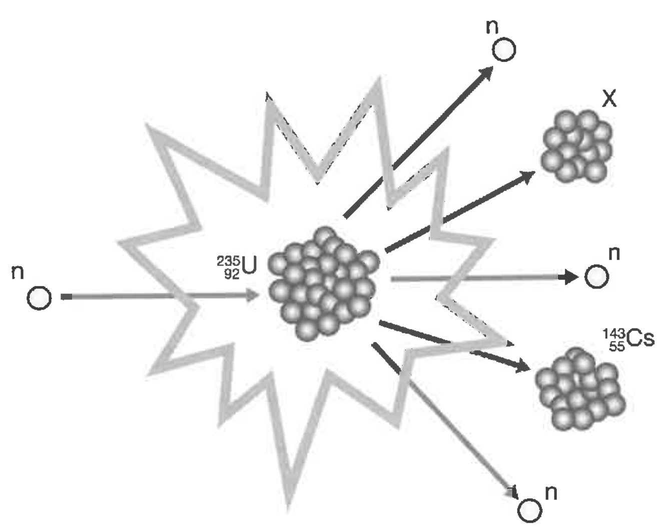
8.25.1.2 The diagram represents the fission reaction of U-235 following neutron bombardment.



(a) Identify the unlabelled nuclide X.

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(b) Write the nuclear equation for the fission reaction (be careful).

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(c) One product has been omitted from the diagram. What is it?

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(d) What is the significance in this particular reaction of the release of three neutrons as product?

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B Nuclear fusion

8.25.1.3

(a) Clarify the concept of nuclear fusion.

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(b) What is the source of the energy released during nuclear fusion reactions?

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(c) In general, which elements undergo nuclear fusion?

....

(d) Explain why it is these elements that undergo fusion rather than fission.

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8.25.1.4 State the conditions required for a spontaneous nuclear fusion reaction to occur. ....

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8.25.1.5 Consider these two statements made by students to define binding energy.

Student 1: Binding energy is the energy required to split an atom into its component parts.

Student 2: Binding energy is the energy released when the nucleons that make up a nuclide combine to form that nuclide.

Which student is correct? Justify your answer. ....

....

C Comparing the energy involved

8.25.1.6 The equations show a U-235 fission reaction and a simplified version of the hydrogen fusion reaction occurring in the Sun. The table shows the masses of the nucleons and isotopes involved in these reactions.

$${}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{90}_{37}Rb + {}^{143}_{55}Cs + 3({}^{1}_{0}n)$$

$$4({}^{1}_{1}H) \rightarrow {}^{4}_{2}He + 2({}^{0}_{1}\beta)$$

(Note that the hydrogen fusion in the Sun occurs in several steps; the equation above simply summarises the net result in one step.)

Particle	Mass (amu)
${}^{1}_{1}H$	1.007276
${}^{1}_{0}n$	1.008664
${}^{4}_{2}He$	4.002602
${}^{235}_{92}U$	235.04393
${}^{90}_{37}Rb$	89.91380
${}^{143}_{55}Cs$	142 92735
${}^{0}_{1}\beta$	0.0005486

(a) Complete the following table by calculating the quantities indicated.

(a)	Mass defect for the U-235 fission reaction in amu	
(b)	Energy released in MeV	
(c)	Mass defect for the U-235 fission reaction in kg	
(d)	Energy released in joules	
(e)	Mass of one U-235 atom in kg	
(f)	Energy released per kg of U-235 fission	
(g)	Mass defect for the hydrogen fusion reaction in amu	
(h)	Energy released in MeV	
(i)	Mass defect for the hydrogen fusion reaction in kg	
(j)	Energy released in joules	
(k)	Mass of fusion reactants in kg	
(l)	Energy released per kg of fusion atoms	

(b) Comment on the relative amounts of energy released in the fusion and fission reactions.

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(c) Explain why the energy amounts calculated in (b) and (h) or (d) and (j) were not used to compare these processes.

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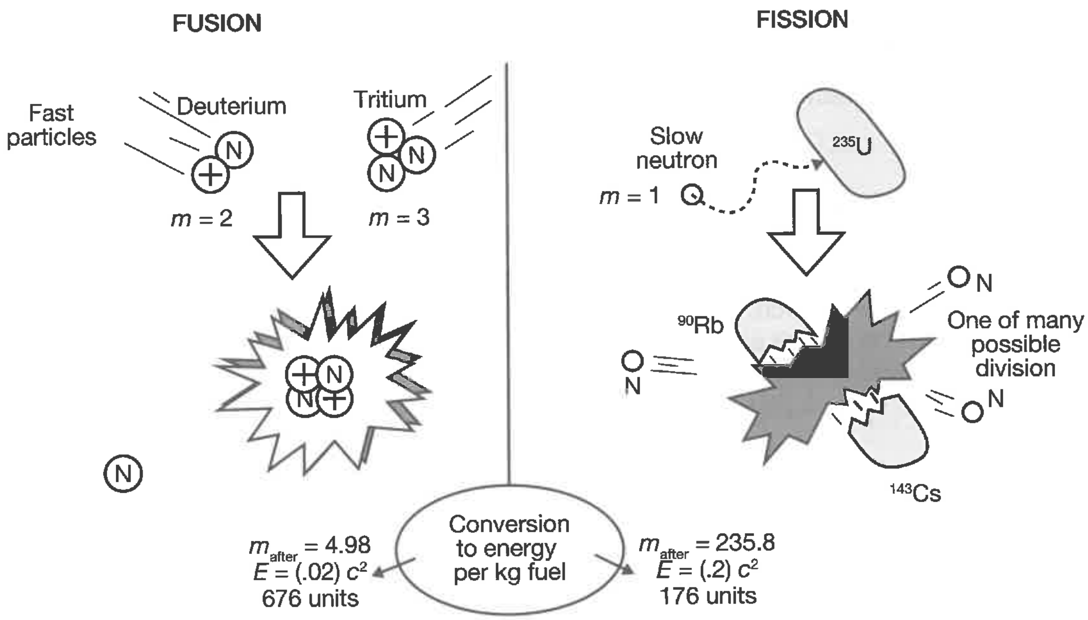
8.25.1.7 The diagram shows a typical fusion and fission reaction and the energy released by 1 kg of fuel in each. In the diagram, I unit of energy represents the amount of energy used by a person during one year.



(a) According to this information, which reaction produces the greater mass defect? Justify your answer.

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(b) If these are typical examples of fusion and fission reactions, which one would be better to use as a source of energy? Justify your answer.

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(c) Account for the fusion reaction being the better to use to produce nuclear energy in spite of the fact that the mass defect is 10 times the size in the fission reaction.

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8.25.2 Neutron induced fission.

8.25.2.1 What is involved in neutron induced fission? ....

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8.25.2.2 Why was the discovery of the neutron significant for artificial nuclear transformations?

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8.25.2.3 One observation of neutron induced nuclear transformations puzzled scientists. What was this observation?

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8.25.2.4 Outline the two different types of transformation different speed neutrons were observed to cause.

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8.25.2.5 What did this observation (see above) and prediction lead to? ....

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8.25.2.6 By 1939 it was known that during neutron induced transformations, a small number of neutrons were often released as a product. Why did this excite scientists at the time?

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8.25.2.7

(a) When a neutron is absorbed into a nucleus, that nucleus does not necessarily become a new element. It may become a heavier isotope of that element. Clarify this statement using as your example an atom of N-14 being bombarded with a neutron. Include the equation for the transformation.

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(b) In gaining an extra neutron an element might become a radioactive isotope. It would then break down by emitting a beta particle. Clarify this by considering K-35 gaining a neutron to form X which then undergoes beta decay, to form Y. Identify X and Y. Include equations for the reactions.

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8.25.2.8 The diagram shows the neutron induced fission of U-235.

(a) Write the nuclear equation for the neutron capture reaction.

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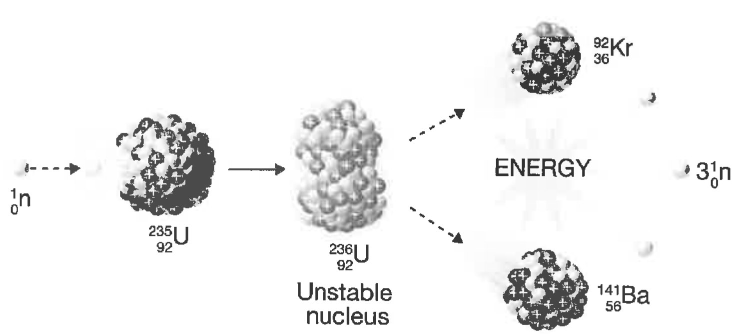
(b) Write the equation for the fission reaction for the product of the neutron capture.

....

(c) What is the significance of the additional neutrons released in the fission reaction?



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8.25.3 The uranium decay series.

8.25.3.1 Using information from the table on the next page, write equations for the following nuclear transformations.

(a) Polonium-214 emits an alpha particle

(b) Thallium-210 emits a beta particle

(c) Lead-212 decays to form bismuth-212

(d) Bismuth-212 emits a beta particle

(e) X emits an alpha particle to form lead-208

(f) Y emits a beta particle to form nitrogen-14

(g) Uranium-232 emits an alpha particle

(h) Sodium-24 emits a beta particle

(i) X emits an alpha particle to form radon-222

(j) Y emits a beta particle to form barium-137

(k) X emits a beta particle to form magnesium-24

(l) Y emits an alpha particle to form a second alpha particle

(m) Alpha decay of Bi-211

(n) Beta decay of the product from (m)

(o) U-239 undergoes beta decay

(p) The product from (o) undergoes another beta decay

(q) Thorium-235 undergoes two successive beta decays

(r) Palladium-235 undergoes a beta decay

8.25.3.2 U-238 undergoes a series of alpha and beta decays to form Pb-206. How many of each are involved in the series? Show your reasoning.

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8.25.3.3 Complete the following general nuclear equations (identify nuclide Y relative to the starting nuclide X) to indicate what happens to X when alpha and beta radiations are released from it.

(a) ${}^{A}_{Z}X \rightarrow Y + {}^{4}_{2}He$

(b) ${}^{A}_{Z}X \rightarrow Y + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$

(c) Identify the particle represented by the symbol ${}^{0}_{0}\overline{v}$ which accompanies beta decay reactions.

8.25.3.4 The table shows the starting atom of each step in the uranium decay sequence as well as its atomic symbol, atomic number and mass number. Complete the table.

Element	Symbol	Atomic number	Mass number	Transmutation equation
Uranium	U	92	238	
Thorium	Th	90	234	
Protactinium	Pa	91	234	
Uranium	U	92	234	
Thorium	Th	90	230	
Radium	Ra	88	226	
Radon	Rn	86	222	
Polonium	Po	84	218	
Lead	Pb	82	214	
Bismuth	Bi	83	214	
Thallium	Tl	81	210	
Lead	Pb	82	210	
Bismuth	Bi	83	210	
Polonium	Po	84	210	
Lead	Pb	82	206	

8.26 Analyse relationships that represent conservation of mass-energy in spontaneous and artificial nuclear transmutations, including alpha decay, beta decay, nuclear fission and nuclear fusion.

8.26.1 Spontaneous and artificial transformations.

8.26.1.1

(a) Clarify the idea of a spontaneous nuclear reaction. ....

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(b) Which radioisotopes undergo spontaneous transformation? Explain why. ....

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8.26.1.2

(a) Clarify the idea of an artificial nuclear reaction. ....

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(b) Why are most artificial transformations done? ....

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(c) The scientist pictured carried out the first artificial transformation. Who is he, and when did he do this?

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....

(d) What important discovery did this experiment (answer (c)) eventually lead to?

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8.26.1.3

(a) The first particles used to bombard atomic nuclei to study atomic structure and to induce artificial nuclear reactions were positively charged protons and alpha particles. Explain why.

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(b) Identify two limitations of using these particles to bombard nuclei. ....

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(c) Explain why most artificial transformations done in laboratories in more modern times use neutrons as the 'bullet' to split the target nucleus apart.

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(d) What is the major limitation of using neutrons as bullets in nuclear transformations? ....

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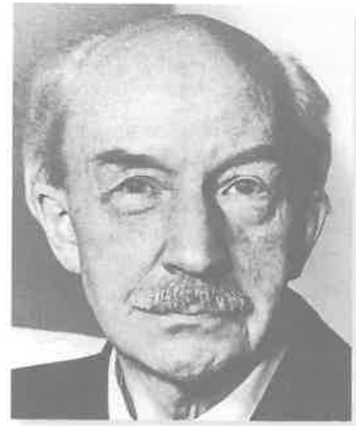
....

8.26.1.4 In 1930 Bothe and Becker used polonium-210 as an alpha particle source to bombard thin sheets of boron, lithium and beryllium metals in their experiments to study radioactivity. Use your knowledge to determine the nuclide produced in each transformation and then write an equation for each metal used.



Walther Bothe (1891-1957).

(a) Aluminium + alpha particle ....

....

(b) Magnesium + alpha particle ....

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(c) Sodium + alpha particle ....

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8.26.2 Nuclear reactors.

8.26.2.1

(a) Which choice best summarises the energy changes that occur in a nuclear reactor?

(A) Nuclear energy to heat energy to kinetic energy to electrical energy.

(B) Nuclear energy to kinetic energy to heat energy to electrical energy.

(C) Nuclear energy to heat energy to magnetic energy to electrical energy.

(D) Nuclear energy to heat energy to kinetic energy to magnetic energy to electrical energy.

(b) What is a steam turbine and what is it used for?

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8.26.2.2

(a) What is the purpose of the heat exchanger in a nuclear power station?

(A) This is where heat energy is absorbed by water flowing around the reactor and the water is boiled to produce steam.

(B) This is where heat energy absorbed by the reactor coolant is passed into water to boil it and produce steam.

(C) This is where heat energy absorbed by steam is passed into cool water which flows through the reactor.

(D) This is where steam is condensed back into liquid water so it can flow through the system again.

(b) Why isn't the coolant of the reactor used to heat water directly to produce the steam to run the turbine?

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8.26.2.3

(a) What name is given to the substance in a reactor that absorbs excess neutrons?

(A) Control rods. (B) Coolant.

(C) Fuel rods. (D) Moderator rods.

(b) Name a substance used for this purpose.

....

8.26.2.4

(a) What is the usual composition of the fuel rods in a nuclear reactor?

(A) U-238 pellets embedded in steel rods.

(B) U-238 and plutonium-239 pellets embedded in steel rods.

(C) U-238 enriched with U-235 as pellets embedded in steel rods.

(D) Plutonium-239 pellets embedded in steel rods.

(b) What is the difference between U-235 and U-238?

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8.26.2.5

(a) What substances can be used as coolants inside a nuclear reactor?

(A) Heavy water, liquid sodium, compressed hydrogen, water.

(B) Heavy water, air, liquid sodium, hydrogen, mercury.

(C) Liquid sodium, water, air, mercury.

(D) Water, heavy water, air, liquid sodium, helium.

(b) What is heavy water? ....

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8.26.2.6

(a) What is the purpose of the moderator rods in a nuclear reactor?

(A) To change U-235 into more reactive U-238.

(B) To produce neutrons so a chain reaction can be sustained.

(C) To slow down neutrons produced in the fission reactions so they can cause additional fission.

(D) To remove excess neutrons so the reaction can be controlled.

(b) What is the composition of moderator rods?

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8.26.2.7

(a) What is meant by the term 'critical mass'?

(A) This is the mass of fuel in a reactor that, if exceeded, would cause an uncontrolled reaction.

(B) This is the minimum mass of fuel in a reactor that is needed to sustain the chain reaction.

(C) This is the mass of fuel in a reactor needed before any reaction can commence.

(D) This is the mass of fuel remaining in the reactor after its fuel load has been used.

(b) What would happen if a fuel load much larger than the critical mass was used in a reactor?

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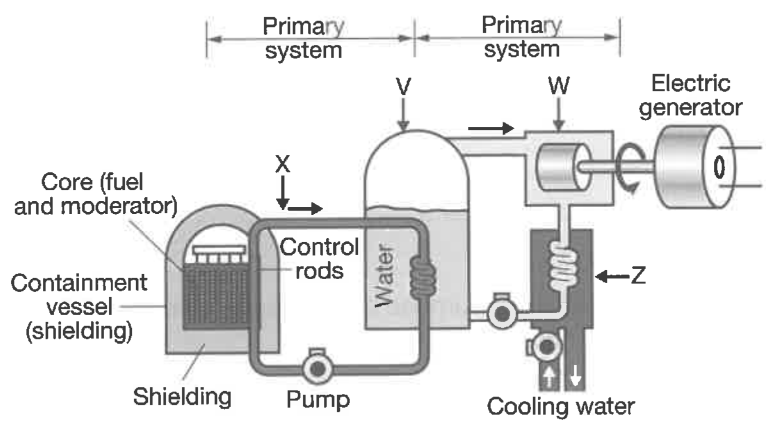
Use the following information to answer the next THREE questions.

The diagram shows the heat exchange units in a typical reactor used to generate electrical power.



8.26.2.8

(a) Which choice correctly identifies V, W, X and Z?

	V	W	X	Z
(A)	Heat exchanger	Turbine	Coolant	Condenser
(B)	Coolant	Condenser	Turbine	Heat exchanger
(C)	Heat exchanger	Turbine	Condenser	Coolant
(D)	Condenser	Coolant	Heat exchanger	Turbine

(b) What happens in Z? ....

....

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8.26.2.9

(a) What is most likely to be at V?

(A) Coolant water. (B) Hot water. (C) Reactor coolant. (D) Steam.

(b) What is its function? ....

....

8.26.2.10

(a) What does the pump do?

(A) Cycles steam through the turbines.

(B) Cycles coolant through the reactor and the heat exchanger.

(C) Cycles steam through the heat exchanger and the condenser.

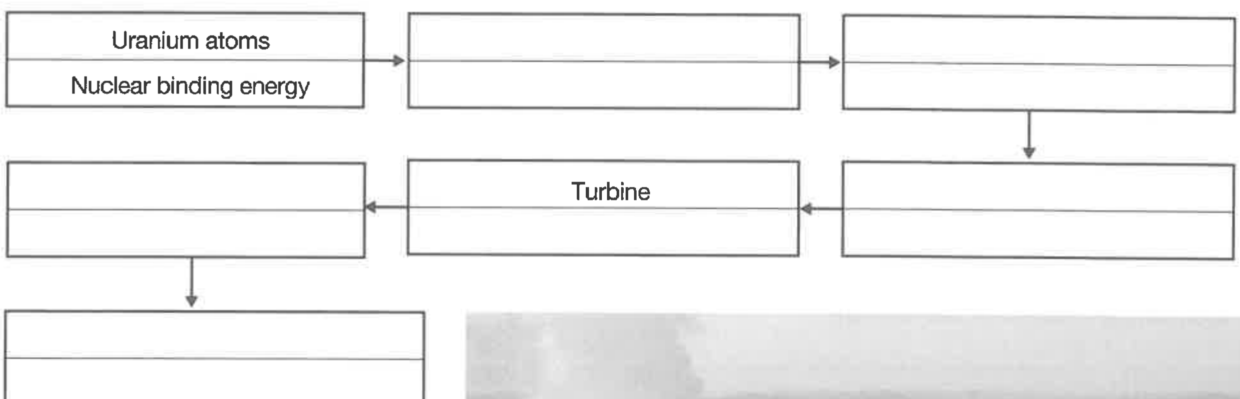
(D) Cycles coolant through the reactor and the condenser.

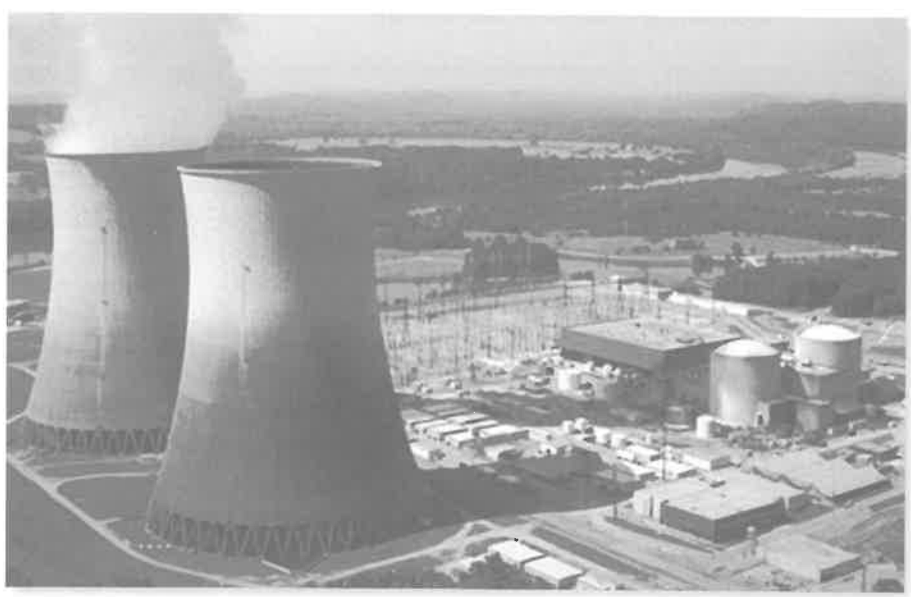
(b) What could happen if the pump broke down? ....

....

8.26.2.11 In a nuclear power station, the nuclear binding energy which holds particles in the nuclei of the uranium atoms is released in a controlled environment. This energy is used to heat the coolant which cycles through the reactor and then out into a heat exchanger. In the heat exchanger, the energy absorbed by the coolant is transferred to water which boils and produces steam. The steam is used to turn a turbine which rotates the mechanisms inside an electricity generator before going into a condenser where it turns back into liquid water and is pumped back into the heat exchange unit. In the condenser, which is really another heat exchange unit, the heat energy from the condensed steam passes into coolant water and then into the environment.

Complete the flow diagram to summarise the energy changes and where they occur in a nuclear power station as outlined in the passage above.





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Deep Inside the Atom

8.27 Analyse the evidence that suggests that protons and neutrons are not fundamental particles, and the existence of subatomic particles other than protons, neutrons and electrons.

INQUIRY QUESTION

How is it known that human understanding of matter is still incomplete?

8.27.1 The standard model.

8.27.1.1 Outline the standard model of the atom.

8.27.1.2 Before the development of the standard model of matter, the particles which were regarded as fundamental particles were the proton, neutron and electron.

(a) Define a 'fundamental' particle.

(b) Recall the fundamental particles according to the standard model.

(c) What were the fundamental particles in the previous model (the Bohr model)?

(d) Identify the reason for the change.

8.27.1.3 What is the general name given to force particles in the standard model?

8.27.1.4

(a) What causes scientists to think about changing the models they have to describe things, like their model for the structure of matter?

(b) Does the need to make changes indicate that the old models are wrong? Explain your answer.

(c) What is often the stimulus that leads to changes in existing models?

(d) What technology has been used to modify the model of the atom since the mid 1900s?

(e) What is the basic logic behind the development of particle accelerators that have been used to enhance our knowledge of the structure of matter?

8.27.1.5 Suppose at some time in the future, it is found that quarks are actually composed of even smaller particles.

(a) Will this mean that the standard model is wrong? Explain.

(b) What will this mean for our ideas about quarks and fundamental particles?

8.28 Investigate the standard model of matter, including quarks, and the quark composition hadrons, leptons and the fundamental forces.

8.28.1 Components of the standard model.

8.28.1.1 What are the fundamental particles in the standard model of matter?

(A) Baryons, hadrons and leptons.
(B) Protons, neutrons and electrons.
(C) Quarks only.
(D) Quarks and leptons.

8.28.1.2 What are hadrons?

(A) Nucleons with two quarks only.
(B) Nucleons with three quarks only.
(C) Nucleons with of two or three quarks
(D) Nucleons with more than two quarks.

8.28.1.3 Which of the following is a baryon?

(A) Electron. (B) Gluon.
(C) Neutron. (D) Neutrino.

8.28.1.4 Which choice contains only hadrons?

(A) Baryons and mesons.
(B) Bosons, baryons and leptons.
(C) Protons, neutrons and electrons.
(D) Protons, neutrons and leptons.

8.28.1.5 How many different types of quarks are there?

(A) 5 (B) 6 (C) 8 (D) 10

8.28.1.6 What does the nucleus of an atom contain?

(A) Baryons and mesons.
(B) Baryons and bosons.
(C) Baryons and hadrons.
(D) Hadrons and electrons.

8.28.1.7 What is a fundamental particle?

(A) One which is not made up of other particles.
(B) One which is composed of two or more other particles.
(C) Particles contained in the nucleus.
(D) Particles in the nucleus plus electrons.

8.28.1.8 Which choice contains all quarks?

(A) Angry, charm, happy, strange.
(B) Charm, top, bottom, tau.
(C) Strange, normal, top bottom.
(D) Up, down, charm, strange.

8.28.1.9 Which choice correctly identifies the quark make-up of a proton and a neutron?

	Proton	Neutron
(A)	u,d,d	u,u,u
(B)	u,d,d	u.u.d
(C)	u,u,d	u,d,d
(D)	u,u,d	d,d,d

8.28.1.10 Which statement about baryons and mesons is correct?

(A) Baryons are made up of two quarks, mesons of three quarks.
(B) Baryons are made up of three quarks, mesons of two quarks.
(C) They are both made up of two quarks.
(D) They are both made up of three quarks.

8.28.1.11 A new particle which is composed of five quarks has recently been discovered. What would it be?

(A) A baryon.
(B) A boson.
(C) A fundamental particle.
(D) A meson.

8.28.1.12 What are bosons in the standard model?

(A) Particles composed of two quarks.
(B) Particles composed of three quarks.
(C) A type of lepton.
(D) Force particles.

8.28.1.13 Define and give examples of quarks.

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8.28.1.14 Recall the quark composition of:

(a) A proton. ....

(b) A neutron. ....

8.28.1.15 When and why was the standard model of matter put forward?

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8.28.1.16

(a) What is a nucleon? ....

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(b) Give two examples. ....

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8.28.1.17 How does a hadron differ from a baryon?

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8.28.1.18

(a) What is an antiparticle? Give an example.

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(b) What happens when matter and antimatter meet?

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8.28.1.19 Identify the baryons which make up all matter that we see normally

....

8.28.2 More about quarks.

8.28.2.1 Complete the tables to show the different quarks and some of their properties.

Quark	Generation	Symbol	Charge

Antiquark	Generation	Symbol	Charge

Use the following information to answer the next TWO questions.

The table shows the charges on the six different quarks, but their names are not given.

Quark	E	F	G	H	I	J
Charge	$+\frac{2}{3}e$	$-\frac{1}{3}e$	$-\frac{1}{3}e$	$+\frac{2}{3}e$	$-\frac{1}{3}e$	$+\frac{2}{3}e$

8.28.2.2

(a) Which quarks could combine to make a proton?

(A) EFG

(B) EEI

(C) FFI

(D) EHJ

(b) Suggest another combination which could make up a proton. ....

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8.28.2.3

(a) Which quarks could combine to make a neutron?

(A) FFE

(B) EEF

(C) GHH

(D) JGI

(b) Suggest another combination which could make up a neutron.

8.28.2.4 Quarks combine in different ways to produce other, larger particles. Describe the quark content of each of these other types of particles.

8.28.2.5 Quarks, being fermions, must obey the Pauli exclusion principle. State this principle.

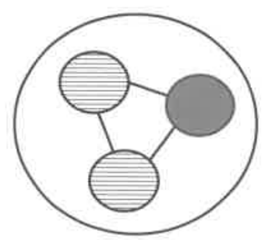
8.28.2.6 Although there are six different quarks identified, only two make up all the matter we know.

(a) What are these two quarks?

(b) When do we observe the other quarks?

8.28.2.7 List the four quantum numbers by which fermions are classified.

8.28.2.8 The diagram represents an antiproton.

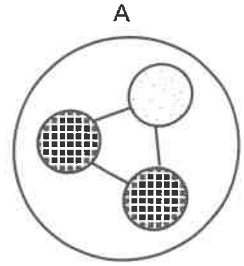


(a) What do the grey circles within the larger circle represent?

(b) Identify the specific particles represented by each of the smaller grey circles.

These two diagrams represent a proton and a neutron.

A



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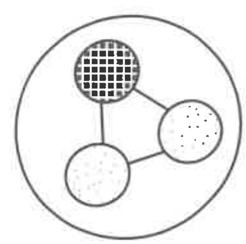
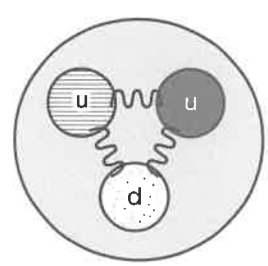


(c) Which is which? Justify your answer.

(d) This diagram represents a proton. What do the wriggly lines between the quarks represent?



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8.28.3 More about leptons.

8.28.3.1 What are leptons? ....

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....

8.28.3.2 Complete the table to show the leptons and some of their properties (the masses have been given).

Lepton	Generation	Symbol	Mass (compared to electron = 1)	Charge	Spin	Baryon number	Lepton number	Antilepton symbol
			1					
			0					
			200					
			0.5					
			3700					
			62					

8.28.3.3 It has been found extremely difficult to get accurate measures of the masses of quarks, but relatively easy to get the masses of the leptons. Explain why this is so.

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8.28.3.4

(a) Only two leptons are found in normal matter. Which ones? ....

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(b) When are the other leptons observed? ....

....

8.28.3.5

(a) What are quantum numbers? ....

....

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(b) What are quantum numbers used for? ....

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8.28.4 The four fundamental forces.

8.28.4.1 Answer the questions below, given the following.

$F_G = \frac{Gm_1m_2}{r^2}$ and $F_E = \frac{Kq_1q_2}{r^2}$ Where $G = 6.673 \times 10^{-11}$ N m^2 kg^{-2}

$K = 9 \times 10^9$

m = mass of proton = 1.673×10^{-27} kg

q = charge on proton = 1.6×10^{-19} C

r = distance between protons in a nucleus = 1.0×10^{-15} m

(a) Use Newton's gravitational force equation to calculate the gravitational force between two protons in a nucleus.

...

(b) Use the Coulomb's law equation for the force between two electrostatic charges to calculate the electrostatic force between two protons in a nucleus.

...

(c) Calculate the ratio of the electrostatic force between two protons in a nucleus to the gravitational force between them.

...

(d) Use the ratio to find the relative strength of the electrostatic force compared to the gravitational force.

...

(e) Analyse the implications of this for the stability of a nucleus with two protons. ...

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...

(f) Compare this with the situation for a nucleus with many protons. ...

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8.28.4.2 Complete the following table to show some information about the four fundamental forces.

Fundamental force	Particle(s) responsible for the force	Strength relative to gravitational force = 1	Distance over which the force acts (m)

8.28.4.3 The graviton, responsible for the gravitational force, has yet to be discovered.

(a) What significance will its discovery have for the standard model? ...

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...

(b) Suppose it is never discovered. What significance will this have for the standard model?

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8.28.5 More about bosons.

8.28.5.1 What name is collectively given to the particles responsible for the fundamental forces?

(A) Bosons. (B) Gluons.
(C) Mesons. (D) Photons.

8.28.5.2 Which of the following is a boson?

(A) The baryon. (B) Leptons.
(C) Photons. (D) Quarks.

8.28.5.3 Which particle is responsible for the strongest force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z.
(D) The photon.

8.28.5.4 Which particle is responsible for the weakest force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z
(D) The photon.

8.28.5.5 What particle(s) is/are responsible for the force that acts over the largest distance?

(A) The gluon and photons
(B) Photons and W and Z particles.
(C) The W^+, W^- and Z particles.
(D) The graviton and photons.

8.28.5.6 What particle(s) is/are associated with the force that acts over the shortest distance?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z particles.
(D) Photons.

8.28.5.7 What particle is responsible for the strong nuclear force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z
(D) The photon.

8.28.5.8 What particle is responsible for the electromagnetic force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z.
(D) The photon.

8.28.5.9 What particle is responsible for the gravitational force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z.
(D) The photon.

8.28.5.10 What particle is responsible for the weak nuclear force?

(A) The gluon.
(B) The graviton.
(C) The W^+, W^- and Z.
(D) The photon.

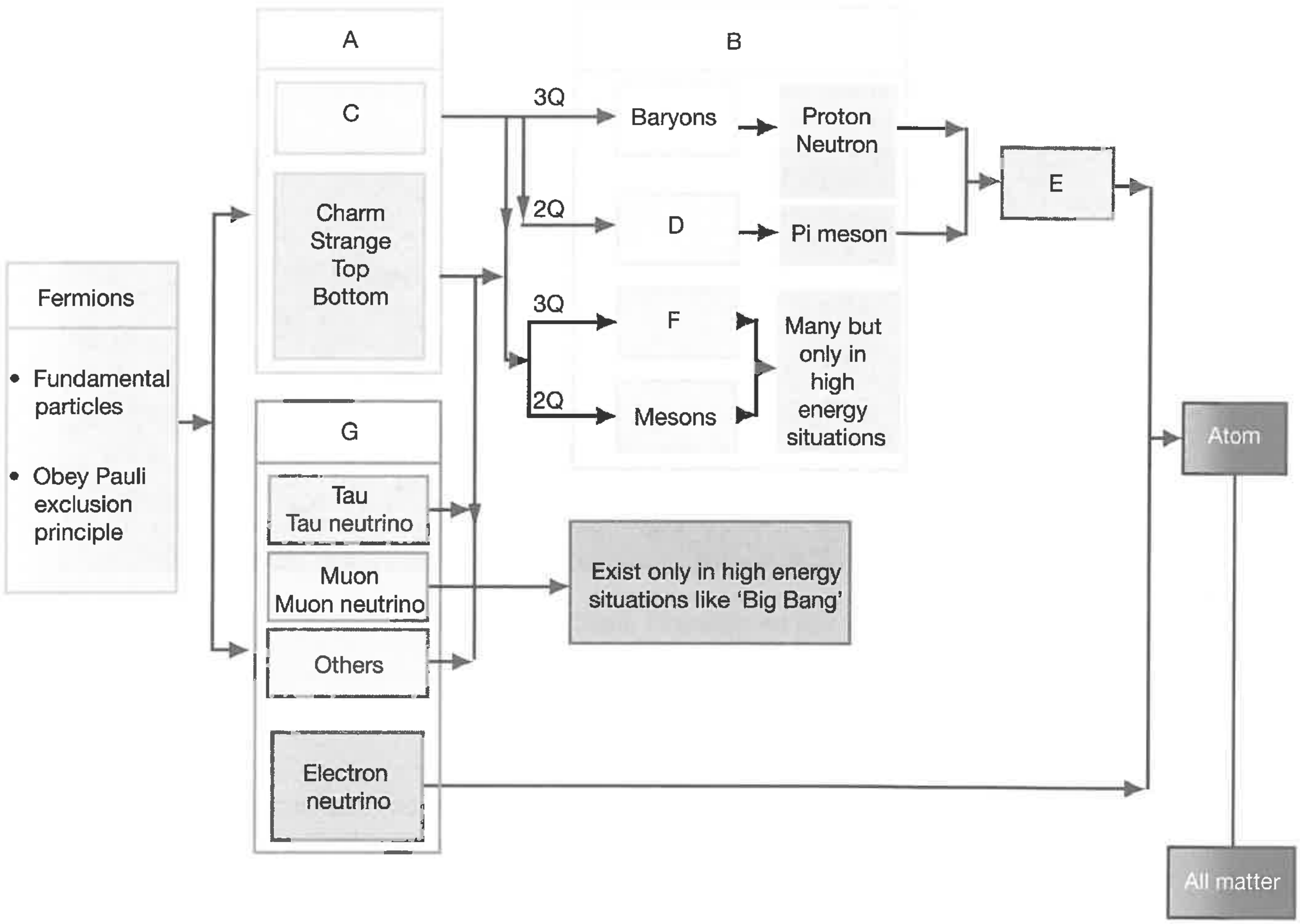
8.28.5.11 How do the force particles act in an interaction between particles?

(A) They move the particles into positions where the interaction can occur.
(B) They push the particles closer together so that the interaction can occur.
(C) They either push the particles closer together or force them apart during the interactions.
(D) They are either emitted or absorbed by the particles.

Bosons (force carriers)	
Photon	Massless, no charge, electromagnetic force carrier.
b g r Gluons	High mass, colour charge (blue, green, red), strong force carrier.
W^+ W^- Z	High mass, weak force carrier.
Graviton	Massless, no charge, gravity force carrier.

8.28.6 Summarising the standard model.

8.28.6.1 The following diagram represents the standard model of matter. Note that it does not include all the particles that have been identified in matter.



(a) Complete the diagram by identifying the missing labels for A to G.

A ....

B ....

C ....

D ....

E ....

F ....

G ....

(b) There is now some evidence that quarks are not fundamental particles. What does this mean, and what effect will it have on this diagram if it is true?

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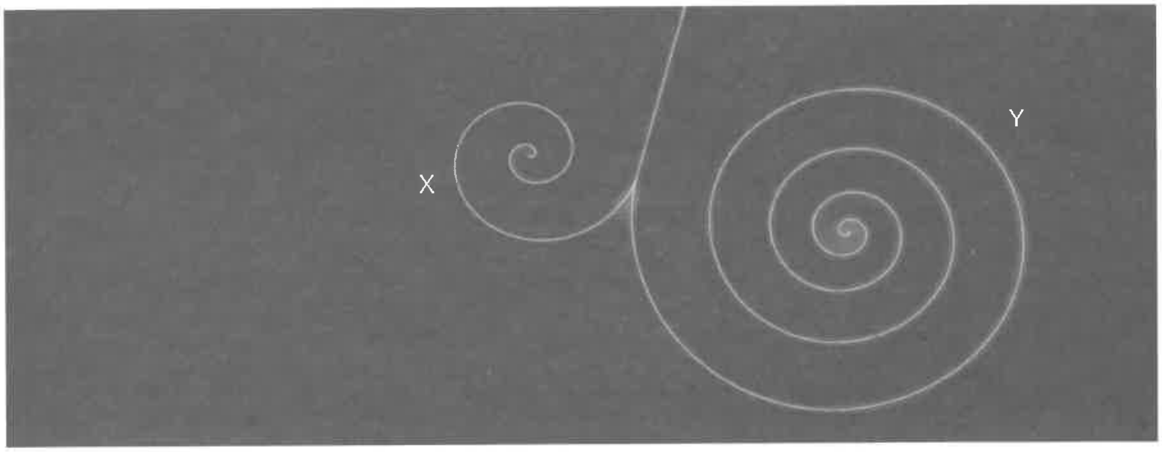
8.29 Investigate the operation and role of particle accelerators in obtaining evidence that tests and/or validates aspects of theories, including the standard model of matter.

8.29.1 Uncovering matter particles.

8.29.1.1 The diagram shows the track left by a high energy particle as it travels through a bubble chamber until it collides with another particle resulting in the formation of two new particles. The tracks of the new particles, X and Y are also shown.



(a) What properties of X and Y must be different? Justify your answer. ....

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(b) Assuming the charges on X and Y are the same magnitude, what conclusion could be drawn about X and Y if they were particles which had the same mass? Justify your answer

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(c) Assuming the charges on X and Y are the same magnitude, what conclusion could be drawn about X and Y if they were emitted from the collision point with the same speed? Justify your answer.

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(d) Explain why the cloud chamber tracks for both X and Y follow a spiral path. ....

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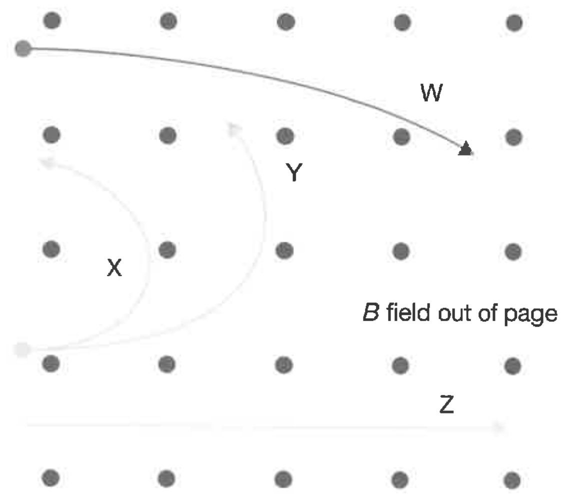
8.29.1.2 The diagram shows four particle tracks in a cloud chamber and the direction of the applied magnetic field (out of the page)



(a) Describe the nature of the charge on each of the four particles.

W = ...

....

X = ...

....

Y = ...

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Z = ...

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(b) Assuming that the magnitude of the charge on each particle is the same (except Z of course), compare their masses. Justify your answer.

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8.29.1.3 Why did scientists start to build machines to accelerate charged particles?

(A) Fast particles are not produced naturally.

(B) They realised that high energy particles would be more useful in studying matter.

(C) Fast particles were needed to cause nuclear reactions in reactors.

(D) The faster a particle moves, the greater its relativistic mass.

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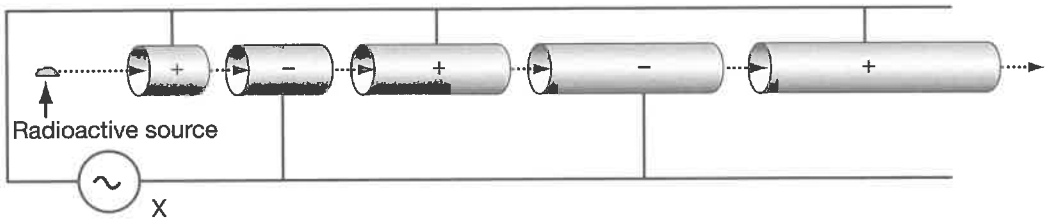
8.29.2 Nuclear accelerators.

Use the following information to answer the next FOUR questions.

The diagram shows one type of particle accelerator.



8.29.2.1

(a) What type of accelerator is this?

(A) Betatron. (B) Cyclotron.
(C) Linear accelerator. (D) Synchrotron.

(b) Identify the component represented by the symbol X.

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(c) Describe the function of this component.

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8.29.2.2

(a) What accelerates the particles in this type of accelerator?

(A) Electric fields between each of the charged tubes.
(B) Electric fields inside the charged tubes.
(C) Both the electric fields within the tubes and the fields between the tubes.
(D) Both electric and magnetic fields between the charged tubes.

(b) Explain how this happens.

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8.29.2.3

(a) Why is each successive tube longer than the one before it?

(A) To accelerate the particle to a higher speed within each tube.
(B) So that particles undergo acceleration for equal time in each tube.
(C) To take into account the changing frequency of the AC power supply.
(D) Because the particle is moving faster within each successive tube.

(b) Justify your answer. ....

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8.29.2.4

(a) The energy of a charged particle in an accelerator cannot be calculated by simply determining its kinetic energy. Why not?

(A) The particles will also have gravitational potential energy.
(B) The rest energy must be added to the kinetic energy.
(C) The relativistic mass increase of the particle needs to be considered.
(D) Its internal nuclear energy also needs to be considered.

(b) Justify your answer. ....

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Use the following information to answer the next FIVE questions.

The diagram shows two other types of accelerator.

Diagram X

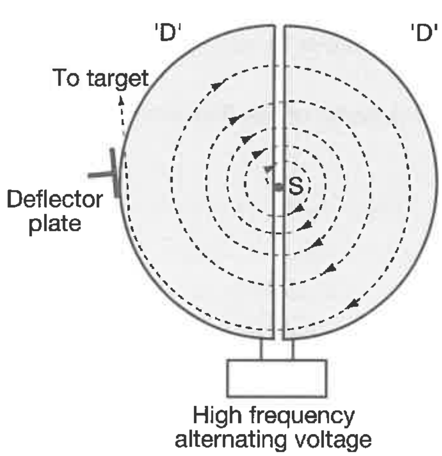
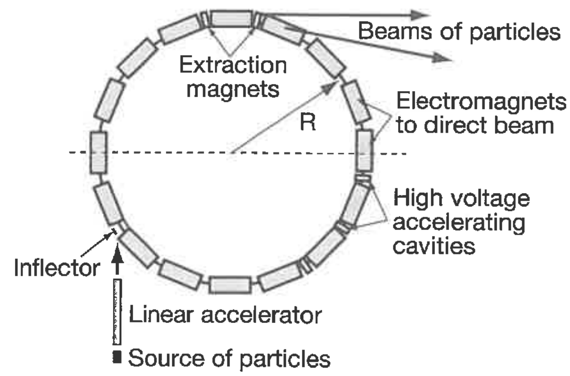


Diagram Y



8.29.2.5

(a) Which choice correctly identifies the types of accelerators shown?

	X	Y
(A)	Synchrotron	Cyclotron
(B)	Cyclotron	Synchrotron
(C)	Cyclotron	Circular linear
(D)	Circular linear	Cyclotron

(b) A vital component of both these accelerators is not shown. What is it and what is its function?

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8.29.2.6

(a) Which choice correctly indicates how the particles are accelerated in these accelerators?

(A) Both by magnetic fields.
(B) Both by electric fields.
(C) X by electric fields, Y by magnetic fields.
(D) X by magnetic fields, Y by electric fields.

(b) Justify your answer. ....

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8.29.2.7

(a) Diagram X has two parts labelled 'D'. What is the function of these parts?

(A) To provide magnetic fields to cause the particles to travel in a circular path.
(B) To provide electric fields to cause the particles to travel in a circular path.
(C) To provide magnetic fields to cause the particles to accelerate as they travel through each 'D'.
(D) To provide magnetic fields to cause the particle to travel in a straight line between each acceleration.

(b) Justify your answer. ....

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8.29.2.8

(a) Would these accelerators work on high voltage DC supply?

(A) Yes. Both DC and AC electric fields will accelerate charged particles.

(B) Yes. Both DC and AC electric voltages will react with the charged particles in the same way.

(C) No. DC voltages cannot be generated to high enough values to successfully accelerate the particles to near light speeds.

(D) No. An alternating voltage is needed to change the polarity of the field across successive accelerating tubes or gaps.

(b) Justify your answer. ....

....

8.29.2.9

(a) In any particle accelerator there is a limit to the speed that a particle can be accelerated regardless of the size or strength of the accelerator. Why?

(A) There is a limit to the size of the magnetic fields that can be produced.

(B) The frequency of the AC supply limits their speed across the gaps.

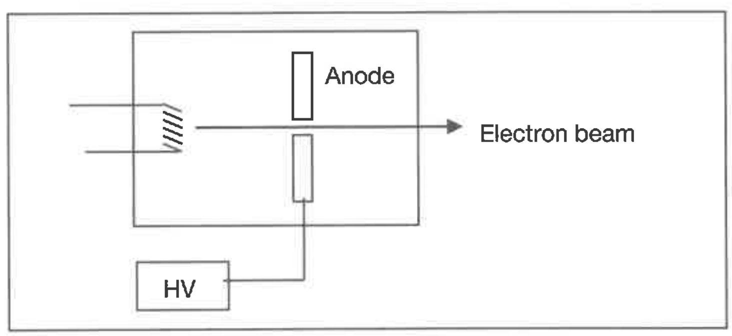
(C) At high speeds enormous forces are required to increase speed further.

(D) The acceleration that can be applied to the particles is limited in magnitude.

(b) Justify your answer. ....

....

8.29.2.10 The diagram represents an electron gun in a synchrotron. The high voltage source (HV) to the anode accelerates the electrons from the cathode to energies around 90 keV.



(a) What would be the speed of these 90 keV electrons?

....

....

....

(b) If each electron leaves the gun above with 6.4×10^{-15} J of energy, what is the potential difference between the cathode and the anode?

....

8.29.2.11 The ends of two consecutive tubes in a linear accelerator are 15 mm apart and have a potential difference of 12 000 V across them. A beam of electrons moving at 2×10^4 m s^{-1} travels across the gap between the two tubes. Calculate:

(a) The electric field between the tubes. ....

....

(b) The kinetic energy gained by each electron as it passes through the gap. ....

....

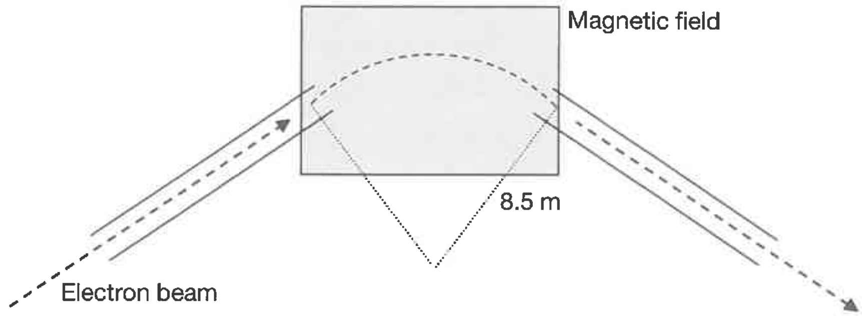
(c) The force on each electron due to the electric field. ....

....

(d) The acceleration of the electrons through the gap. ....

....

8.29.2.12 The diagram represents part of a storage ring in a synchrotron. The electrons in the beam travel through this section with a momentum of 9.0×10^{-19} kg m s^{-1}, and are bent through an arc of radius 8.5 m by an applied magnetic field.



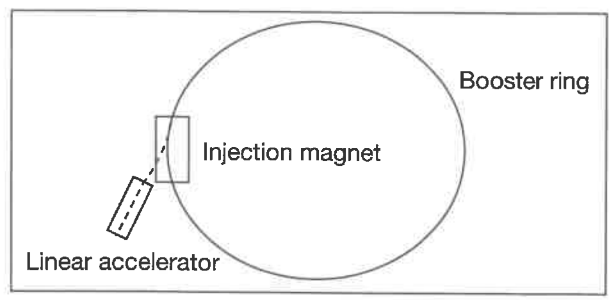
Given that the charge on each electron is 1.6×10^{-19} C, calculate the strength and direction of the magnetic field required to produce this change in direction.

....

....

....

8.29.2.13 The diagram shows the design of a synchrotron in which pulses of electrons, accelerated by a short linear accelerator, entering the booster ring, have their direction of travel adjusted by an injection magnet. Note that direction of the electrons as they leave the linear accelerator is not (necessarily) tangential to the booster ring.



(a) If the electrons leave the linear accelerator at 4.5×10^6 m s^{-1} and the strength of the magnetic field applied to them by the injection magnet is 2.25×10^{-4} T, what is the radius of the path of the electrons as they pass through the injection magnet?

....

....

....

(b) What prevents the electron beam from travelling in a straight line according to Newton's first law of motion, once it enters the booster ring?

....

....

(c) In the normal operation of the injection magnet it only operates for the fraction of a second needed to redirect the electron pulse into the booster ring. Imagine that its 'on/off' mechanism fails and that it is still on when the electron pulse completes a revolution through the booster ring.

Predict what would happen to the electron pulse. Justify your prediction. ....

....

....

....

....

8.29.3 The Higgs boson.

Note: This is not required by the syllabus.

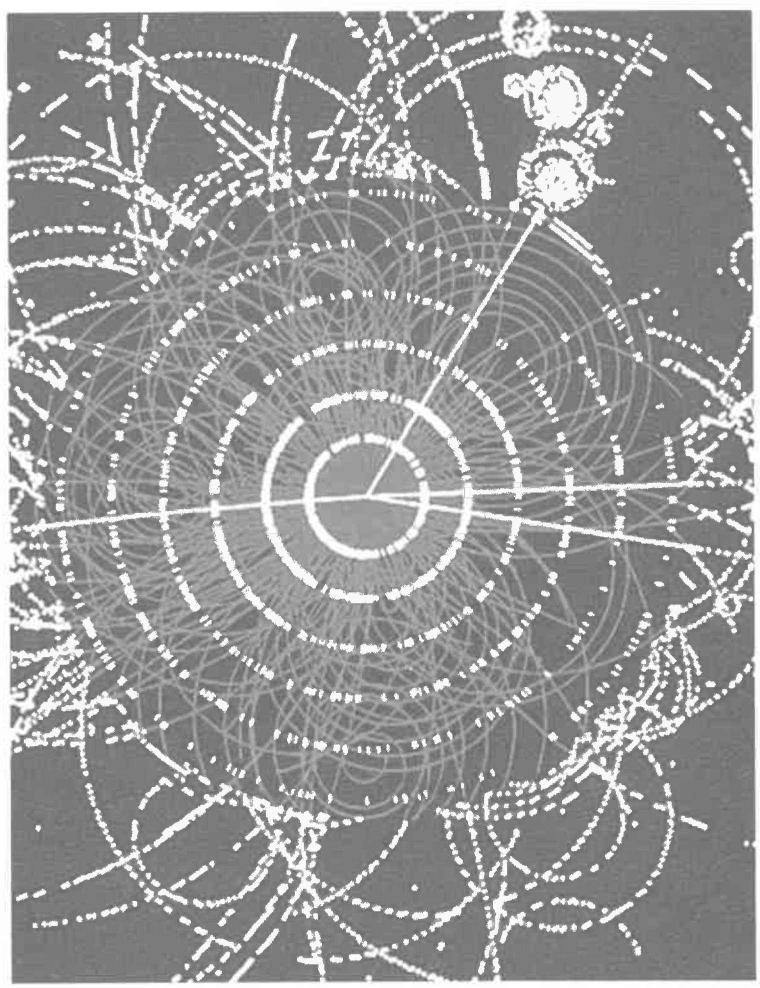
8.29.3.1 What is the Higgs boson? ....

8.29.3.2 Explain the Higgs field as proposed by the standard model. ....

8.29.3.3 Why was it so difficult to find the Higgs boson? ....

8.29.3.4 The popular nickname for the elusive particle, 'The God Particle' was created for the title of a book by Nobel Prize winning physicist Leon Lederman – reportedly against his will. Why was this term used?

....



8.29.3.5 What was the importance of the discovery of the Higgs boson to the standard model of matter?

....

DOT POINT

Answers

Module 5 Advanced Mechanics

5.1.1.1

	Horizontal component = vector cos θ	Vertical component = vector sin θ
(a)	30.6	25.7
(b)	43.3	25.0
(c)	112.8	41.0
(d)	45.1	31.6
(e)	33.8	72.5
(f)	49.8	41.8
(g)	49.1	34.4
(h)	20.5	56.4

5.1.2.1 B
5.1.2.2 D
5.1.2.3 C
5.1.2.4 A
5.1.2.6 C
5.1.2.6 A
5.1.2.7 A
5.1.2.8 B
5.1.2.9 C
5.1.2.10 D
5.1.3.1 C
5.1.3.2 D
5.1.3.3 D
5.1.3.4 B
5.1.3.5 (a) Answer will be the same.
(b) Answer will be the same.
(c) Answer will be the same.
(d) Answer will be the same.
5.1.4.1 C
5.1.4.2 D
5.1.4.3 C
5.1.4.4 A
5.1.4.5 A
5.1.4.6 C
5.2.1.1 Horizontal component of its motion is constant velocity (zero acceleration), while the vertical component is accelerated by gravity.
5.2.1.2 Horizontal component is 10.35 m s^{-1}, vertical component is 38.64 m s^{-1}.
5.2.1.3 Horizontal and vertical components of the motion of a projectile are independent of each other.
Horizontal component of its motion is constant velocity (zero acceleration).
Vertical component is constantly accelerated (by gravity).
5.2.1.4 (a) B
(b) Taking the upward direction as positive, then because the ball has landed vertically below its launch point, its final vertical displacement, and therefore its overall displacement is negative.
5.2.1.5 D
5.2.1.6 B
5.2.1.7 C
5.2.1.8 (a) A
(b) 45°
5.2.1.9 (a) B
(b) The acceleration of each is the same, equal to gravitational acceleration directed downwards. (1 : 1 : 1)
5.2.1.10 D
5.2.1.11 (a) D
(b) Positive and negative velocities refer to velocities in opposite directions to each other. Which one is taken as positive is purely up to the person doing the problem or analysis; there is no rule which defines this.
5.2.2.1 (a) A
(b) Which statement about the horizontal velocity of the projectile is correct?
5.2.2.2 D
5.2.2.3 B
5.2.2.4 C
5.2.2.5 A
5.2.2.6 (a) C
(b) 5.31 s
5.2.2.7 B
5.2.2.8 B
5.2.2.9 A
5.2.2.10 B
5.3.1.1 B
5.3.1.2 54.5 cm
5.3.1.3 115.5 m
5.3.1.4 39.1 m s^{-1}
5.3.1.5 (a) 6.32 s
(b) 948.7 m
(c) 162 m s^{-1} at 22.5° down from the horizontal
5.3.1.6 (a) 160 m s^{-1}
(b) 68.9 m
(c) Up at 164.2 m s^{-1} at 12.9° to the horizontal
5.3.1.7 55.4 m s^{-1} at 45° to the horizontal
5.3.1.8 (a) 49 m s^{-1}
(b) 122.5 m
5.3.1.9 (a) The ball fired at an elevation of 50° will rise higher but without actual figures, we are unable to determine by how much.
(b) Neither. They will both have a range of 251.2 m since the firing angles are complementary.

5.4.1.1 Using Pythagoras,

At $t = 1$, 17.92 = vector sum of v_y + 15

So $v_y^2 = 17.92^2 - 15^2$

Therefore $v_y = 9.8$ m s^{-1}

At $t = 2$, 24.68 = vector sum of v_y + 15

So $v_y^2 = 24.68^2 - 15^2$

Therefore $v_y = 19.6$ m s^{-1}

At $t = 3$, 33.01 = vector sum of v_y + 15

So $v_y^2 = 33.01^2 - 15^2$

Therefore $v_y = 29.4$ m s^{-1}

At $t = 4$, 41.97 = vector sum of v_y + 15

So $v_y^2 = 41.97^2 - 15^2$

Therefore $v_y = 39.2$ m s^{-1}

So, change in velocity each second = 9.8 m s^{-1}, so acceleration is constant at 9.8 m s^{-2} which is consistent with Galileo's analysis.

5.4.1.2 D (A) and (B) incorrectly show constant vertical motion, while (C) does not show constant horizontal motion.

5.4.1.3 (a) Each space in the diagram represents one unit of time = inverse of the frequency (2.5 Hz) = 0.4 s.

There are 10 spaces in the flight, so time of flight = 4 s.

(b) Maximum height = 4 spaces = 4 × 0.4 = 1.6 s

(c) From $v_{top} = 0 = u_{vertical} + at$

$0 = u - 9.8 \times 1.6$ (motion is upwards but gravity is downwards, so g is negative)

Therefore $u_{vertical} = 15.7$ m s^{-1} vertically upwards

(d) Time to fall from highest position = 2.4 s (6 spaces)

Therefore, from $s = ut + \frac{1}{2}at^2 = 0 + 4.9 \times 2.42^2$ = 28.2 m above the ground

(e) There is no mathematical data for this, so need to measure the range and the vertical height and apply the scale used to draw the diagram.

Vertical height = 28.2 m = 6.5 cm on the diagram

Therefore scale used in diagram is 1 cm = 4.34 m

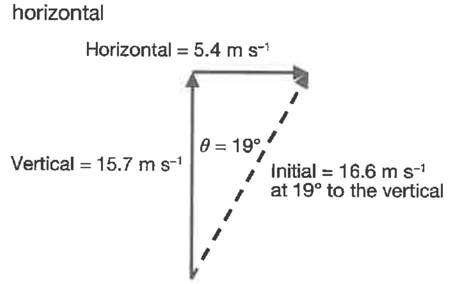
Therefore range, measured as 5.0 cm is = 4.34 x 5 = about 21.7 m (may be slight differences if using a photocopy)

(f) Time of flight = 4 s

Range = 21.7 m

Horizontal velocity is constant = $\frac{21.7}{4}$ = 5.4 m s^{-1} (your answer may vary a little)

(g) Initial velocity = vector sum of vertical and horizontal



Therefore initial velocity = about 16.6 m s^{-1} at 19° to the vertical (71° to the horizontal)

(h) About 3.4 × 4.34 = 14.3 m (tall guy eh!)

5.5.1.1

Mass	Weight
Amount of matter in an object	Measure of gravitational force on an object
Measured in kilograms	Measured in newtons
Does not vary	Varies as gravitational acceleration varies
Cannot be zero	Can be zero
Is a scalar quantity	Is a vector quantity

5.5.1.2 (a) $W_F = mg$

(b) $g = \frac{W_F}{m}$

(c) Gravitational field is the force per unit mass acting on a mass

(d) N m^{-1} and m s^{-2}

5.5.1.3 $g_X : g_Y = 9 : 4$

5.5.1.4 16 : 1

5.5.1.5 D

5.5.1.6 A

5.5.1.7 C

5.5.1.8 A

5.5.1.9 B

5.5.1.10 C

5.5.1.11 (a) A

(b) While the mass of the object would still be 8 kg, the scales that measure it rely on the compression of a spring and this relies on the value of the acceleration due to gravity – the scales are calibrated in kg, but actually work because of the weight of the object. Therefore, on Mars, the scale spring will only be compressed 0.38 times as far as on Earth – hence 0.38 × 8 = 3.04 kg.

5.5.1.12 C

5.5.1.13 C

5.5.1.14 C

5.5.1.15 B

5.5.1.16 A

5.5.1.17 D

5.5.1.18 A

5.5.1.19 A

5.5.2.1 Every object in the Universe attracts every other object with a gravitational force.

The force is directly proportional to the masses of the objects.

The force is inversely proportional to the square of the distance between them.

5.5.2.2 1.702×10^{20} N

5.5.2.3 (a) 247.95 N

(b) 24.795 m s^{-2}

5.5.2.4 9.75 m s^{-2}

5.5.2.5 $g_M : g_{4M} = 4 : 1$, therefore weight X : weight Y = 4 : 1

5.5.2.6 $g_M : g_P = 4.01 : 0.63 = 6.37 : 1$

5.5.2.7 6×10^{-8} N attraction

5.5.2.8 (a) Multiplies the force by 4

(b) Multiplies the force by 4

(c) Multiplies the force by 8

5.5.2.9 1.93×10^5 km

5.5.2.10 (a) 2.53×10^7 m

(b) Same altitude as (a) – field does not depend on the mass of the satellite, only the mass of the planet.

5.5.3.1 92.9 N

5.5.3.2 C

5.5.3.3 B

5.5.3.4 A

5.5.3.5 A

5.5.3.6 (a) D

(b) Mass never changes, and at the centre of the Earth, the gravitational pull on the mass due to the Earth would be equal (radially outwards) in all directions, so the net force on it would be zero.

5.5.3.7 C

5.5.3.8 C

5.5.3.9 A

5.5.3.10 (a) $0.25F$

(b) $4F$

(c) $2F$

(d) $9F$

(e) $0.5F$

(f) $\frac{F}{3}$

5.5.4.1 (a) $2F$

(b) $4F$

(c) $3F$

(d) F

(e) $0.25F$

(f) $4F$

(g) F

5.5.4.2 All these answers obtained using Newton's formula for gravity, $F = \frac{GMm}{r^2}$.

	Object 1	Mass 1 (kg)	Object 2	Mass 2 (kg)	Distance between objects (m)	Gravitational force between objects (N)
A	Football player	90	Earth	6.0×10^{24}	6.4×10^6	879.3
B	Tennis player	65	Earth	6.0×10^{24}	6.4×10^6	635.1
C	Physics student	55	Earth	6.0×10^{24}	6.4×10^6	537.4
D	Physics student	55	Physics student	55	5.0 m	8.07×10^{-9}
E	Physics student	55	Physics student	55	1.0 m	2.02×10^{-7}
F	Physics student	55	Surfing Physics book	1	0.5	1.47×10^{-8}
G	Physics student	55	Moon	7.34×10^{22}	1.74×10^6 (surface)	88.94
H	Physics student	55	Mercury	3.29×10^{23}	2.44×10^6 (surface)	202.1
I	Physics student	55	Mars	6.42×10^{23}	3.4×10^6 (surface)	203.74
J	Physics student	55	Jupiter	1.90×10^{27}	7.0×10^7 (surface)	1422.5

5.6.1.1 To examine the relationship between the time it takes an object to fall from various heights and the height from which it is dropped or, to examine the rate at which an object falls.

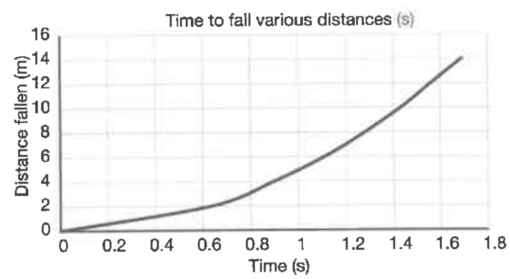
5.6.1.2 Object being dropped, stopwatch used, place where object dropped, air temperature, altitude.

5.6.1.3 Height object dropped from.

5.6.1.4

Distance fallen (m)	Time to fall (s)	(Time)^2 (s^2)
0	0	0
2	0.64	0.41
4	0.90	0.81
6	1.11	1.23
8	1.28	1.64
10	1.43	2.04
12	1.56	2.43
14	1.69	2.86

5.6.1.5



5.6.1.6 About 1.0 s

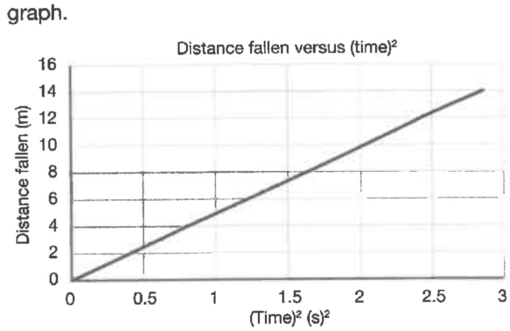
5.6.1.7 Difficult to do – author's estimate is 2.4 s (theoretical value is 2.26 s).

5.6.1.8 The interpolation at 5 m is more accurate and reliable than the extrapolation at 25 m. Extrapolations rely on the trend shown by the graph continuing and this may not happen. It also involves estimating beyond the limits of the graph grid which causes inaccuracy.

5.6.1.9 About 11 m (theoretical answer is 11.025 m).

5.6.1.10 No. Conclusion can only be drawn from a straight line graph.

5.6.1.11



5.6.1.12 Time to fall squared is directly proportional to height dropped from.

5.6.1.13 9.8 m s^{-2}

5.6.1.14 Yes (unless coincidentally the planet it is on has the same gravitational field as Earth) gravity on Earth is 9.8 m s^{-2} or very close to this, depending on altitude.

5.6.1.15 Time to fall squared is directly proportional to height dropped from.

5.6.1.16 Use average times to fall, repeat with objects of different mass, measure distances several times and use averages.

5.6.1.17 From the diagram scale, 1 cm = 0.15 m.

From the camera frequency, the time interval for each space = $\frac{1}{f} = \frac{1}{11} = 0.091$ s

The distance from the bottom of the first ball (assume it has started falling from rest), to the bottom of the last ball in the picture is 17.1 cm.

This distance also represents 9 strobe spaces, therefore time to fall = 9 × 0.091 = 0.818 s

According to the scale, 1 cm = 0.15 m, therefore 17.1 cm = 2.57 m

From $s = ut + \frac{1}{2}at^2 = 2.57 = 0 + 0.5 \times a \times (0.818)^2$

From which, $a = g = 7.66$ m s^{-2} (answer may vary slightly due to rounding off errors)

5.7.1.1 B It is believed that there is an explanation for fields – electric, magnetic and gravitational – which explains how and why they exist and ties them all together with some mutual cause. This is unified field theory. It has not been discovered yet.

5.7.1.2 D

5.7.1.3 D Zero – gravitational force is a vector quantity and therefore has direction. A mass placed at this midpoint would experience identical forces in opposite directions (towards each of the planets). The net force on the object would be zero.

5.7.1.4 D

5.7.1.5 A

5.7.1.6 C

5.7.1.7 A

5.7.1.8 Weight on Earth will be about 40% of the weight on Jupiter since 9.8 = about 40% of 24.8 (weight on Earth = 9.8 × 5 = 49 N, on Jupiter = 24.8 × 5 = 124, $\frac{49}{124}$ = 39.5%)

5.7.1.9 B

5.7.1.10 D

5.7.1.11
(a) 0.25g
(b) 4g
(c) 2g
(d) 0.5g
(e) 0.5g

5.7.1.12
(a) E
(b) A
(c) C
(d) A
(e) F

5.7.1.13
(a) D
(b) A and B

5.8.1.1
(a) Orbital velocity is a measure of the speed at which a satellite moves around its primary.
(b) A primary is the object being orbited. For example, for the Solar System, the primary is the Sun, for Phobos and Deimos, the moons of Mars, their primary is the planet Mars.
(c) Orbital radius is the distance from the centre of the primary to the centre of the orbiting planet or moon (assuming perfectly circular) whereas altitude is the distance of the orbiting object above the surface of the primary.

5.8.1.2 The orbital speed of the satellite around Jupiter would have to be greater than that of the satellite around Earth if both are to be in stable orbits because the gravitational pull of Jupiter is greater than that of Earth.

5.8.1.3
(a) 1 : 1 : 1 (orbital speed is independent of the mass of the satellite)
(b) 12 : 4 : 3

5.8.1.4
(a) 1 : 1 : 1
(b) 1 : 1 : 1

5.8.1.5 2.968 m s^{-1} = 106 839 km h^{-1}

5.8.1.6
(a) The mass of the primary, the orbital radius (and indirectly in that it is incorporated into the value of the universal gravitational constant, the gravitational field of the planet).
(b) The greater the gravitational pull of a planet, the greater the orbital velocity needed to maintain a particular altitude orbit.

5.8.1.7 A Given the different masses and radii of the planets, the orbital velocities cannot be the same.

5.8.1.8 A

5.8.1.9 D

5.8.1.10
(a) A
(b) 1 : 1 : 1

5.8.1.11
(a) B
(b) Orbital speed must be higher for a lower radius orbit since, from the equation, v is inversely proportional to orbital radius. Gravitational potential energy increases with height above the Earth, so higher orbit satellite has more energy.

5.8.1.12 D

5.8.1.13 C

5.9.1.1
(a) The Van Allen belts are regions of high concentration of charged particles from the solar wind at three specific altitudes above Earth.
(b) The ionised particles in the solar wind have an induced magnetic field around them and this interacts with the Earth's magnetic field causing them to move along the field lines towards the north or south pole.
(c) They limit the region of space above the Earth that satellites can use because of the threat the ionisation poses to humans and electronic equipment.
(d) The outer belt (at geostationary and geosynchronous orbit altitudel) is composed mainly of electrons, the middle belt (1000 km) mainly protons, and the inner belt (300 km) contains larger ions. Placing satellites and/or people at these altitudes requires protective measures to be taken.
(e) The minimum altitude required to avoid significant atmospheric friction is 250 km.
(f) The will slow down allowing the gravitational force to pull them closer to Earth. In other words, they undergo orbital decay.

5.9.1.2
(a) Communications and weather forecasting.
(b) Cover most of the populated world and do not need to be tracked. Can see long distance weather patterns.

5.9.1.3 (a) Spy satellites, emergency searches.

(b) Cover the Earth's surface at least once per day, get close up camera views of events and people.

5.9.1.4 Geosynchronous satellites cover the small areas of Earth that the geostationary satellites do not reach (mainly the polar regions) and therefore provide communications links with people there and with weather beacons in those regions.

5.9.1.5

Low Earth satellites	Geostationary satellites	Geosynchronous satellites
Altitude 250 to 1000 km	Altitude 35 800 km	Altitude 35 800 km
Period 90 minutes to 4 or 5 hours	Period 23 hours 65 min 4 sec	Period 23 hours 65 min 4 sec
Usually polar orbit	Equatorial orbit	Non-equatorial orbit
Not fixed relative to Earth's surface	Stay over same position on Earth's surface	Do not stay over same position on Earth's surface
Used for spying	Used for communications and weather forecasting	Used for communications and weather forecasting especially from polar regions

5.9.1.6

Advantages of ...		
Low Earth Satellites	Geostationary satellites	Geosynchronous satellites
Cover the entire surface of the Earth in short time	Cover most of the Earth's surface	Cover polar regions
Have high powered cameras to record details of events or people	Do not need to be tracked	
Very useful military technology		
Less expensive to put into orbit than the geo satellites		

5.9.1.7

Disadvantages of ...		
Low Earth Satellites	Geostationary satellites	Geosynchronous satellites
Need to be tracked	Do not cover polar regions	Need to be tracked
Need a carefully placed sequence of satellites to maintain cover of a particular region	More expensive to put into orbit than LEO satellites	Need a carefully placed sequence of satellites to maintain cover of a particular region
		More expensive to put into orbit than LEO satellites

5.9.1.8 D

5.9.1.9 A

5.9.1.10 C Tracking refers to the movement of a satellite signalling or receiving dish to follow the path of the satellite across the sky if it is not in a geostationary orbit.

5.9.1.11 A

5.9.1.12 B

5.9.1.13 C

5.9.1.14 D

5.9.1.15 B

5.10.1.1 (a) Escape velocity is the velocity an object with no power source of its own must be given in order to escape a gravitational field.

(b) Surface escape velocity will be larger than orbital escape velocity because the strength of the gravitational field at the orbital position will be less than the strength of the field on the surface of the planet.

(c) Escape velocity refers to the initial velocity that must be given a projectile in order to escape the Earth's gravitational field. The projectile has no form of propulsion. If a rocket has its own motors, then as long as it has fuel, it can rise as slowly as it likes until it is eventually far enough from Earth to be considered out of the gravitational field.

5.10.1.2 1.9×10^{27} kg

5.10.1.3 From $v_{escape} = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6 \times 10^{24}}{6.4 \times 10^6 + 350\,000}}$

$v_{escape} = 10\,889.3 \text{ m s}^{-1}$

5.10.1.4 (a) From $\Delta E_P = \Delta E_K$

$-\frac{GmM}{R} = \frac{1}{2}mv_e^2$

Cancelling m, and rearranging we get $v_e = \sqrt{\frac{2GM}{R}}$

(b) $6.12 \times 10^4 \text{ m s}^{-1}$

(c) From $g = \frac{GM}{r^2} = 1.17 \times 10^6 \text{ N kg}^{-1}$ (or m s^{-2})

(d) The centripetal acceleration $= \frac{v^2}{R}$

$= \frac{(\text{circumference/period of rotation})^2}{R}$

$= \frac{(2\pi \times 1.6 \times 10^3)^2}{(4 \times 60)^2 \times 1.6 \times 10^3}$

$= 1.1 \text{ m s}^{-2}$

This is far less than the surface gravitational field strength, so matter will not be lost due to the rotation.

5.10.1.5 (a) $11\,200 \text{ m s}^{-1}$

(b) $11\,200 \text{ m s}^{-1}$

(c) Escape velocity is independent of the mass of the projectile, so these answers must be identical.

5.10.2.1 (a) From $v_{escape} = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6 \times 10^{23}}{5.6 \times 10^6}}$

$v_{escape} = 3780 \text{ m s}^{-1}$

(b) From $v_{escape} = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6 \times 10^{23}}{5.6 \times 10^6 + 5.6 \times 10^6}}$

$v_{escape} = 2673 \text{ m s}^{-1}$

(c) The gravitational field strength at the orbital position is less than at the surface, so a lesser velocity is required to overcome the gravitational force from the orbital position.

5.10.2.2 (a) From $v_{escape} = \sqrt{\frac{2GM}{R}}$ doubling the mass and the radius means this equation becomes

$v_{escape} = \sqrt{\frac{2G2M}{2R}}$ which makes no change, so the escape velocities from A and B are equal.

(b) From $v_{escape} = \sqrt{\frac{2GM}{R}}$ nine times the mass and double the radius means this equation becomes

$v_{escape} = \sqrt{\frac{2G9M}{2R}}$ he escape velocity of A will be $\sqrt{\frac{9}{2}}$ larger than that of B – that is escape velocity A = 2.12 larger than that of B.

5.10.2.3 From $v_{escape} = \sqrt{\frac{2GM}{R}}$ we get the following ratio:

$v_{Earth} : v_{Uranus} = 11\ 200 : 21\ 700 = 1 : 1.94$

$= \sqrt{\frac{2GM}{R}}_{Earth} : \sqrt{\frac{2GM}{R}}_{Uranus}$

Therefore $1 : 1.94 = \sqrt{\frac{M}{1}}_{Earth} : \left(\frac{M}{4}\right)_{Uranus}$

Squaring both sides, $1 : 3.75 = \sqrt{\frac{M}{1}}_{Earth} : \sqrt{\frac{M}{4}}_{Uranus}$

Rearranging, $M_{Uranus} = 3.75 \times 4M_{Earth} = 15M_{Earth}$

Therefore the mass of Uranus is about $15 \times 6 \times 10^{24}$ $= 9 \times 10^{25}$ (compared to actual value of 8.7×10^{25} kg)

5.10.2.4 (a) From $g = \frac{GM}{r^2}$

$2.5 = \frac{6.67 \times 10^{-11} \times M}{(1.6 \times 10^6)^2}$

From which $M = 9.6 \times 10^{22}$ kg

(b) From $v_{escape} = \sqrt{\frac{2GM}{R}} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 6 \times 10^{22}}{1.6 \times 10^6}}$

$v_{escape} = 2829$ m s^{-1}

(c) Because 2500 m s^{-1} is less than the escape velocity, it will rise and slow down because of the pull of gravity backwards until it reaches its maximum height, where momentarily it will stop, then fall back to the surface of the moon.

5.10.2.5 From $v_{escape} = \sqrt{\frac{2GM}{R}}$ we get the following ratio:

$v_{Earth} : v_{Saturn} = 11\ 200 : v_{Saturn} = \sqrt{\frac{2GM}{R}}_{Earth} : \sqrt{\frac{2GM}{R}}_{Saturn}$

Therefore $11\ 200 : v_{Saturn} = \sqrt{\frac{M}{1}}_{Earth} : \sqrt{\frac{95M}{9.1}}_{Uranus}$

Rearranging, $v_{Saturn} = 11\ 22 \times \sqrt{\frac{95}{9.1}}$

Therefore $v_{Saturn} = 36\ 187.5$ m s^{-1} on this data (theoretical value = 35 500 m s^{-1})

5.10.2.6 (a) From $v_{escape} = \sqrt{\frac{2GM}{R}}$

$= \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 2.0 \times 10^{30}}{6.96 \times 10^8}}$

Therefore, escape velocity for the Sun $= 6.19 \times 10^5$ m s^{-1}

(b) From $v_{escape} = \sqrt{\frac{2GM}{R}}$

$= \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 1.08 \times 2.0 \times 10^{30}}{24.5 \times 6.96 \times 10^8}}$

Therefore, escape velocity for Arcturus $= 1.3 \times 10^5$ m s^{-1}

5.11.1.1 At infinity. It is only at infinity that an object is outside any gravitational field so that the force acting on it is zero. It therefore has no tendency to 'fall'.

5.11.1.2 The gravitational potential energy of an object at any point in space is equal to the work done in moving it from infinity to the point. $U = -\frac{GMm}{r}$, measured in joules (J).

5.11.1.3 We do not use this equation because the value of g is not constant, and because it refers only to objects close to the surface of Earth (or any other planet or moon) where the zero reference point is the surface of the planet or moon. It cannot be used at significant distances from the Earth because the value of the gravitational field changes and is not constant at 9.8 m s^{-2} as we have been used to using.

5.11.1.4 The gravitational potential energy at infinity is zero so the only direction it can move is downwards, towards a planet. As it falls its gravitational potential energy will change to kinetic energy. Because the law of conservation of energy must be obeyed, and the object's kinetic energy will be positive, its gravitational potential energy must be negative.

5.11.1.5 Adjusting the equation $\Delta U = mg\Delta h$ so that it can be used to determine the magnitude of the gravitational potential energy of any position in space – which means correcting for the value of 'g', as well as changing the Δh (change in position relative to the Earth's surface) to r (position relative to the centre of the Earth, we get: $\Delta U = mg\Delta h = m.\ \frac{GM}{r^2}.r = \frac{GMm}{r}$

Taking into account the negative value for gravitational potential energy at any point except at an infinite distance from the Earth, we adjust this equation to be: $U = \frac{GMm}{r}$

5.11.1.6 (a) Change in gravitational potential energy

$= U_{final} - U_{initial}$

So $\Delta U = \left(-\frac{GMm}{R_{final}}\right) - \left(-\frac{GMm}{R_{initial}}\right) = \frac{GMm}{R_{initial}} - \frac{GMm}{R_{initial}}$

$= GMm\left(\frac{1}{R_{initial}}\right) - \left(\frac{1}{R_{final}}\right)$

That is, $\Delta U = GMm\left(\frac{1}{R_{initial}} - \frac{1}{R_{final}}\right)$

(b) The satellite will be raised to an orbit with a higher altitude.

(c) Its gravitational potential energy will increase because it will now be further from Earth's centre and therefore its magnitude will be less negative. (Note that its kinetic energy will decrease.)

(d) The satellite will move to an orbit with a lower altitude.

(e) Its gravitational potential energy will decrease because it will now be closer to closer to Earth's centre and therefore its magnitude will be more negative. (Note that its kinetic energy will increase.)

5.11.2.1 -1.93×10^{10} J

5.11.2.2 The gravitational potential energy of an object can only be zero when its distance from a planet is infinite. As the object then falls towards the planet, its gravitational potential energy will decrease (its kinetic energy increases). If *GPE* decreases from zero, it must become negative in value.

5.11.2.3 A The U of an object is zero at infinity and is a negative quantity anywhere else, being infinite at the centre of the Earth.

5.11.2.4 (a) A

(b) U is zero at infinity, and as an object 'falls' from infinity towards a planet its U decreases (changes into increased *KE*). U can only become negative if it decreases from zero.

5.11.2.5 (a) B

(b) Yes – double since gravitational potential energy depends on the mass of the satellite.

5.11.2.6 (a) C

(b) U would be greater as object is further from Earth, so energy has to be put into it to increase its altitude.

5.11.2.7 (a) B

(b) Less since the gravitational force of attraction of the Moon is only one sixth that of the Earth.

5.11.2.8 From $U = -\frac{GMm}{r} = \frac{-6.67 \times 10^{-11} \times 6.4 \times 10^{23} \times 1.07 \times 10^{16}}{9\ 390\ 000}$

$= -4.86 \times 10^{23}$ J

5.11.2.9 From $U = -\frac{GMm}{r} = \frac{-6.67 \times 10^{-11} \times 6.4 \times 10^{24} \times 5000}{7\ 500\ 000}$

$= -2.85 \times 10^{11}$ J

5.12.1.1 (a) From $v = \frac{s}{t} = \frac{2\pi r}{T}$

(b) From $F_{centripetal} = \frac{mv^2}{r} = F_{gravity} = \frac{GMm}{r^2}$

We get $v = \sqrt{\frac{Gm}{r}}$

(c) Kinetic energy $= \frac{1}{2}mv^2 = \frac{1}{2}m\left(\sqrt{\frac{Gm}{r}}\right)^2 = \frac{1}{2}m.\ \frac{GM}{r}$

$= \frac{GMm}{2r}$

(d) $U = -\frac{GMm}{r}$

(e) Total energy = kinetic energy + gravitational potential energy

$= \frac{GMm}{2r} + (-\frac{GMm}{r})$

$= -\frac{GMm}{2r}$

(f) The zero reference point for gravitational potential energy is infinity because it is only at infinity that an object will have zero U. When an object falls from infinity, it will lose U and gain KE. The value of U at any point is therefore negative. In the case of the orbiting satellite, the magnitude of the gravitational potential energy is greater than that of the kinetic energy, and since the gravitational potential energy is negative, the total energy is also negative.

(g) KE = –half U

(h) Total energy = half gravitational potential energy.

(i) Total energy = –kinetic energy.

5.12.1.2 (a) From $U = -\frac{GMm}{r}$

$U = -\frac{6.67 \times 10^{-11} \times 6.42 \times 10^{23} \times 200}{3.4 \times 10^7 + 350\ 000}$

Therefore gravitational potential energy $= -2.5 \times 10^8$ J

(b) Orbital $KE = -0.5U = 1.25 \times 10^8$ J

(c) $KE = \frac{1}{2}mv^2 = 1.25 \times 10^8 = 0.5 \times 200 \times v^2$

From which $v = 1118$ m s^{-1}

(d) Total energy $= 0.5U = -1.25 \times 10^8$ J

5.12.1.3 (a) $KE = \frac{1}{2}mv^2 = 3.51 \times 10^{11} = 0.5 \times 400 \times v^2$

From which $v = 41\ 892.7$ m s^{-1}

(b) Total energy = –kinetic energy $= -3.51 \times 10^{11}$ J

(c) U = twice total energy $= -7.02 \times 10^{11}$ J

(d) From $U = -\frac{GMm}{r} = -7.02 \times 10^{11}$

$M = 7.02 \times 10^{11} \times \frac{750000 + 7.15 \times 10^7}{6.67 \times 10^{-11} \times 400}$

Therefore mass Jupiter $= 1.88 \times 10^{27}$ kg

5.12.1.4 (a) Orbital KE = –half $U = 1.22 \times 10^{11}$ J

(b) Total energy = –kinetic energy $= -1.22 \times 10^{11}$ J

(c) From $U = -\frac{GMm}{r} = -2.44 \times 10^{11}$

$m = 2.44 \times 10^{11} \times \frac{5.8 \times 10^7 + 2.5 \times 10^6}{6.67 \times 10^{-11} \times 5.68 \times 10^{26}}$

Therefore mass of satellite = 389.6 kg (390 kg is a better answer)

(d) $KE = \frac{1}{2}mv^2 = 1.22 \times 10^{11} = 0.5 \times 390 \times v^2$

From which $v = 2.5 \times 10^4$ m s^{-1}

5.12.1.5 (a) $U = -2KE = 1.58 \times 10^{-11}$ J

(b) Total energy $= -KE = -7.9 \times 10^{10}$ J

(c) From $KE = \frac{1}{2}mv^2 = 7.9 \times 10^{10} = 0.5 \times 800 \times v^2$

From which $v = 1.41 \times 10^4$ m s^{-1}

(d) From $U = -\frac{GMm}{r}$, $r = \frac{GMm}{U}$ (Note that the negative sign is removed here)

Therefore $r = \frac{6.67 \times 10^{-11} \times 8.68 \times 10^{25} \times 800}{1.58 \times 10^{11}}$

From which $r = 2.93 \times 10^7$ m

Therefore altitude $= 2.93 \times 10^7 - 2.54 \times 10^7$ m $= 3.91\times 10^7$ m (Note that rounding off errors mean that the actual altitude of 3.91×10^7 m is not obtained here)

5.12.1.6 (a) From $KE = \frac{GMm}{2r} = \frac{6.\ 67 \times 10^{-11} \times 6 \times 10^{24} \times 1500}{2 \times 7.6 \times 10^7}$

$= 3.95 \times 10^9$ J

(b) From $v = \sqrt{\frac{Gm}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{7.6 \times 10^7}}$

$= 2295$ m s^{-1}

(c) From $U = -\frac{GMm}{r}$

$= -\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 1.5 \times 10^3}{7.6 \times 10^7}$

$= -7.9 \times 10^9$ J

(d) Total energy of satellite = $KE + U$

$= 3.95 \times 10^{10} - 7.9 \times 10^9$ J $= -3.95 \times 10^{10}$ J

5.12.1.7 (a) From $KE = \frac{GMm}{2r}$

$= \frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22} \times 2500}{2 \times 3.24 \times 10^6} = 1.9 \times 10^9$ J

(b) From $v = \sqrt{\frac{Gm}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{3.24 \times 10^6}}$

$= 1230$ m s^{-1}

(c) From $U = -\frac{GMm}{r}$

$= -\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22} \times 2500}{3.24 \times 10^6} = -3.8 \times 10^9$ J

(d) Total energy of satellite = $KE + U$

$= 1.9 \times 10^9 - 3.8 \times 10^9$ J $= -1.9 \times 10^9$ J

5.12.1.8 (a) From $KE = \frac{GMm}{2r} = \frac{6.\ 67 \times 10^{-11} \times 4.87 \times 10^{24} \times 600}{2 \times 6.95 \times 10^6}$

$= 1.4 \times 10^{10}$ J

(b) From $v = \sqrt{\frac{Gm}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24}}{6.95 \times 10^6}}$

$= 6836.5$ m s^{-1}

(c) From $U = -\frac{GMm}{r}$

$= -\frac{6.67 \times 10^{-11} \times 4.87 \times 10^{24} \times 600}{6.95 \times 10^6} = -2.8 \times 10^{10}$ J

(d) Total energy of satellite = $KE + U$

$= 1.4 \times 10^{10} - 2.8 \times 10^{10}$ J $= -1.4 \times 10^{10}$ J

5.13.1.1 (a) $+4.61 \times 10^9$ J

(b) Because there is an increase in the gravitational potential energy of the satellite, work has been done against gravity by the rockets of the satellite.

5.13.1.2 (a) -4.7×10^8 J

(b) This represents a kinetic energy increase of the same amount which means the speed increases by 3232 m s^{-1}.

(c) 4.7×10^8 J of work is done on the satellite by the gravitational field.

5.13.1.3 (a) The gravitational field of the planet.

(b) Initial U is $\frac{-GMm}{2R}$, final U is $\frac{-GMm}{3R}$. This represents a decrease by a factor of $\frac{W}{6}$, so U has been increased by a factor of $\frac{W}{6}$. (It must be an increase since work has to be done on the satellite to boost it to a higher orbit.) The change in U is therefore $+\frac{W}{6}$.

5.13.1.4 Work done to raise the satellite to 8000 km is U at 8000 km $- U$ at the surface $= E$

Work done to raise the satellite to 16000 km is U at 16000 km $- U$ at the surface = about $1.29E$ (2 dp rounding at all calculations)

5.13.1.5 (a) A

(b) Orbital period would increase as orbital speed decreases. At a higher altitude orbit, gravitational field is less, so orbital velocity needed to remain in orbit will be less. The satellite is in a larger circumference orbit and moving more slowly, so the orbital period will increase.

5.13.1.6 A

5.13.1.7 (a) A

(b) Projectile will be subject to gravitational acceleration so its *KE* will decreases as a function of v^2. As it increases in altitude, the U of the projectile must increase in the same way as the *KE* decreases (law of conservation of energy). Since U is a negative quantity, as it increases, it will become less negative, approaching zero.

5.13.1.8 (a) D

(b) Since thrust is constant, applied force will be constant and because mass is decreasing as fuel is used, acceleration will increase, so velocity will increase exponentially as will *KE*, so *KE* graph must rise. Since work is being done on the rocket continually, its U will also increase, again exponentially as altitude increases proportional to v^2.

5.13.1.9 (a) C

(b) Yes, double since gravitational potential energy depends on the mass of the satellite.

5.13.1.10 (a) B

(b) Yes. Double. Although the orbital velocity would be the same (orbital velocity is independent of the mass of the satellite), its kinetic energy at this velocity also depends on its mass.

5.13.1.11 (a) $-\frac{E}{3}$ J

(b) $-3E$ J

(c) Its gravitational potential energy will increase from $-3E$ to $-E$. It increases by $+2E$.

5.13.1.12 (a) No. More work would need to be done as a higher orbit involves greater gravitational potential energy, but tripling the altitude does not triple the orbital radius, so less than triple the work would be involved.

(b) Its altitude would be $3(6380 + R)$ km.

5.14.1.1 (a) From $\frac{mv^2}{r} = \frac{GMm}{r^2}$

We get $v^2 = \frac{GM}{r}$

From which $v = \sqrt{\frac{Gm}{r}}$

(b) From $v = \frac{s}{t}$

$v = \frac{2\pi r}{T}$

(c) Equating these $v = \sqrt{\frac{Gm}{r}} = \frac{2\pi r}{T}$

Squaring both sides $\frac{GM}{r} = \frac{4\pi^2 r^2}{T^2}$

Rearranging $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$

5.14.1.2 (a) From $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ = constant

We get $\left(\frac{r^3}{T^2}\right)_{\text{for X}} = \left(\frac{r^3}{T^2}\right)_{\text{for Y}}$

That is $\left(\frac{r^3}{T^2}\right) = \left(\frac{8r^3}{T_Y^2}\right)$

From which $T_Y = (2\sqrt{2})T$

(b) From $v = \frac{2\pi r}{T}$

$v_Y = \frac{2\pi 2r}{(2\sqrt{2})T} = \frac{v}{\sqrt{2}}$

(c) The answer would still be the same as orbital speed and period are both independent of the mass of the planet.

(d) Orbital velocity values would all be multiplied by $\sqrt{2}$, and period values would therefore be decreased by a factor of $\sqrt{2}$.

5.14.1.3 (a) From $\frac{r^3}{T^2} = \frac{GM}{4\pi^2}$ = constant

We get $\left(\frac{r^3}{T^2}\right)_{\text{for X}} = \left(\frac{r^3}{T^2}\right)_{\text{for Y}}$

That is $\left(\frac{125r^3}{T^2}\right) = \left(\frac{r^3}{T_Y^2}\right)$

From which $T_X : T_Y = 11.18 : 1$

(b) From $v = \frac{2\pi r}{T}$

$v_X : v_Y = \frac{2\pi 5r}{T} : \frac{2\pi . r}{11.81} = 1 : 2.24$

(c) Gravitational force on X : gravitational force on Y $= \frac{GMm_X}{r^2} : \frac{GMm_Y}{(5r)^2} = 4 : 25 = 1 : 6.25$

5.15.1.1 (a) The planets move in elliptical orbits with the Sun at one focus, the other focus being empty.

(b) The line joining the planet to the Sun sweeps out equal areas in equal periods of time.

(c) The squares of the orbital periods of the planets are directly proportional to the cubes of their mean distance from the Sun.

5.15.1.2 108 686 s = 30.2 hours

5.15.1.3 20 229.2 km

5.15.1.4 A

5.15.1.5 A = 129 643 km
B = 2.51 days
C = 436 464 km

5.15.1.6 A

5.15.1.7 (a) 5.075 hours
(b) 12 798.6 km

5.15.1.8 (a) A
(b) No. Period is not related to altitude. Period and orbital radius are connected through Kepler's third law.

5.15.1.9 (a) D
(b) Calculate the distance of planets from the Sun and of the moons from their various planets, and more recently, it allows astronomers to determine the mass of distant stars which are known to have planets.

5.15.1.10 (a) C
(b) No. Orbital radius includes the radius of the planet. This could only be the case if the radius of the planet was zero in this example.

5.15.1.11 A

5.15.1.12 B

5.16.1.1 (a) The acceleration of the moving object is perpendicular to the direction of its motion (directed to the centre of curvature of the motion).
(b) It is a centripetal force.

5.16.1.2 B

5.16.1.3 C

5.16.1.4 C

5.16.1.5 B

5.16.1.6 A

5.16.1.7 A

5.16.1.8 A

5.16.1.9 D

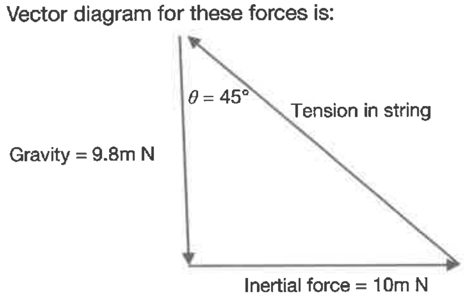
5.16.1.10 C

5.16.1.11 D

5.16.1.12 C

5.16.1.13 B

5.16.1.14 (a) From the data, centripetal force acting = $\frac{mv^2}{r}$ = 10m N, so inertial force acting on the bob = −10m
Gravitational force acting on the bob = mg = 9.8m N
Vector diagram for these forces is:



From which angle = 45°
(b) Tension = 14.1m N acting both ways in the string.

5.16.1.15 In the initial situation, $F_1 = \frac{mv^2}{r}$ where r = 16 cm
In the new situation, $F_2 = \frac{m(2v)^2}{r}$ where r = unknown
Therefore the magnitude of the force at 16 cm is now 4 times as great.
To reduce the force to the original value, the coin needs to be moved to a position where its speed is still v.
Therefore, for F_1 to equal F_2, r must be reduced to one quarter to its original value.
Therefore new r = 4 cm from the centre.

5.17.1.1 (a) 5400 N
(b) Towards the centre of curvature of the curve.
(c) The frictional force is the centripetal force which holds the truck on the road. Without that force its tangential velocity would cause it to fail to take the corner and move straight ahead.

5.17.1.2 (a) 75 m s^{-1}
(b) 28.125 m s^{-2}
(c) Friction between the tyres and the road – the inertia of the car tries to keep it going straight and the friction opposes this, pulling the car around in the curve.
(d) 4.21 × 10^4 N
(e) Towards the centre of the curve.
(f) Will be 4 times smaller = 1.05 × 10^4 N
(g) Will be 4 times greater = 16.84 × 10^4 N

5.17.1.3 X stops in 22.5 m so does not hit the wall.
Y turns a curve with a radius of 45 m, so Y hits the wall.

5.17.1.4 (a) 0.3 m s^{-1}
(b) 0.225 m s^{-2}
(c) 0.034 N towards centre of curve.
(d) Force would halve = 0.017 N towards the centre.

5.17.1.5 (a) 465.23 m s^{-1} (taking one day as 23 hours, 56 minutes, 4 seconds) or 1674.83 km h^{-1}
(b) 3.39 × 10^{-2} m s^{-2}
(c) The gravitational field at the equator would be reduced by this amount, but the field at the poles would be unaffected. A point on the equator has this speed but a point at the poles rotates in a circle with an infinitely small radius, so has negligible speed.

5.17.1.6 (a) From $a_c = \frac{v^2}{r} = \frac{(12)^2}{56}$
= 2.57 m s^{-2} towards the centre of the curve
(b) From $F = \frac{mv^2}{r}$ = 900 × 2.57
= 2314.3 N towards the centre of the curve
(c) Friction per tyre = 2314.3 ÷ 4 = 578.6 N towards the centre of the curve

5.17.1.7 From $F = \frac{mv^2}{r} = \frac{(1500 \times 23^2)}{65}$ = 12 207.7 N

5.17.1.8 (a) From $g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{(6\,380\,000 + 400\,000)^2}$
= 8.706 m s^{-2} towards the centre of the Earth
(b) From $a_c = \frac{v^2}{r} = \frac{(7683)^2}{6\,380\,000 + 400\,000}$
= 8.706 m s^{-2} towards the centre of the Earth

(c) The values are the same, the slight difference (in further decimal places – not shown) being due to rounding off the orbital speed (it is actually 7682.87 m s^{-1}), and they should be the same because the centripetal acceleration is the gravitational acceleration/field strength.

(d) From $F_G = \frac{GMm}{r^2} = \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 750}{(6\,380\,000 + 400\,000)^2}$
$= 6529.5$ N towards the centre of the Earth

(e) $F_c = ma_c = 750 \times 8.706 = 6529.5$ N towards the centre of the Earth

(f) The values are the same, no differences occur because the values used have been to 3 decimal places. Differences do occur in higher decimal places due to rounding off errors.

5.18.1.1

(a) 37.7 m s^{-1}

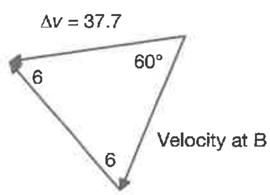
(b) From $v = r\omega$
$\omega = \frac{37.7}{1.2} = 31.42$ rad s^{-1}

(c) 1184.4 m s^{-2}

(d) 3553.2 N

(e) 0.033 s

(f) Remember instantaneous velocities are given by the tangents to the point on the circle.



(g) The change in velocity from vector diagram is 37.7 m s^{-1}, time for change is 0.033 s which gives an acceleration of 1142.4 m s^{-2}. The difference can be attributed to rounding off errors.

5.18.1.2

(a) From $v = \frac{s}{t} = 2\pi rf$
Linear speed $= 2 \times \pi \times 2.5 \times 3 = 47.12$ m s^{-1}

(b) From $v = r\omega$
$\omega = \frac{47.12}{2.5} = 18.85$ rad s^{-1}
Or
From $f = 3$ Hz, $\omega = 2\pi \times 3 = 18.85$ rad s^{-1}

(c) From $a_c = \frac{v^2}{r}$
$= 888.1$ m s^{-2} towards the centre of rotation

(d) From $F_c = ma_c$ = tension in string $= 5 \times 888.1$
$= 4440$ 6 N acting both ways in the string

(e) Double the frequency = double the linear velocity = 4 times the tension.

5.18.1.3

(a) From $f = \frac{1}{T}$, frequency = 8 Hz

(b) Angular velocity $= 2\pi f = 16$ rad s^{-1}

(c) From $v = 2\pi rf$
Linear speed = 25.13 m s^{-1}

(d) From $a_c = \frac{v^2}{r}$
$= 1263.3$ m s^{-1} towards centre

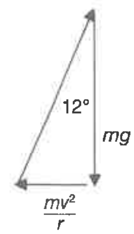
(e) From $F_c = \frac{mv^2}{r}$
$m = \frac{F_c r}{v^2} = \frac{144 \times 0.5}{25.13^2} = 0.114$ kg $= 114$ g

5.19.1.1

(a) 40 km h^{-1} = 11.11 m s^{-1}
Total frictional force $= 220 \times 0.25 = 55$ N
From $F = \frac{mv^2}{r} = 55$
$= \frac{220 \times 11.1^2}{r}$
$r = 493.8$ m

(b) From $v = \sqrt{rg \tan\theta}$
$v = \sqrt{493.8 \times 9.8 \times \tan 25°}$
$= 47.5$ m s^{-1}

5.19.1.2 From the vector diagram:
$F_c = \frac{mv^2}{r} = mg \tan 12°$,
Therefore $v = \sqrt{gr \tan 12°}$
$= \sqrt{9.8 \times 450 \times \tan 12°}$
$= 30.6$ m s^{-1} = 110.2 km h^{-1}



5.19.1.3 From $v = \sqrt{gr \tan\theta} = 28$
$= \sqrt{9.8 \times 600 \times \tan\theta}$
Therefore $\theta = 7.6°$

5.19.1.4 From $v = \sqrt{gr \tan 45°} = \frac{550}{3.6} = \sqrt{9.8 \times r \times \tan 45°}$
Therefore $r = 2381.7$ m

5.19.1.5

(a) 23.3 m s^{-2}

(b) 0.8°

5.19.1.6

(a) 14.6 m s^{-1} (52.7 km h^{-1})

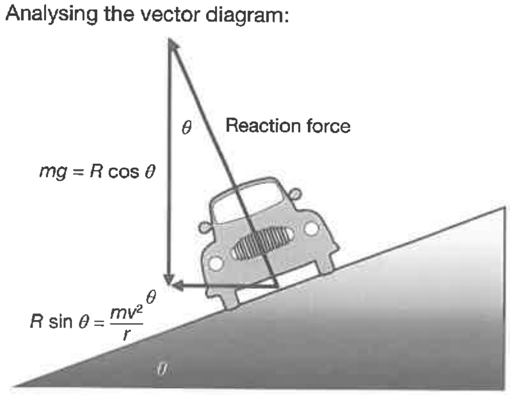
(b) 56.8°

5.19.1.7 From $v = \sqrt{gr \tan 30°} = \sqrt{9.8 \times 80 \times \tan 30°}$
$= 21.8$ m s^{-1} = 76.6 km h^{-1}

5.19.1.8 28.1 m s^{-1} = 101.3 km h^{-1}

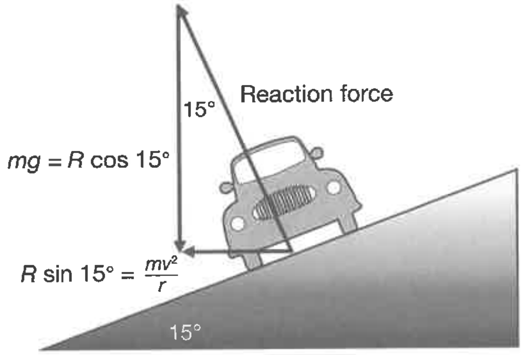
5.19.1.9 48.9°

5.19.1.10 Analysing the vector diagram:



The car's weight = mg and
The normal reaction to the surface = R
The vertical component of $R = mg = R\cos\theta$
The horizontal component of the reaction $= R\sin\theta$
$= \frac{mv^2}{r}$
Also, $\tan\theta = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg} = v^2$
So $\theta = \tan^{-1}\frac{v^2}{rg} = \frac{(11.1)^2}{60 \times 9.8}$
Therefore $\theta = 11.8°$

5.19.1.11 Analysing the vector diagram:



The car's weight = mg and

The normal reaction to the surface = R

The vertical component of $R = mg = R\cos\theta$

The horizontal component of the reaction = $R \sin 15° = \frac{mv^2}{r}$

Also, $\tan 15° = \frac{\frac{mv^2}{r}}{mg} = \frac{v^2}{rg}$

So $v^2 = rg \tan 15° = 50 \times 9.8 \times 0.2679$

Therefore $v = 11.46$ m s^{-1}

5.20.1.1 (a) Linear speed = $\frac{2\pi r}{T} = \frac{2\pi \times 60}{24 \times 60} = 0.26$ m s^{-1}

(b) Angular velocity, $\omega = \frac{v}{r} = \frac{0.26}{60}$

$= 4.36 \times 10^{-3}$ rad s^{-1}

Or, $\omega = \frac{\theta}{T} = \frac{2\pi}{24 \times 60} = 4.36 \times 10^{-3}$ rad s^{-1}

(c) From $a_c = \frac{v^2}{r} = \frac{(0.26)^2}{60}$

$= 1.12 \times 10^{-3}$ m s^{-2} towards the centre

(Note that answers could vary due to rounding off errors)

(d) From $F_c = ma_c = 60 \times 1.04 \times 10^{-3} = 0.0676$ N towards the centre

(Note that answers could vary due to rounding off errors)

5.20.1.2 (a) From $v = \frac{s}{t} = \frac{2\pi r}{T} = 27.5$ m s^{-1}

(b) From $v = r\omega$

$\omega = \frac{27.5}{35} = 0.79$ rad s^{-1}

(c) $a_c = \frac{v^2}{r} = \frac{(27.5)^2}{35}$

$= 21.6$ m s^{-2} towards the centre of the curve

(d) From $F = ma = 55 \times 21.6 = 108$ N towards the centre of the curve

5.20.1.3 (a) From $v = r\omega$

$\omega = \frac{13}{1.2} = 10.83$ rad s^{-1}

(b) $a_c = \frac{v^2}{r} = \frac{(13)^2}{1.2}$

$= 140.83$ m s^{-2} towards the centre of the curve

(c) Tension = centripetal force = $ma = 0.3 \times 140.83$ = 42.25 N acting both ways in the string

5.20.1.4 (a) From $v = r\omega$, $\omega = \frac{25}{70} = 0.36$ rad s^{-1}

(b) From friction = $F_c = \frac{mv^2}{r} = \frac{1200 \times 625}{70}$

= 10 714.3 N towards centre

5.20.1.5 (a) From $v = r\omega$, $\omega = \frac{15}{42} = 0.36$ rad s^{-1}

(b) $a_c = \frac{v^2}{r} = \frac{225}{42} = 5.36$ m s^{-2} towards centre

(c) From friction = $F_c = \frac{mv^2}{r} = \frac{800 \times 225}{42}$

= 4285.7 N towards centre

(if you use $F_c = ma_c$ you will get 4288 N here)

(d) Assuming 4 wheels, friction per tyre = $\frac{4285.7}{4}$

= 1071.4 N towards centre

(4288 gives1072 N per tyre)

5.20.1.6 (a) Angular velocity = 10π rad s^{-1}

(b) Linear speed = $r\omega = 0.9 \times 10\pi = 28.27$ m s^{-1}

(c) $a_c = \frac{v^2}{r} = 888.3$ m s^{-2} towards centre

(d) Tension = $F_c = \frac{mv^2}{r} = ma_c$

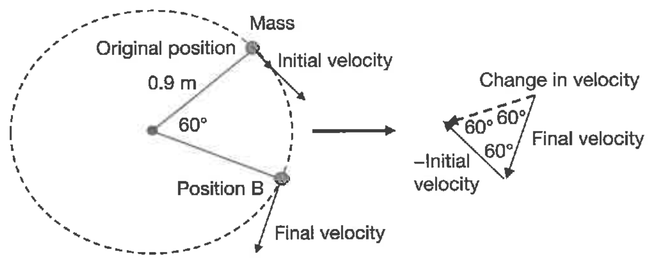
= 3553 N towards centre

(e) Angular velocity = 5 revolutions per second = 5 × 360° = 1800° s^{-1}

Therefore time to travel 60° = $\frac{60}{1800} = 0.033$ s

(f) From the diagram, acceleration

$= \frac{\text{final velocity} - \text{initial velocity}}{\text{time taken}}$



Therefore change in velocity = 28.27 m s^{-1}

So acceleration = $\frac{28.27}{0.033}$

= 857 m s^{-2} towards centre

(g) Difference in the answers for the acceleration (888.3 compared to 857) is most likely due to rounding off errors.

5.20.1.7 (a) 2 rev s^{-1} = 4π rad s^{-1} = 12.57 rad s^{-1}

(b) $v = r\omega = 0.75 \times 12.57 = 9.43$ m s^{-1}

(c) $a_c = \frac{v^2}{r} = \frac{(9.43)^2}{0.75}$

= 118.6 m s^{-2} towards the centre of rotation

5.20.1.8 From $T = F_c = \frac{mv^2}{r} = 50 = \frac{2 \times v^2}{10}$

From which $v = 15.91$ m s^{-1}

5.20.1.9 Because *centripetal force* varies with the square of the velocity, an increase in velocity by a factor of two must be accompanied by an increase in centripetal force by a factor of four.

5.20.1 10 (a) Angular velocity = $\frac{2\pi}{T} = \frac{2\pi}{23.93 \times 60 \times 60}$

$= 7.29 \times 10^{-5}$ rad s^{-1}

(b) $v = r\omega = 4.22 \times 10^7 \times 7.29 \times 10^{-5} = 3076.4$ m s^{-1}

(c) Gravitational field = centripetal acceleration

$= \frac{v^2}{r} = \frac{(r\omega)^2}{r} = r\omega^2$

$= 4.22 \times 10^7 \times (7.29 \times 10^{-5})^2 = 0.22$ m s^{-2}

5.21.1.1 (a) $U_{surface} = \frac{-GMm}{R}$

(b) $U_{orbit} = \frac{-GMm}{R + r}$

(c) $KE = \frac{GMm}{2(R + r)}$

(d) Total energy of satellite = $KE + U$

$= \frac{GMm}{2(R + r)} - \frac{GMm}{R + r} = \frac{-GMm}{2(R + r)}$

(e) $\Delta U = -\frac{GMm}{R + r} - \frac{-GMm}{R}$

$= \frac{GMm}{R} - \frac{GMm}{R + r}$

(f) Work done = $KE + \Delta U$

$= \frac{GMm}{2(R + r)} + \left(\frac{-GMm}{R + r}\right) - \left(\frac{-GMm}{R}\right)$

$= \frac{GMm}{2(R + r)} - \frac{GMm}{R + r} + \frac{GMm}{R}$

$= \frac{GMm}{R} - \frac{GMm}{R + r}$

5.21.1.2 (a) From $U = -\frac{GMm}{R}$

$= -\frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 11\,110}{6.92 \times 10^{6}}$

$= -6.43 \times 10^{11}$ J

(b) From $v = \sqrt{\frac{Gm}{r}}$

$= \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{6.92 \times 10^{6}}}$

= 7605 m s^{-1} (rounded)

(c) From $KE = \frac{GMm}{2r}$

$= \frac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 11\,110}{2 \times 6.92 \times 10^{6}}$

$= 3.21 \times 10^{11}$ J

(d) Total energy of satellite = $KE + U$

$= 3.21 \times 10^{11} - 6.43 \times 10^{11}$ J

$= -3.22 \times 10^{12}$ J (rounding off error)

(e) From $\Delta U = GMm\left(\frac{1}{r_{orbit}} - \frac{1}{r_{Earth}}\right)$

$= (6.67 \times 10^{-11} \times 6 \times 10^{24} \times 11\,110)$

$\times \frac{1}{6.4 \times 10^{6}} - \frac{1}{6.92 \times 10^{6}}$

$= 5.22 \times 10^{10}$ J

(f) Total work = $KE + \Delta U = 3.21 \times 10^{11} + 5.22 \times 10^{10}$ J

$= 3.73 \times 10^{11}$ J

5.21.1.3 (a) From $U = -\frac{GMm}{r} = -\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22} \times 750}{1.735 \times 10^{6} + 3.0 \times 10^{5}}$

$= -1.81 \times 10^{9}$ J

(b) From $v = \sqrt{\frac{Gm}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22}}{2.035 \times 10^{6}}}$

= 2214 m s^{-1}

(c) From $KE = \frac{GMm}{2r}$

$= \frac{6.67 \times 10^{-11} \times 7.35 \times 10^{22} \times 750}{2 \times 2.035 \times 10^{6}}$

$= 9.03 \times 10^{8}$ J

(d) Total energy of satellite = $KE + U$

$= 1.85 \times 10^{9} - 3.7 \times 10^{9}$ J $= -9.03 \times 10^{8}$ J

(e) From $\Delta U = GMm\left(\frac{1}{r_{orbit}} - \frac{1}{r_{Earth}}\right)$

$= (6.67 \times 10^{-11} \times 7.35 \times 10^{24} \times 750)$

$\times \frac{1}{1.735 \times 10^{6}} - \frac{1}{2.035 \times 10^{6}}$

$= 3.1 \times 10^{8}$ J

(f) Total work = $KE + \Delta U = 9.03 \times 10^{8} + 3.1 \times 10^{8}$ J

$= 1.21 \times 10^{9}$ J

5.21.1.4 (a) From $U = \frac{-GMm}{r}$

$= \frac{-(6.67 \times 10^{-11} \times 6.42 \times 10^{23} \times 500)}{3.395 \times 10^{6} + 3.0 \times 10^{5}}$

$= -5.79 \times 10^{9}$ J

(b) From $v = \sqrt{\frac{Gm}{r}} = \sqrt{\frac{6.67 \times 10^{-11} \times 6.42 \times 10^{23}}{3.695 \times 10^{6}}}$

= 3404 m s^{-1}

(c) From $KE = \frac{GMm}{2r} = \frac{6.67 \times 10^{-11} \times 6.42 \times 10^{23} \times 500}{2 \times 3.695 \times 10^{6}}$

$= 3.49 \times 10^{9}$ J

(d) Total energy of satellite = $KE + U$

$= 3.49 \times 10^{12} - 6.99 \times 10^{12}$ J $= -2.9 \times 10^{9}$ J

(e) From $\Delta U = GMm\left(\frac{1}{r_{orbit}} - \frac{1}{r_{Earth}}\right)$

$= (6.67 \times 10^{-11} \times 6.24 \times 10^{23} \times 500)$

$\times \frac{1}{36\,395 \times 10^{6}} - \frac{1}{3.395 \times 10^{6}}$

$= 5.2 \times 10^{8}$ J

(f) Total work = $KE + \Delta U = 3.49 \times 10^{9} + 5.2 \times 10^{8}$ J

$= 4.01 \times 10^{9}$ J

5.22.1.1 Torque is a measure of how much a force acting on an object causes that object to rotate.

5.22.1.2 (a) Torque = $r \times F_{\perp} \times \sin 90°$

$= 0.25 \times 250 \times \sin 90°$

= 62.5 N m anticlockwise.

(b) Torque = $r \times F_{\perp} \times \sin 60°$

$= 0.25 \times 500 \times \sin 60°$

= 108.25 N m clockwise.

(c) Torque = $r \times F_{\perp} \times \sin 60°$

$= 0.25 \times 250 \times \sin 60°$

= 54.1 N m anticlockwise.

(d) Torque = $r \times F_{\perp} \times \sin 30°$

$= 0.25 \times 500 \times \sin 30°$

= 62.5 N m anticlockwise.

(e) Torque = $r \times F_{\perp} \times \sin 30°$

$= 0.25 \times 250 \times \sin 30°$

= 31.25 N m clockwise.

(f) Torque = $r \times F_{\perp} \times \sin 60°$

$= 0.25 \times 250 \times \sin 60°$

= 9.64 N m clockwise.

(g) Torque = $r \times F_{\perp} \times \sin 30°$

$= 0.25 \times 500 \times \sin 30°$

= 54.1 N m anticlockwise.

(h) Torque = $r \times F_{\perp} \times \sin 30°$

$= 0.25 \times 250 \times \sin 30°$

= 31.25 N m clockwise.

(i) Torque = $r \times F_{\perp} \times \sin 30°$

$= 0.25 \times 500 \times \sin 60°$

= 108.25 N m anticlockwise.

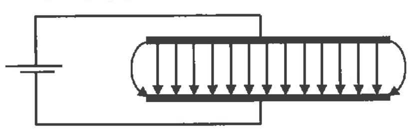
Module 6 Electromagnetism

6.1.1.1 (a) The field between parallel plates is directed from the positive plate to the negative plate and is uniform in intensity.
(b) The vector arrows will be directed from positive towards negative and they will be equally spaced.
(c) Relative intensity is indicated by the closeness of the vector arrows – the closer the vector arrows, the more intense the field.

6.1.1.2 (a) Top plate is the positive plate because, by definition, electric field is direction from positive towards negative.
(b) It will accelerate towards the bottom plate (note that if you said 'move' you are not quite correct).
(c) There will be no change in the force on it because the field between parallel plates is uniform in intensity.
(d) Work is done by the field.
(e) There will be no change in the force acting on it because electric field is uniform in intensity between parallel plates, but to move it, work will have to be done by an external source, because the field will place a force towards the top plate on it.

6.1.1.3 (a) A and C are correct diagrams. They correctly show a uniform field directed from positive to negative.
(b) A, B and C show a uniform field (B is, however in the wrong direction to be a correct representation) because the field lines are equidistant from each other.
(c) A is the strongest correct field because the field lines are closest together and drawn in the correct direction.

6.1.1.4 (a)



(b) Field lines are directed downwards from positive to negative plates.
Field lines are evenly spaced indicating uniform field intensity between the plates.
Field lines at the ends are curved as they leave and enter the surfaces of the plates at 90°.

6.1.1.5 C

6.1.1.6 From $E = \frac{V}{d}$, $8 \times 10^3 = \frac{400}{d}$
From which $d = 5$ cm

6.1.1.7 From $E = \frac{V}{d}$, $d = \frac{V}{E} = \frac{250}{5 \times 10^5} = 5 \times 10^{-4}$ m

6.1.1.8 C

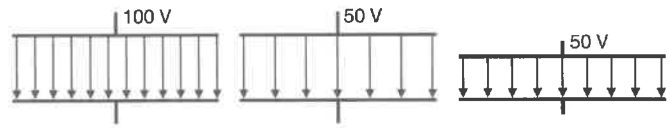
6.1.1.9 A

6.1.1.10 B

6.1.1.11 B

6.1.1.12 (a) E (Field between parallel plates is uniform in intensity.)
(b) E
(c) E
(d) E
(e) 1 : 1
(f) $2E$ (Next three from $E = \frac{V}{d}$)
(g) $0.5E$
(h) $2E$

6.1.1.13



6.1.1.14 (a) $0.5E$
(b) $3E$
(c) $0.25E$
(d) As no effect on the field, therefore still E.

6.1.1.15 (a) In each case, field is 25 000 V m^{-1}
(b) The distance apart is the same for each as is the potential different between them ($E = \frac{V}{d}$).

6.1.1.16 (a) 40 000 V m^{-1}
(b) 32 000 V m^{-1}
(c) 5000 V m^{-1}
(d) 50 000 V m^{-1}

6.2.1.1 (a) From $F = Eq$, $E = \frac{1.36 \times 10^{-3}}{4.2 \times 10^{-6}}$
$= 323.8$ V m^{-1} (or N C^{-1})
(b) From $E = \frac{V}{d}$, $d = \frac{300}{323.8} = 0.926$ m
(c) Mass $= \frac{1.36 \times 10^{-3}}{1.2 \times 10^{6}} = 1.13 \times 10^{-9}$ kg

6.2.1.2 D

6.2.1.3 D

6.2.1.4 From $E = \frac{F}{q} = \frac{2.0 \times 10^{-5}}{8.0 \times 10^{-3}} = 2.5 \times 10^{-3}$ N C^{-1} = B

6.2.1.5 C

6.2.1.6 (a) A
(b) No. The field lines are parallel and equally spaced and therefore represent the field between parallel plates.
(c) The particle will accelerate in the direction of the force because the force is an unbalanced, net force.

6.3.1.1 (a) $\Delta W = F\Delta x$
(b) $\Delta W = -q\Delta V$
(c) $F = -qE$
(d) $E = -\frac{\Delta V}{\Delta x}$
(e) V m^{-1}

6.3.1.2 From $W = qV = 1.6 \times 10^{-19} \times 15 = 2.4 \times 10^{-18}$ J = B

6.3.1.3 A

6.3.1.4 (a) X will accelerate to the left. Y will accelerate to the right.
(b) Work will be done by the field.
(c) Work will need to be done by an external force.
(d) Work will need to be done by an external force.
(e) Work will be done by the field.
(f) In each case, provided the distance moved is the same, twice the work will need to be done for each move of Y compared to X.

6.3.1.5 (a) From Y to X because Y is connected to the positive terminal of the power supply.
(b) From $q = It$, $I = \frac{5 \times 10^{18}}{6.25 \times 10^{18}} \times 1 = 0.8$ A
(c) From $W = qV = \frac{5 \times 10^{18}}{6.25 \times 10^{18}} \times 2500 = 2000$ J

6.3.1.6 B

6.3.1.7
(a) T – it is furthest from the point charge – the field lines are furthest apart at T.
(b) More work would be done moving the charge from R to T than from R to S because the distance to be moved in the field is greater between R and T. Because T is further from the point charge than R then the work done will be done by the field whereas, because S is closer to the point charge, the work would have to be done by an external force.
(c) S
(d) (i) Statement is incorrect. Point S is at a higher positive potential than point R, so work will need to be done by an external source to move the positive test charge to S.
(ii) No. Work will still be done to move the charge but this time it will be done by the field.

6.3.1.8
From $W = qE = 1.6 \times 10^{-19} \times 3500 = 5.6. \times 10^{-16}$ J
$= 3500$ eV

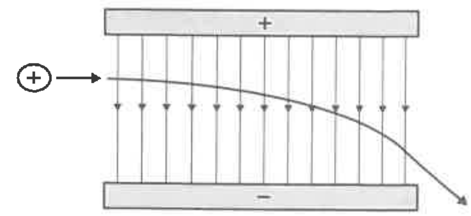
6.3.1.9
(a) From $W = qV$, $V = \frac{W}{q} = \frac{3.2 \times 10^{-17}}{1.6 \times 10^{-19}} = 200$ V
(b) 200 V
(c) Zero

6.3.1.10
(a) From $W = qV = 200 \times 1.8 \times 10^{6} = 3.6 \times 10^{8}$ J
(b) From $KE = \frac{1}{2}mv^2$, $v = \sqrt{2 \times 5000 \times 3.6 \times 10^{8}}$
$= 9.49 \times 10^{5}$ m s^{-1}
(c) Energy will be used to heat the water to 100°, then to evaporate it.
Therefore $W = mc\Delta T + m(\Delta H_v)$
$3.6 \times 10^{8} = (200 \times 4.18 \times 80) + (2260m)$
Therefore $3096m = 3.6 \times 10^{8}$
So, $m = 116.28$ kg (L)

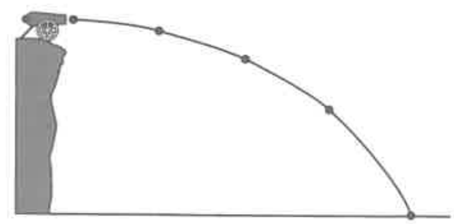
6.3.1.11
(a) The bottom plate is positive because field lines are directed away from positive towards negative.
(b) Towards the bottom plate – it is a negative charge so the force is in the opposite direction to the field.
(c) Force will not change. $F = Eq$, and both E and q do not change in values (field between parallel plates is constant).
(d) Work will need to be done on the charge by an external force because it is being moved closer to the negative plate (it is a negative charge and would not do this naturally).
(e) Work will not be done on the charge by the field because it is being moved closer to the negative plate, and being positive, this is the natural direction it will move as a result of the field.

6.3.1.12
(a) $E = \frac{V}{d} = \frac{20}{50 \times 10^{-3}} = 400$ V m^{-1}
(b) The electron will *accelerate* towards the positive plate.
(c) $F = Eq = 400 \times 1.6 \times 10^{-19} = 6.4 \times 10^{-17}$ N
(d) $a = \frac{F}{m} = \frac{6.4 \times 10^{-17}}{9.1 \times 10^{-31}} = 7 \times 10^{13}$ m s^{-2}
(e) $W = qV = 1.6 \times 10^{-19} \times 20 = 3.2 \times 10^{-18}$ J
($= Fs = 6.4 \times 10^{-17} \times 50 \times 10^{-3}$)
(f) $W = \Delta E_K = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2 = 3.2 \times 10^{-18}$
From which $v = 2.65 \times 10^{6}$ m s^{-1}
(g) (b), (c), (e) would be the same.
(d) would be 3.83×10^{10} m s^{-2}
(mass of proton $= 1.673 \times 10^{-27}$ kg)
(f) would be $\Delta E_K = \frac{1}{2} \times 1.673 \times 10^{-27} \times v^2$
$= 3.2 \times 10^{-18}$,
From which $v = 6.185 \times 10^{4}$ m s^{-1}

6.4.1.1
(a) The path will be parabolic.
(b) Ignoring any gravitational forces, the only force acting on the charge will be the force due to the field. This always acts in the same direction (vertically downwards in this example) and as there is no horixontal force, these are the conditions for projectile motion, so the charge will follow a parabolic path.
(c)



6.4.1.2
(a) The path will be parabolic.
(b) The only force acting on the projectile will be gravity. This always acts in the same direction (vertically downwards) and as there is no horixontal force (ignoring air resistance), these are the conditions for projectile motion, so the charge will follow a parabolic path.
(c)



6.5.1.1
Uniform circular motion.

6.5.1.2
Because a charged particle moving in a magnetic field undergoes uniform circular motion, the force acting on it must also be a centripetal force – hence the magnetic force equation can be equated to the equation for centripetal force.

6.5.1.3
Increase B, v or q.

6.5.1.4
(a) Forces will be equal in magnitude but opposite in direction. Equation shows force is independent of mass and all other variables are equal, so forces equal. Signs of charges are opposite, so forces in opposite directions.
(b) Forces will be the same magnitude, but opposite in direction.

6.5.1.5

(a)	Up	(b)	Out of page
(c)	Up	(d)	Into page
(e)	Out of page	(f)	Left
(g)	Out of page	(h)	Down
(i)	Right	(j)	Into page
(k)	Down	(l)	Into page
(m)	Into page	(n)	Left
(o)	Left	(p)	Out of page
(q)	Up	(r)	Into page
(s)	No force	(t)	Down
(u)	Out of page	(v)	Up
(w)	Right	(x)	No force
(y)	Out of page	(z)	Into page
(aa)	Out of page	(bb)	Right

6.5.2.1
A

6.5.2.2 (a) X is positively charged as determined by applying the right hand rule.
Y is negatively charged – it is deflected in the opposite direction to X.
(b) X is deflected more, so if the masses and speed are equal, it has a higher charge.
Or, if the charges and masses are equal, it has a higher velocity.
Or, if the speeds and charges are equal, it has less mass.
Or, there is some combination of two of the variables or all three that result in more deflection for X.

6.5.2.3 D (Use RHPR remembering that cathode rays are negatively charged.)

6.5.2.4 A

6.5.2.5 C

6.6.1.1 (a) From $F = Bqv \sin\theta = 0.4 \times 1.6 \times 10^{-19} \times 3.5 \times 10^5 = 2.24 \times 10^{-14}$ N up the page
(b) From $F = \frac{mv^2}{r}$,
$r = 2.0 \times 10^{-26} \times (3.5 \times 10^5)^2 \div (2.24 \times 10^{-14}) = 0.11$ m
(c) Because force is at 90° to the motion, the particle changes direction but not speed, so $v = 3.5 \times 10^5$ m s^{-1}.
(d) Will travel through a semicircle of diameter 0.22 m, therefore exits the field 0.22 + 0.02 = 0.24 m up from the bottom left corner or 6.0 cm down from the top left corner.

6.6.1.2 (a) 2.9×10^7 m s^{-1}
(b) 4.5×10^{14} N
(c) 1.7 cm

6.6.1.3 (a) 3×10^{-12} N
(b) Left (west initially, then in anticlockwise circular path)

6.6.1.4 (a) C (Use the RHPR)
(b) From $F = Bqv \sin\theta$, force is directly proportional to the charge, therefore C.
(c) Magnesium ion, being positive, will be deflected down, but being more massive than the alpha particle, will have more inertia and follow a path less curved than R.

6.6.1.5 (a) 0.5 T
(b) East (right)

6.6.1.6 C

6.6.1.7 B

6.6.1.8 (a) 0.5 T
(b) East (right)

6.6.1.9 (a) Force on electron from the east = 8×10^{-16} N out of the page (circular path while in field)
(b) Force on electron from the west = 8×10^{-16} N into the page (circular while in field)
(c) Force on electron from the south = 0 (parallel to the field) – travels in straight line

6.6.1.10 C

6.6.1.11 D

6.7.1.1 (a) $F = Eq = \frac{Vq}{d}$
(b) Because the force due to the field always acts in the same direction and because the component of the velocity of the charged particle perpendicular to the field is constant, the charged particle will follow a parabolic path.
(c) $F = Bqv \sin\theta = Bqv_{\perp}$
(d) Because the force due to the magnetic field is always perpendicular to the direction of motion of the charged particle, it follows a circular path with uniform motion.

6.7.1.2 From $F = Bqv \sin\theta = \frac{Vq}{d}$
$v = \frac{V}{dB} = \frac{200}{0.02 \times 0.01} = 1 \times 10^6$ m s^{-1}
Therefore answer = B

6.7.1.3 B (Being negatively charged, the magnetic field will deflect the cathode rays downwards, so the electric field deflection must be downwards – therefore the top plate is negatively charged. on the Note that the fields do not cancel each other, they act independently on the electron deflecting it in opposite directions.)

6.7.1.4 B (Being negatively charged, the magnetic field will deflect the cathode rays downwards, so the electric field deflection must be upwards – therefore the top plate is positively charged.)

6.7.1.5 (a) A
(b) By the RGPR a positive charge would be deflected to the bottom plate by the magnetic field and upwards by the electric field.

6.7.1.6 From $F = Eq = \frac{Vq}{d} = \frac{12.5 \times 1.6 \times 10^{-19}}{0.005} = 4 \times 10^{-16}$ = B

6.7.1.7 From $F = Bqv \sin\theta = 8 \times 10^{-2} \times 1.6 \times 10^{-19} \times 5 \times 10^3 = 6.4 \times 10^{-17}$ = A

6.7.1.8 Force due to electric field is larger, therefore electron moves through the fields but deflecting up the page = D

6.8.1.1 (a) Gravitational force between Moon and Earth acting towards centre of Earth.
(b) Electrostatic force between protons in the nucleus and electrons acting towards nucleus.
(c) Air pressure on the underside of the wings acting towards centre circle or loop.
(d) Frictional force between skates and ice acting towards centre of circle.

6.9.1.1 (a) Up
(b) Out of page
(c) Down
(d) Into page
(e) Into page
(f) Left
(g) Into page
(h) Down
(i) Right
(j) Into page
(k) Left
(l) Into page
(m) Out of page
(n) Right
(o) Towards bottom right hand corner of the field
(p) No force
(q) Towards bottom left corner of field
(r) Out of page
(s) No force
(t) Up the page
(u) Out of page
(v) Towards top right corner of field
(w) Towards top left corner of field
(x) Out of page
(y) Into page
(z) No force
(aa) Out of page
(bb) Towards bottom left corner of field

6.9.2.1 (a) A current carrying conductor placed in and at an angle to a magnetic field will experience a force.
(b) The length of the conductor, the flux density of the field, the sine of the angle between the direction of the current and the field (and the number of turns in the conductor if it is a coil).
(c) $F = nBIL \sin \theta$
(d) The direction of the magnetic flux and the direction of the current.
(e) The interaction of two (or more) magnetic fields.

6.9.2.2 (a) Electric currents *do not* interact with each other.
(b) Electric currents *do not* interact with magnetic fields.
(c) Stationary charges *do not* interact with magnetic fields.
(d) Moving charges *do not* interact with magnetic fields.
(e) Magnetic fields *do* interact with each other.
(f) A magnetic field *is* induced around all current carrying conductors.
(g) A magnetic field *is* induced around all moving charges.

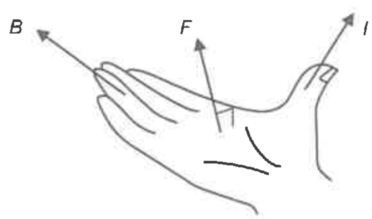
6.9.2.3 B

6.9.2.4 C

6.9.2.5 B

6.9.2.6 (a) A
(b) By using the right hand palm rule.

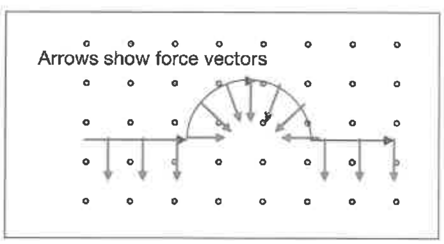
6.9.2.7 (a) C
(b)



6.9.2.8 (a) A
(b) Some component of the current must be perpendicular to the magnetic field for there to be a force. If $\theta = 0°$, then $\sin \theta = 0$, so force is zero.

6.9.2.9 D

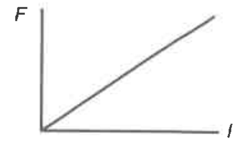
6.9.2.10 (a) C



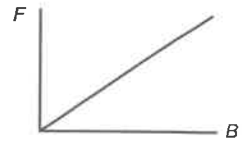
(b) Vector additions of the forces on either side of the semicircular section of wire all add together to give forces down the page.

6.9.2.11 B

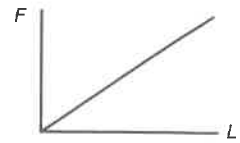
6.9.3.1 (a) D
(b)



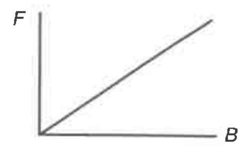
6.9.3.2 (a) A
(b)



6.9.3.3 (a) B
(b)

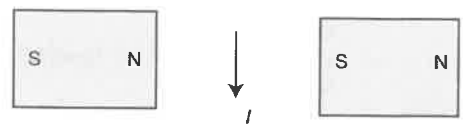


6.9.3.4 (a) C
(b)



6.9.3.5 From $F = nBIL = 1 \times 2B \times \frac{I}{3} \times 1 = \frac{2}{3}$ original F

6.9.3.6 (a) From $F = nBIL = 1 \times 4 \times 0.5 \times 0.05 = 0.1$ N up the page (from RHPR)
(b)



6.9.3.7 (a) From $V = RI$, current flowing $= \frac{12}{0.6} = 20$ A
From $F = nBIL = 1 \times 8 \times 10^{-4} \times 20 \times 0.012$
$= 1.92 \times 10^{-4}$ N
(b) From RHPR, current flows east to west.

6.9.3.8 (a) From $V = RI$, current flowing $= \frac{36}{4} = 9$ A
(b) From $F = nBIL = 1 \times 0.3 \times 9 \times 0.5 = 1.35$ N
(c) From $F = ma$, acceleration of the bar $= \frac{1.35}{0.04}$
$= 33.75$ m s^{-2} (in the direction of the force)
Therefore from $s = ut + \frac{1}{2}at^2$
$= 0 + 0.5 \times 33.75 \times 0.25^2 = 1.05$ m

6.9.3.9 For all, from $F = nBIL \sin \theta$, and the RHPR we get:
(a) 1.125 N south
(b) 0.3 N west
(c) 0.45 N IP
(d) 0.9 N OOP
(e) 0.27 N IP
(f) 0.225 N NW

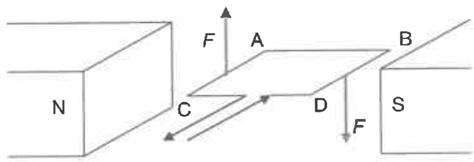
6.9.3.10 (a) B
(b) Force on the wire when current is flowing = reading on balance +/– weight force (depends on the direction of the current flow – motor force may be in same direction as weight force (if down) or opposite (if up). Having determined the motor effect force, she can calculate the magnetic field strength using $F = BIL$.

6.9.3.11 (a) Side AB Zero – current is parallel to the magnetic field.

Side BD Vertically downwards – by applying RHPR.

Side CD Zero – current is parallel to the magnetic field.

Side AC Vertically upwards – by applying RHPR.



(b) Side AB Back into the page – current is now perpendicular to the magnetic field.

Side BD Vertically downwards – by applying RHPR.

Side CD Forwards out of the page – current is now perpendicular to the magnetic field.

Side AC Vertically upwards – by applying RHPR.

(c) From $F = nBIL = 50 \times 0.25 \times 1.5 \times 0.1$
$= 1.875$ N upwards.

(d) From $F = nBIL = 1 \times 0.125 \times 1.5 \times 0.1$
$= 0.01875$ N upwards.

(e) From $F = nBIL = 1 \times 0.25 \times 3.0 \times 0.1$
$= 3.75$ N upwards.

6.9.4.1 (a) $2F$

(b) $0.5F$

(c) $0.5F$

(d) $1.73F$ ($\sin 60° = 1.73 \sin 30°$)

(e) $0.866F$

6.9.4.2 (a) From $F = nBIL \sin\theta$,

$$\sin\theta = \frac{0.3}{0.5 \times 2.5 \times 0.4} = 0.6$$

Therefore $\theta = 36.9°$

(b) Perpendicular to the field, $\theta = 90°$ because $\sin 90° = 1$ = maximum sine value.

(c) Parallel to the field, $\theta = 0°$ because $\sin 0 = 0$ = minimum sine value.

(d) 0.6 N because halving the resistance will double the current, which will double the force.

6.9.4.3 $F = nBIL \sin\theta = 1 \times 0.2 \times 3.0 \times 0.25 \times \sin 30°$
$= 0.075$ N into the page

6.9.4.4 C (Conductor is still perpendicular to the magnetic field. The 30° angle affects only the direction of the force not its magnitude.)

6.9.4.5 D (All the conductors are at right angles to the magnetic field.)

6.9.4.6 (a) From $F = nBIL = 0.17 = 1 \times B \times 2.5 \times 0.4 \times \sin 60°$
From which $B = 0.2$ T, therefore answer = A

(b) The direction of flow of the current.

6.9.4.7 From $F = nBIL \sin\theta$, if θ increases, then $\sin\theta$ also increases (conductor approaches becoming perpendicular to the field), so the force acting on the conductor will also increase.

6.9.4.8 From $F = nBIL_{\text{perpendicular}} = 1 \times 0.4 \times 5 \times 0.2 \times \sin 30°$
= A (direction by RHPR)

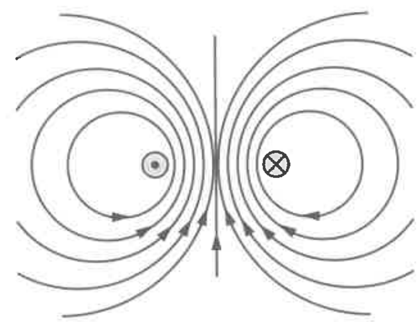
6.9.4.9 (a) From $F = nBIL_{\text{perpendiular}} = 1 \times 0.4 \times 5 \times 0.13 \times \sin 50°$
= A (direction by RHPR)

(b) This is a bit of a trick question in that when the angle is changed, the length of the conductor in the magnetic field also changes (becomes shorter $= \frac{0.1}{\sin 50°} = 0.13$ m) such that $L \sin\theta$ (= 0.1) remains the same (the perpendicular component of the conductor in the wire does not change, and it is this component that determines the force on the conductor). The force is unchanged.

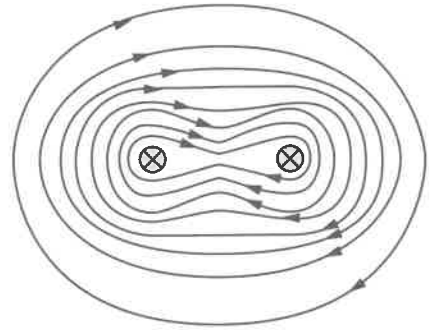
6.9.4.10 (a) D

(b) (A) and (B) because the force must be at right angles to both the magnetic field and the current. These two choices place the force in the same direction as the (perpendicular component of the) current.

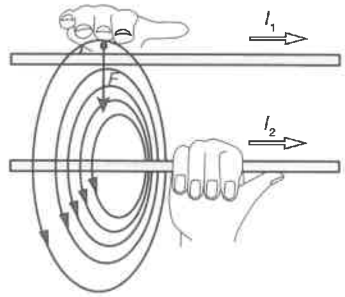
6.10.1.1 When the currents are in opposite directions, the magnetic fields between the conductors are in the same direction and so add together producing a stronger magnetic field between the conductors than outside them. This results in a force of repulsion between the wires.



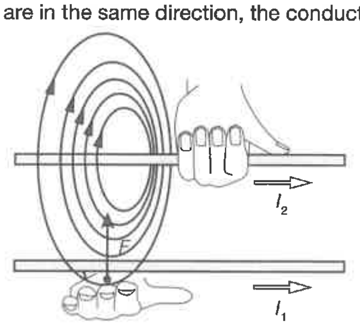
When the currents are in the same direction the fields between the wires are in opposite directions. They interact such that the intensity of the field between the wires is lower than that outside them. The result is a force of attraction between the wires.



6.10.1.2 The diagram shows the induction of a magnetic field due to I_2 and its direction using the right hand grip rule, and then the direction of the motor effect force in conductor 1 using the right hand palm rule. Wire 1 moves towards wire 2.



The same process applied to the top wire shows that the motor effect force on the bottom wire shows that wire 2 will be attracted to wire 1. When the currents are in the same direction, the conductors attract.



6.11.1.1 (a) 2×10^{-5} N attraction
(b) 8×10^{-6} N attraction

6.11.1.2 (a) 2×10^{-5} N repulsion
(b) 2.5×10^{-5} N repulsion

6.11.1.3 Force on X = vector sum of the force due to Y and Z
$= 9.6 \times 10^{-6}$ N repulsion + 6.4×10^{-6} N repulsion
$= 1.6 \times 10^{-5}$ N up (away from Y)
Force on Y = vector sum of the force due to X and Z = 9.6×10^{-6} N repulsion (down) + 7.2×10^{-6} N attraction (down)
$= 1.68 \times 10^{-5}$ N down (towards Z)
Force on Z = vector sum of the force due to X and Y = 6.4×10^{-6} N repulsion (down) + 7.2×10^{-6} N attraction (up)
$= 8.0 \times 10^{-6}$ N up (towards Y)

6.11.1.4 (a) B
(b) A

6.11.1.5 (a) D
(b) It wouldn't. If the force between them is the same, then the force per unit length would be the same.

6.11.1.6 (a) B
(b) From Newton's third law, the force on the wires will be equal and opposite in direction.

6.11.1.7 C

6.11.1.8 (a) C
(b) Force would be four times greater since, from the equation, force is directly proportional to the common length of the conductors.

6.11.1.9 D

6.11.1.10 (a) B
(b) The relationship between the forces would not change.

6.11.1.11 (a) C
(b) The current in Y contributes to the force on conductor Y twice – through interaction with both X and Z. The forces on X and Z are increased only by their interaction with Y – the force between X and Z does not change. Therefore, the force on Y is increased more than the forces on X and Z.

6.11.1.12 (a) A
(b) When the current flows in the loop, any small increments of the length of the wire in the loop of wire opposite any other lengths of the loop will carry currents in opposite directions, so the lengths will repel each other. The wire will move into a circular shape.

6.11.1.13 (a) A
(b) 0.5 N

6.11.1.14 (a) A
(b) It is only the parallel length of the wires close together that contributes significantly to the force.

6.11.1.15 B

6.11.1.16 C

6.11.1.17 B

6.11.1.18 (a) D
(b) Because counterbalance mass needs to beaded, the wires attract each other, which means the currents in them are flowing in the same direction, but it is not possible to say either to the left or right, so either (A) or (B) could be correct. More information is needed to decide.

6.11.1.19 C

6.11.1.20 D

6.12.1.1 Magnetic flux is a measure of the amount of magnetic field permeating an area. Measured in webers (Wb).

6.12.1.2 Magnetic flux density is a measure of the amount of magnetic field per unit area. Measured in webers per square metre (Wb m^{-2}) also known as teslas (T).

6.12.1.3 Both diagrams have 9 units of magnetic field through them (represented by the 9 crosses), so both have the same magnetic flux permeating them. Diagram A has these 9 units of flux through 4 m^2 while diagram B has 9 units of flux through only 1 m^2. Therefore, the magnetic flux density through A is 2.25 units (T) and that through B is 9 units.

6.12.1.4 (a) Weakest A < F < B, < E < C = D Strongest
(b) Weakest A < C < B < F < D < E Strongest

6.12.1.5 (a) *W*
(b) 2*B*
(c) *W*
(d) 0.5*B*
(e) *W*
(f) 0.33*B*

6.12.1.6 (a) D
(b) Magnetic flux is a measure of the amount of magnetic field permeating an area.

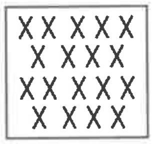
6.12.1.7 (a) B
(b) (i) Into the page = collection of symbols like this: × × ×
(ii) Out of the page = collection of symbols like this: • • •
(iii) Down the page = vector arrows like this: ↓ ↓ ↓
(iv) From left to right = vector arrows like this: → → →

6.12.1.8 A

6.12.1.9 Magnetic flux = webers (Wb).
Magnetic flux density = teslas (T).

6.12.1.10 C

6.12.1.11 (a) A
(b) It doesn't. It stays the same.

6.12.1.12 (a) D
(b) 
(Need twice as many crosses closer together)

6.12.1.13 B Initial flux though the coil is zero, so coil must be parallel to the magnetic field initially.

6.12.1.14 A

6.12.1.15 As the coil rotates past 180° from its initial position, the flux through it must change direction. Only (A) shows this change in direction. The other three choices do not.

6.12.1.16 C (Each 'hump' in the graph represents 180° of rotation.)

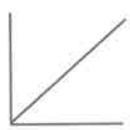
6.12.1.17 (a) D
(b) Yes – all of them at the position of the coil in the magnetic field except the position shown – i.e. if the area is *not* parallel to the field, other actions would all increase the flux through the coil.

6.12.1.18 C

6.12.1.19 Magnetic flux (A): magnetic flux (D) = 9 : 4

6.12.1.20 B

6.12.1.21 Area A has 9 units of flux in an area of 432 mm^2 which gives it a flux density of 0.0208 units. D has 4 units of flux in an area of 200 mm^2 which gives it a flux density of exactly 0.02 units. Therefore A has the slightly higher flux density, although if you said they were equal, this can be accepted as correct.

6.12.1.22 (a) A
(b) 

6.12.1.23 A < B < C. This is the order of the area of each coil perpendicular to the field lines and therefore also the order of the amount of flux through each.

6.12.1.24 (a) B or C (b) C
(c) B (d) A

6.13.1.1 Induced potential difference is potential difference produced whenever there is relative movement between a conductor and a magnetic field.

6.13.1.2 Induced potential difference is potential difference produced whenever there is relative movement between a conductor and a magnetic field.

6.13.1.3 The rate of the relative movement between the conductor and the magnetic field.

6.13.1.4 The relative direction of the movement between the conductor and the magnetic field.

6.13.1.5 In 1831 Michael Faraday did a series of experiments that showed that when he moved a magnet into or out of a coil of wire, an electric current flowed in the coil. In his first experiment, he simply moved a magnet into and out of a coil and noticed that the ammeter in the circuit registered a current whose direction depended on the direction of movement of the magnet. He also noted that the size of the induced current depended on how fast the magnet (or coil) was moved and the strength of the magnet.
Faraday also experimented with two coils of wire wrapped around opposite sides of a soft iron ring. He noticed that when he switched on the current in the first loop nothing happened, but when he switched the current on and off continuously, a current was induced in the second circuit. He concluded that it was the changing current in the first coil that caused the induced current in the second coil.

6.13.1.6 When there is relative movement between a conductor and a magnetic field (either physical movement or change in magnitude of the magnetic field) a potential difference is generated. If the conductor is part of an electric circuit, a current is induced in the circuit. The magnitude of the induced potential difference is directly proportional to the rate at which the conductor 'cuts through' the magnetic field.

6.13.1.7 (a) Current increases.
(b) Current decreases and is in opposite direction.
(c) Same magnitude current but in opposite direction.
(d) Double the current in original direction.
(e) Current halves.
(f) Current doubles.
(g) Current more than doubles in same direction.

6.13.1.8 Relative motion refers to the fact that the conductor can be moving and the magnetic field is stationary, or the conductor is stationary and the magnetic field is changing in intensity.

6.13.1.9 (a) Strength of magnetic field, how fast the magnet is moving, or how quickly the magnetic field is changing, whether the magnet is moving towards the coil or out of the coil, south or north pole nearest the coil, number of turns in the coil.
(b) Each of the variables listed is directly related to the 'relative movement' between the coil and the field either in terms of the speed of the movement or the direction of the movement.

6.13.1.10 (a) B
(b) Emf will be in opposite directions as magnet enters and leaves the coil, so (A) and (D) must be incorrect, and while the magnet is totally inside the coil, rate at which flux is cut is constant therefore there will be zero emf, so (C) is also incorrect. This leaves (B).

6.13.1.11 B

6.13.1.12 D

6.13.1.13 C

6.13.1.14 C

6.13.1.15 A

6.13.1.16 A

6.13.1.17 B (Note that (A) says 'affected by' – it doesn't specify whether this effect is to make the current smaller, larger, opposite direction, turn it purple or whatever. (C) and (D) each only mention one of the two variables studied.)

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6.13.1.18 C (*Note:* Using a strong magnet in Q but from a lower height than R and S would make the induced current definitely less than R or S. However, not knowing the ratio of the heights, we cannot say anything definite about the comparison between the induced currents in P and the new Q. Therefore the only definitely correct answer is (C).)

6.13.1.19 Many possibilities, for example:
By using different sized coils by dropping the magnets from a larger variety of heights.
By dropping a larger variety of strength magnets.
By recording current on a data logger.
By taking multiple readings for each run.

6.13.1.20 (a) B
(b) When the conductor is moved horizontally (towards the north pole) no magnetic flux is cut, so no induction occurs.

6.13.1.21 C

6.13.1.22 C (The AC current in coil X induces a changing magnetic field around coil X and this induces a current in coil Y.)

6.13.1.23 B (The iron cores will increase the transmission of the magnetic field from coil X to coil Y, so there will be a stronger magnetic induction near coil Y and therefore an increased induced current in coil Y.)

6.13.2.1 The direction of any induced potential difference will be such that it opposes the change that causes it.

6.13.2.2 Whenever there is an induced potential difference.

6.13.2.3 C

6.13.2.4 A

6.13.2.5 (a) X to Y
(b) X to Y
(c) Y to X
(d) Y to X

6.13.2.6 (a) Up the page
(b) To the right
(c) To the left
(d) Up the page

6.13.2.7 (a) From left to right
(b) Into the page
(c) Down the page
(d) Down the page

6.13.2.8 D (All the other choices result in either more magnetic flux being cut, (A) and (C), or in magnetic flux being cut more rapidly, (B)).

6.13.2.9 (a) D
(b) Rod, although circling, is always cutting a constant amount of magnetic flux and in the same direction relative to the field. So, emf is constant, and in a constant direction (from Y to X).

6.13.2.10 B

6.13.2.11 A (The emf would increase as the magnetic flux would be cut at a faster rate.)

6.13.2.12 C

6.13.3.1 (a) C
(b) If switch is closed, relative movement between the magnetic field and the coil will induce a current in the coil. The direction of this current will be such that the magnetic field it induces will oppose the motion of the magnet moving towards the coil – therefore more energy is needed if switch is closed.

6.13.3.2 (a) B (Note that B is a better answer than A. A implies a constant field but this may not necessarily be the case.)
(b) There will be no induced emf because the flux through the coil is still not changing.

6.13.3.3 C

6.13.3.4 A

6.13.3.5 (a) D
(b) Direction of the induced emf will be such that it induces a magnetic field so as to oppose the increase in the existing field. By applying the RHGR, we get an anticlockwise emf (current).

6.13.3.6 (a) C
(b) As the coil expands and contracts continually the amount of flux through it increases and decreases continually resulting in an induced emf which is continually changing direction. This will produce AC current in the coil.

6.13.3.7 (a) C
(b) Because coil will be crossing into a weaker magnetic field, the flux through it will be decreasing, so the direction of the induced emf and current in it will change – i.e. there will be an anticlockwise emf induced in the coil.

6.13.3.8 (a) B
(b) The size of the induced emf would increase.

6.13.3.9 Induction requires a changing magnetic field. With DC supply, the emf is constant and so the induced magnetic field is constant. No induction occurs in the second coil. AC provides a constantly changing emf and therefore a constantly changing magnetic field which causes induction in the second coil.

6.13.3.10 (a) Induced current flows XAY
(b) Induced current flows XAY

6.13.3.11 (a) A
(b) The direction of the induced current in each solenoid will be such that they both induce magnetic fields to oppose the movement of the magnetic fields which are approaching them. In other words, both induced magnetic fields will be repulsive, resulting in both solenoids being repelled and therefore moving to the left.

6.13.3.12 D (Applying the RHGR for solenoids and Lenz's law provides the answer to this question.)

6.13.3.13 A No induction
B Clockwise
C No induction
D Anticlockwise
E No induction
F No induction
G No induction
H No induction
I Anticlockwise
J Clockwise
K Clockwise
L Anticlockwise

6.13.3.14 (a) A
(b) There would be no induced current but there would still be an induced emf in the coil in the same direction.

6.13.3.15 (a) Momentary current flows as emf is induced in the coil attached to the galvanometer as current grows from zero to a steady amount.
(b) Reading is zero as there is no changing emf in the first coil to cause induction in the second coil.
(c) Momentary current in galvanometer in opposite direction to (a) as current reduces to zero.

6.14.1.1 Transformers are used in electrical circuits to either step up or step down the voltage in the circuit. In this way power losses through heating effects during transmission will be minimised and components in the circuit will operate correctly and will not be damaged.

6.14.1.2 Step-up transformers change low voltages into higher voltages. They have more turns in their secondary coils than in their primary coils. Their output current is lower than their input current. Step-down transformers change high voltages into lower voltages. They have fewer turns in their secondary coils than in their primary coils. Their output current is higher than their input current.

6.14.1.3 (a) From $V_P n_S = V_S n_P$,
$12 \times n_S = 1.5 \times 2400$
Therefore $n_S = 300$
(b) From $V_P I_P = V_S I_S$,
$12 \times 10 = 1.5 \times I_S$
Therefore $I_S = 80$ mA

6.14.1.4 (a) Step-up
(b) Ratio of voltage = 1 : 100 so ratio of turns in coils is also 1 : 100
(c) It would be used in an old cathode ray tube TV.

6.14.1.5 (a) Ratio turns = ratio voltage = 11 000 : 240 = 45.8 : 1
(b) Step-down
(c) From $(VI)_P = (VI)_S$
$11\,000 \times 5 = 240 \times I_S$
Therefore $I_S = 229.16$ A
(d) The transformer must have an internal resistor to reduce the current to the required 10 A.
(e) From $V_P : V_S = n_P : n_S$
$11\,000 : 240 = 2000 : n_S$
Therefore $n_S = 43.7$

6.14.1.6 Changing current in the primary coil induces a changing magnetic field in the iron core which in turn induces a current in the secondary coil. Induction in the output coil is proportional to the ratio of the coils in the primary and secondary coils.

6.14.1.7 A constantly changing supply voltage is needed to produce a varying induced magnetic field to induce an output voltage.

6.14.1.8 (a) Input is 240 volts AC voltage with frequency 50 cycles per second, producing 15 amps of current. Output, because of other electrical components built into transformer circuit, is 12 volts direct current voltage producing 1 amp of current. (Note that the output from the transformer component of the device would be 12 V, 300 A).
(b) Step-down
(c) Changing AC input to DC output.
(d) 100 (voltage ratio is 20 : 1, therefore coil ratio is also 20 : 1)
(e) If voltage steps down by a factor of 20, current will increase by a factor of 20 = 15 × 20 = 300 A
(f) Output circuit must have a resistor in circuit to reduce current to required value (1 amp).
(g) The transformers get hot as internal resistance converts the excess electrical energy into heat energy, allowing only the desired output current to go into the attached device.

6.14.1.9 A (The induced magnetic fields and voltages involved in the operation of a transformer are covered by the principle of electromagnetic induction which was discovered and developed by Faraday.)

6.14.1.10 (a) B
(b) In order for power input and power output to be equal (so as not to violate the law of conservation of energy), if voltage is stepped up, then current must be lower – always.

6.14.1.11 (a) Step-down
(b) Number of coils in output circuit is fewer than the number in the input coil.
(c) 250 is input, 50 is output
(d) Ratio coils = 5 : 1, therefore ratio voltage = 5 : 1, therefore output voltage = $\frac{220}{5}$ = 44 V

6.14.1.12 (a) A
(b) D Real transformers would not be 100% efficient in their energy conversion, so some power would be lost in the transformations. Output power would therefore be less in both cases.

6.14.1.13 (a) Same
(b) Same
(c) Current
(d) Each side of this transformer cancels the effect of the other – input and output voltages and currents are identical. There is no point in having a device which simply cancels itself out in a circuit.
(e) Transformer at a substation needs to be a step-down transformer so that input power is a high voltage to minimise energy losses through heating effects and output voltage is at an appropriate lower voltage for transmission to district substations or homes.

6.14.1.14 (a) A
(b) The iron core is used to increases the permeability of the magnetic field induced by the changing current in the primary coil so that there is a more efficient induction of emf in the secondary coil. The laminations are to reduce the induction of eddy currents in the core and so minimise heat energy losses and therefore increase the efficiency of the transformer.

6.14.1.15

	Appliance containing transformer	Step up or down?
1	Cathode ray tube TV	Step up
2	Battery charger	Step down
3	Clocks in ovens	Step down
4	Printer	Step down
5	Portable electric drill	Step down
6	Bedside lamps	Step down
7	Computer	Step down
8	Telephone	Step down
9	LCD TV monitor	Step down
10	Low voltage lights	Step down

6.14.1.16 (a) C
(b) Given that the voltage is directly proportional to the number of turns in the coil and that power in and out must be conserved, then whatever happens to the voltage, the inverse must happen to the current. Therefore, current is indirectly proportional to the number of turns in the coils.

6.14.1.17 (a) Input = 864 V, 15 A
(b) V_2 = 432 V, 30 A
(c) V_3 = 576 V, 22.5 A

6.14.1.18 (a) C
(b) 16 : 3

6.14.1.19 (a) C
(b) D It must be a step-down transformer, so number of turns in the secondary coil has to be fewer than 640.

6.14.1.20 By the law of conservation of energy, the power output from a transformer cannot exceed the power input, so if voltage is stepped up, current must be stepped down by an equivalent factor ($VI_{in} = VI_{out}$).

6.14.1.21 (a) Step down
(b) 105 V, 22.9 A

6.14.1.22 C

6.14.1.23 A

6.14.1.24 C

6.14.1.25 A

6.15.1.1 (a) The flux linkage of a solenoid is equal to the product of the flux density through each turn in the coil and the number of turns.
(b) Flux linkage is directly proportional to the number of turns in the coil.
(c) Incomplete flux linkage refers to the efficiency at which the magnetic flux from one coil in a transformer is transferred to the second coil of that transformer.
(d) Because the rate of transfer of flux determines the induced emf produced by a coil and because transformers work on the principle of induced emf's, then incomplete flux linkage will result in less induced emf than theoretically possible, therefore reducing the efficiency of the transformer.

6.15.1.2 Answers will vary, for example: As seen in previous problems, transmission at low voltages and high currents over almost any distance from power stations is impossible – so transformers are needed for this. Power supply to isolated areas would not be possible. Many would be relying on their own generators or solar cells. In addition, if we had appliances requiring different voltages to operate correctly, then additional complete transmissions lines would have to be provided for each different voltage. Electricity would be enormously expensive.

6.15.1.3 Transformers are used at generating stations to step up transmission voltage to mimimise energy losses by heating effects during transmission. Step-down transformers lower the voltage at the consumer end to safer and more usable sizes.

6.15.1.4 (a) and (b) – answers in the table.

	Homes	Factories	Street networks	Suburban substation	City substation	Power stations
Voltage	240	415	11 000	33 000	132 000	500 000
Coils	1000	1729	45833	137 500	550 000	2 083 333
Current	15	8.67	0.33	0.11	0.027	0.0072

(c) At high voltages the current is much smaller, so loss of energy through heating effects in the transmission wires is reduced ($P_{loss} = I^2R$).

6.15.1.5 (a) From $P = VI$
4 000 000 = 500 000 × I
Therefore I = 80 A
(b) From $P_{loss} = I^2R$
P_{loss} = 80 × 80 × 4.0 = 25 600 W (per kilometre)
(c) Loss over 50 km = 25 600 × 50
Therefore % loss = [(25 600 × 50) ÷ 4 000 000] × 100 = 3.2%

6.15.1.6 B

6.15.1.7 (a)

Transmission voltage (V)	30 000	50 000	250 000	500 000
Power generated	4 MW	4 MW	4 MW	4 MW
Current in lines ($I = \frac{P}{V}$)	133.33	80	16	8
Power loss in lines ($P = I^2R$)	3 555 555	1 280 000	51 200	12 800
Power left after losses	444 444	2 720 000	3 948 800	3 987 200
Power lost (%)	89	32	1.28	0.32

(b) Energy losses if transmitted at low voltage make transmission totally ineffective – must be transmitted at high voltages.

6.15.1.8 (a) A
(b) The moving electrons in the current collide with atoms and other electrons in the transmission lines, and these collisions, being non-elastic, result in a transfer of kinetic energy from the electrons carrying the current to other particles in the lines. This appears in the lines as heat energy.

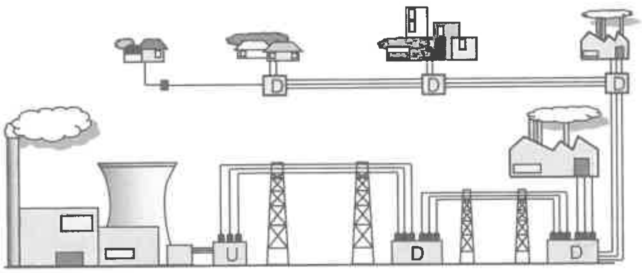
6.15.1.9 (a) B
(b) A constantly changing magnetic field is needed to induce an output emf in a transformer. Direct current induces a constant magnetic field, so it cannot be transformed.

6.15.1.10 (a) A
(b) 350 000 to 500 000 volts.

6.15.1.11 (a) Six – there are six output connection terminals plus the common (bottom) terminal.
(b) (i) 350 V (ii) 300 V
(iii) 200 V (iv) 100 V
(c) 250 V

6.16.1.1 When answering 'impact' questions, give at least two examples and then describe how they affect you and then outline what other things you can do because of them. Many possible answers, e.g. Electricity allows the use of computerised games and learning (1). This provides entertainment at home and opportunities to reinforce school work (1). This can lead to better results at school and better employment opportunities down the track (1). These in turn will allow a better adult lifestyle (1). Another example: The domestic use of electricity has enabled me to use many handyman tools and learn many carpentry skills (1). This has provided a hobby for leisure time as well as allowing me to build useful items which I might otherwise either not have or have to pay for (1). This leaves my pocket money free for other pursuits (1). In the future these skills may save a lot of money in adult life allowing for available money to be used on other things – clothes, education for children, leisure activities (1).

6.16.1.2 (a)



(b) The transformer closest to the power station is the step-up transformer to transmit power the longest distances at the lowest current (highest voltage) to minimise energy losses through heating effects.

The step-down transformers in the rest of the line are there to lower the voltage to safer levels in areas where people work with or use those voltages.

6.16.1.3 Because it is a step-down transformer, the voltage drops and the secondary current will increase accordingly. Because the device only works on a very small current, most of the current produced in the secondary coil has to be diverted through a resistor inside the transformer. This produces wasted heat energy ($P = I^2R$) which makes the transformer get warm.

6.17.1.1 A torque is a turning force caused by two equal and opposite forces and is equal to the product of the magnitude of those forces and the perpendicular distance between them.

6.17.1.2 $\tau = Fr$

τ = torque measured in newton metres (N m).

F = refers to the equal and oppositely acting forces in newtons.

d = perpendicular distance between the two forces in metres.

or

$\tau = nBIA \cos\theta$

τ = torque measured in newton metres (N m).

n = number of turns in the coil.

B = magnetic field strength (flux) in teslas.

I = current in coil (amperes).

$A \cos\theta$ = area of coil parallel to the magnetic field.

6.17.1.3 (a) B

(b) C (The perpendicular distance between the two forces on the opposite sides of the coil.)

(c) D (The perpendicular distance between the two forces on the opposite sides of the coil is affected by the rotation of the coil according to the cosine of the angle of rotation.)

6.17.1.4 D

6.17.1.5 B

6.17.1.6 There are no forces on the top and bottom wires because the currents are parallel to the magnetic field.

6.17.1.7 (a) B

(b) There is now a torque on the coil as the two forces, acting in opposite directions, are a distance apart.

6.17.1.8 (a) A

(b) After rotating 90° the two forces (on sides X and Y) will be directly opposed to each other, so the torque on the coil will be zero. It will stop moving.

6.17.1.9 B (Changing the lengths of the sides quarters the area of the coil.)

6.17.1.10 D (Changing either one of these would reverse the direction of the torque, but changing two variables means the reverse has been reversed again – i.e. no change in direction. None of the magnitudes of the variables have been changed so the size of the torque does not change.)

6.17.1.11 From $T = nBIA \cos\theta$,

$B = \dfrac{0.35}{25 \times 0.4 \times 0.1 \times 0.1 \times 1} = 3.5$ T. Therefore answer = C

6.17.1.12 C

6.17.1.13 (a) From $T = nBIA \cos\theta$,

$B = (\dfrac{T}{\cos\theta}) \div nIA = \dfrac{\text{gradient of graph}}{nIA}$

$= \dfrac{0.8}{250 \times 4 \times 0.0016} = 0.5\text{ T} = \text{C}$

(b) Torque would be doubled.

6.17.2.1 (a) AB The component of AB perpendicular to the field is CD sin 30°, so from

$F = nBIL \sin\theta$

$= 150 \times 0.25 \times 3 \times 0.05 \times \sin 30°$

$= 2.8125$ N

BD From $F = nBIL \sin\theta$

$= 150 \times 0.25 \times 3 \times 0.05 \times \sin 90°$

= the two sides at 30° to the magnetic field,

$F = 5.625$ N (BD is perpendicular to the field.)

CD The component of CD perpendicular to the field is CD sin 30°, so from

$F = nBIL \sin\theta$

$= 150 \times 0.25 \times 3 \times 0.05 \times \sin 30°$

$= 2.8125$ N

CA From $F = nBIL \sin\theta$

$= 150 \times 0.25 \times 3 \times 0.05 \times \sin 90°$

= the two sides at 30° to the magnetic field,

$F = 5.625$ N (AC is perpendicular to the field.)

(b) From $\tau = Fr = 5.625 \times 0.05 \times \cos 30°$

$= 0.24$ N m anticlockwise, or

From $\tau = nBIA \cos\theta$

$= 150 \times 0.25 \times 3 \times 0.05 \times 0.05 \times \cos 30°$

$= 0.24$ N m anticlockwise

(c) When area of coil is parallel to the magnetic field ($\theta = 0$, $\cos\theta = 1$).

(d) When area of coil is parallel to the magnetic field ($\theta = 90°$, $\cos\theta = 0$).

6.17.2.2 (a) A

(b) Torque would be 0.09 N m because the area would be 625 cm^2, 25 times greater than the area of the given coil.

6.17.2.3 Letters refer to labels on the graph.

(a) When area of coil is parallel to the magnetic field torque acting on it is maximum value.

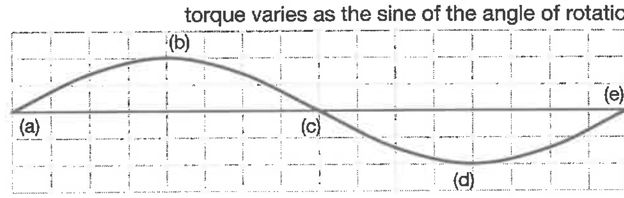
(b) As it rotates through the 90° the torque increases to minimum value (= zero) as its area is perpendicular to the magnetic field.

(c) Rotation to 180° increases torque to maximum again, and

(d) To 270° to zero,

(e) Then at 360° (back in its original position), the torque is maximum again.

Between minimum and maximum values, the torque varies as the sine of the angle of rotation.



6.17.2.4 From $\tau = nBIA \cos\theta$

$= 250 \times 0.04 \times 3.2 \times 0.1 \times 0.1 \times \cos 50°$

$= 0.21$ N m = A

6.17.2.5 A

6.17.2.6 (a) A

(b) When angle is zero, torque is maximum, and torque varies as the cosine of the angle, so (A) must be correct.

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6.17.2.7 (a) B
(b) A

6.17.3.1 A simple DC motor works because the current flowing through the coil indicates a magnetic field around the coil. This field interacts with the magnetic field produced by the stator magnet to produce forces on each side of the coil perpendicular to the field (the motor effect). The opposing forces produce a torque which rotates the coil.

6.17.3.2 (a) B
(b) All other factors being equal, the 5000 turn motor will develop twice the torque of the 2500 turn motor.

6.17.3.3 (a) A
(b) The key phrase here is 'relative to the magnetic field', and the current needs to be in the same direction in the coil relative to the magnetic field (i.e. clockwise or anticlockwise). To do this, yes, the split rings change the direction of the current through the coil 'relative to the external circuit'. Make sure you are clear on the difference here – it is the subtle difference in the language used that is important.

6.17.3.4 (a) D
(b) Current enters the coil through lead U and exits through lead Z (flows clockwise through the coil as we look at it in the diagram).
(c) B
(d) Assuming the axle of rotation is metallic for strength, the split rings need to be insulated from it or current will flow continuously through the coil regardless of the position of the split rings.
(e) There are typically two different answers to this question. The most common is:
- To change the direction of the current in the coil so that the rotor continues to turn in the same direction.

A better answer, which is technically more correct is:
- To ensure that the current in the coil is always in the same direction relative to the magnetic field so that the coil rotates in a constant direction.

6.17.3.5 (a) D
(b) Electromagnets produce a stronger field than bar magnets and the soft iron core intensifies the electromagnetic induction, so both these features will result in a stronger magnetic interaction and therefore a stronger forcer on the sides of the coil, and therefore a stronger torque. Increasing the number of coils will also increase the net force on the rotor ($F = nBIL$ for each coil), and therefore the net torque on the rotor.

6.17.3.6 (a) C
(b) Increase the number of turns in its coil, increase the current flowing through it, add a soft iron core (laminated) it if does not already have one.

6.17.3.7 (a) B
(b) The torque produced by a motor depends on the forces on the windings, and from $F = nBIL$, this depends (partly) on the strength of the magnetic field. Using electromagnets means the force, and therefore the torques can be altered by simply changing the strength of the electromagnetic field (among other ways).

6.17.4.1 A back emf is an induced potential difference which opposes any supply potential difference (as in electric motors).

6.17.4.2 Because a motor involves relative movement between a conductor (the coil) and a magnetic field, an induced emf will be produced which opposes the direction of the supply emf and therefore the direction of rotation of the motor coil.

6.17.4.3 The back emf will reduce the effective supply emf, so to get maximum efficiency from the motor, the supply emf will need to be larger than the emf needed by the amount of the back emf. This means that until the motor reaches maximum speed, the current flowing through the coil may be too large, so a variable resistor needs to be built into the circuit. This resistor automatically reduces to zero as running speed (and maximum back emf) is reached.

6.17.4.4 From $V = IR$, the motor should produce $\frac{12}{1.5} = 8$ A
It only produces 3 A, therefore from $V = IR = 3 \times 1.5 = 4.5$ V, therefore effective voltage is only 4.5 V.
Therefore, the motor produced a back emf of 7.5 volts.

6.17.4.5 The direction of any induced emf will be such that it induced a magnetic field which will interact with the applied magnetic field to oppose the change that causes it.

6.17.4.6 D

6.17.4.7 (a) B
(b) The principle of electromagnetic induction produces the back emf in the coil as it rotates in the magnetic field of the motor, and Lenz's law, which is really an application of the law of conservation of energy, is used to determine its direction.

6.17.4.8 (a) C
(b) If the speed of the motor decreases then the rate at which its coil is cutting flux also decreases so the induced back emf will decrease.

6.17.4.9 (a) D
(b) If the back emf did not exist, then more input energy would be converted to output energy. This would increase the efficiency of the motor. If the back emf was, in fact, a forwards emf which is what the question is implying, then additional input energy would be supplied for no additional energy input. The efficiency of the motor would be further increased.

6.17.4.10 (a) A
(b) Initially, with the motor coil not moving or not moving at maximum speed, the back emf in the motor will be low, so the supply current may be too large and cause the coils to overheat. The resistor is used to reduce this initial current and then adjust itself to zero resistance as back emf increases and takes over its role – reducing the current through the coil to protect it from overheating.

6.17.4.11 (a) D
(b) They often contain a variable internal resistor which reduces supply current when the motor coil is not turning and reduces to zero resistance when the motor is operating normally and is producing a back emf which assumes the role of this resistor.

6.17.4.12 (a) D
(b) Back emf is induced in the motor's coil as it rotates in the stator magnetic field. This rotation is the essence of the operation of a motor and cannot be changed.

6.17.4.13 (a) B
(b) As motor in the drill slows down back emf decreases, so the net supply emf increases which allows for a greater current through the coil.

6.17.4.14 (a) C

(b) Any current carrying coil moving inside a magnetic field will have an emf induced in it (Faraday's law). The direction of this emf will be such that it opposes the change causing it (i.e. the motion caused by the supply emf – Lenz's law). The induced emf will therefore oppose and reduce the supply emf.

6.17.4.15 (a) B

(b) Because there is no changing magnetic field in the DC circuit, there will be no induction in the coil, so the brightness of the globe is not affected. In the AC circuit, the AC current induces a changing magnetic field which the soft iron core intensifies and this changing field induces a (back) emf in the coil. This opposes the supply emf, so the brightness of the globe decreases.

6.18.1.1 Both operate because of the interaction of a magnetic field induced in their coils as current flows through them with the stator magnetic field. The only difference in operation is the split ring commutator in the DC to ensure that the direction of the torque on the coil is constant. The phase changes in the input AC do this automatically.

6.18.1.2

Part	Name of part	Function(s) of part
U	Slip rings	To provide electrical contact between the input AC and the motor coil.
V	Carbon brushes	To provide electrical contact between the input AC and the slip rings.
W	Stator magnets	To provide the stator magnetic field.
X	Connection to the negative terminal of the power supply	To connect power supply to output current.
Y	Connection to the positive terminal of the power supply	To provide input current from the power supply.
Z	Rotor axle	To allow the rotor to rotate.

6.18.1.3 A

6.18.1.4 (a) Student A – incorrect. The slip rings are simply electrical contact for the ends of the wire making up the coil and the carbon brushes, Student B – also incorrect in that it is the phase change in the AC itself that results in a constant direction of flow of the current through the coil and therefore the constant direction torque.

(b) B is better because the statement that the function of the slip rings is to 'ensure that the direction of the current flow though the coil is in the same direction relative to the magnetic field' is correct and does not necessarily imply that the rings actually do anything – it is the phase change in the AC that does this as long as the slip rings do nothing except maintain the electrical contact.

6.18.1.5 C The torques must be in the same quadrant so that the motor coil continues to rotate in the same direction. The phase change in the AC supply ensures this.

6.18.1.6 D The torques must be in the same direction for the motor to turn, so the graph is in the one quadrant. The radial magnetic field ensures a constant magnitude torque, therefore choice (D) rather than (C).

6.18.1.7 A

6.18.1.8 B

6.18.1.9 B

6.18.1.10 C

6.18.1.11 A

6.18.1.12 D

6.18.1.13 A

6.18.1.14 B

6.18.2.1

Part	Name of part	Function of part
A	Split ring commutator	To ensure delivery of DC to external circuit.
B	Brushes	Electrical contacts between commutator and external circuit.
C	Electrical leads	Carry current to external load.
D	Magnet	Provide magnetic field.
E	Rotor coil	To produce the induced AC emf and current.
F	Input energy device	To provide energy to the coil to rotate it.

6.18.2.2 (a) Decreases the current.

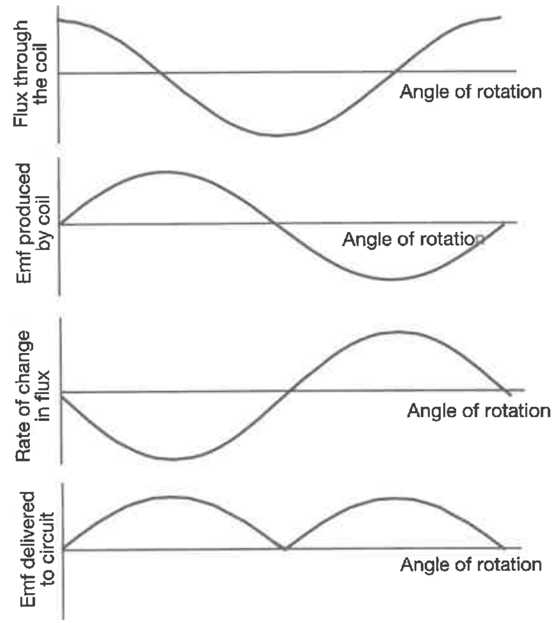
(b) Increases the current.

(c) Increases the current.

(d) Increases the current.

(e) Increases the current.

6.18.2.3 (a)



(b) From (b), through the ammeter to (a).

(c) The amplitude and the frequency of the output emf would be halved.

(d) The amplitude and the frequency of the output emf would be doubled.

(e) The amplitude and the frequency of the output emf would be tripled.

(f) The amplitude and the frequency of the output emf would be four times greater.

6.18.2.4 In both AC and DC simple generators, the internally produced emf varies as a sine/cosine curve because the rate at which magnetic flux is cut depends on the position of the coil in its rotation. If it is parallel to field lines, then flux is cut at a maximum rate, so emf is maximum. If perpendicular to the field lines, then flux is not cut at all, so emf is zero instantaneously. In between the rate of flux cut varies as a sinusoidal curve.

6.18.2.5 (a) A
(b) When the coil is perpendicular to the field, the sides do not cut magnetic flux (they are momentarily moving parallel to the field) so no emf is induced.

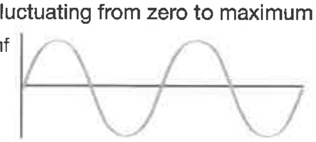
6.18.2.6 (a) D
(b) Coil is attached to a split ring commutator, so current output must be DC, therefore (A) and (B) incorrect, and coil starts with area parallel to field, so rate at which flux is cut is maximum at the start, so (D) rather than (C).

6.18.3.1

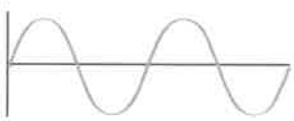
Part	Name of part	Function of part
A	Coil	Induced emf and current produced in coil.
B	Slip rings	Electrical contact to coil ends.
C	Brushes	Electrical contact between external power supply and slip rings.
D	Leads to power supply	To provide input electrical power.
E	Magnet	To provide the magnetic field.
F	Handle	To input mechanical energy to the coil.

6.18.3.2 (a) 2*I*
(b) 2*I*
(c) 0.5*I*
(d) Current would be more constant in value rather than fluctuating from zero to maximum 1.

6.18.3.3 (a) AC emf



(b) AC emf



6.18.3.4 (a) A
(b) Graph X has a larger amplitude so is producing a larger emf, so either number of coils is different (and it isn't) or rate of rotation is different (is not as both graphs show two rotations in the same time period), so magnetic field strength must be greater for X (note that coil could also be larger in size, but this is not a given option).

6.18.3.5 (a) A
(b) Rate at which flux is cut is greatest when emf produced is greatest. This is at time P.

6.18.3.6 It doesn't internally – the structure of motors and generators are the same – they differ only in their input and output energies (being reversed) and in the mechanism to input either mechanical or electrical energies and to output either electrical or mechanical energies.

6.18.3.7 (a) D
(b) You need to apply the right hand rule and Lenz's law to determine the direction of the induced current (clockwise), which makes X the source of the output current and therefore the positive terminal of the generator. Remember the rotation is due to an external force *not* the induced current, so the direction of the induced current has to be such that the magnetic field it induces interacts with the stator field to produce an anticlockwise torque on the coil.

6.18.4.1 Emf is produced whenever magnetic flux is cut. This occurs when the rotor coil moves relative to the magnetic field.

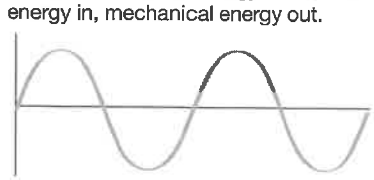
6.18.4.2 (a) In both DC generators and AC alternators, the rotation of the coil within the magnetic fields produces AC internally. The delivery of DC or AC to the external circuit depends on whether split ring commutators or slip rings are used (respectively).
(b) As a coil rotates in a magnetic field, the direction of motion of each side (relative to the magnetic field) changes every 180°. This changes the direction of the current induced in that side every 180°. Thus all generators produce AC internally.

6.18.4.3 (a) It is an AC generator – it has slip rings.
(b) The DC generator would have a split ring commutator instead of the slip rings.

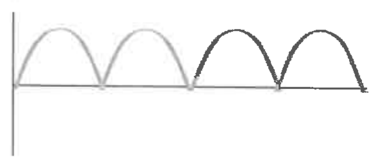
6.18.4.4 (a) An AC generator will have slip rings while a DC generator has a split ring commutator.
(b) The only differences are the slip rings (AC compared to split ring commutator (DC).
(c) The only differences are the mechanisms for energy input and output. Generator – mechanical energy in, electrical energy out. Motor – electrical energy in, mechanical energy out.
(d) The only differences are the mechanisms for energy input and output. Generator – mechanical energy in, electrical energy out. Motor – electrical energy in, mechanical energy out.

6.18.4.5

AC

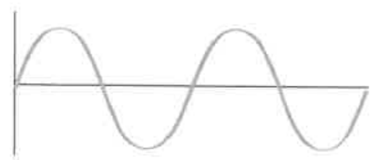


DC

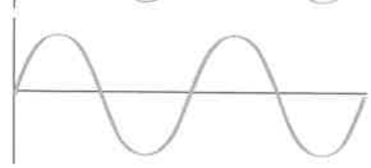


6.18.4.6

AC



DC



6.18.5.1 The diagram is showing how an AC induction motor works. by considering the relative motion between the stator magnetic field and the squirrel cage. It is easier to explain the operation if we analyse it by imagining that the squirrel cage is rotating anticlockwise compared to a stationary magnetic field rather than trying to analyse the real situation where it is the magnetic field which rotates clockwise relative to a stationary squirrel cage.
The relative motion between the cage and the magnetic field induces a current in the squirrel cage bars. By applying Lenz's law, we deduce this to be into the page through the squirrel cage bars. This current interacts with the stator magnetic field to place a force on the squirrel cage bars (motor effect) which is directed clockwise (part (b) of diagram).
Applying this to the real situation where it is the magnetic field that is rotating, we see that the squirrel cage will rotate in the same direction as the field.

6.18.5.2 (a) C

(b) Answers will vary, but, for example – washing machines, dishwashers, power drills, electric beaters and mix masters, vacuum cleaners, electric saws, hair dryers, food processors, fans, fan heaters (most electrical motor driven devices in homes are induction motors).

6.18.5.3 B

6.18.5.4 (a) B

(b) Faraday's principle of electromagnetic induction.

(c) D

(d) It would take more input energy to rotate the heavy magnet than would be produced by the rotation of the light disc.

6.18.5.5 (a) A

(b) The stator magnetic field rotates about the squirrel cage and the induction results in the rotation of the squirrel cage.

6.18.5.6 (a) Because there is relative motion between a magnetic field and a conductor (the moving magnet), an induced current will be set up in the disc (Faraday's law). The direction of this current will be such that its interaction with the magnetic field will produce a force on the disc to oppose the motion of the disc – i.e. to try to stop its rotation. Because the magnet is kept moving by an external force it will not stop so the force will cause the disc to 'follow the magnet' and rotate in the same direction.

(b) This motor will not be very efficient because it is the heavy part of it (the magnet) that needs to be physically moved. More energy will probably be used to do this than the rotational kinetic energy produces by the much less massive disc.

6.19.1.1 Whenever there is relative movement between a conductor and a magnetic field, there will be an emf induced in the conductor. The motion of the electrons in the conductor because of this emf induces a magnetic field around the conductor. This induced field and the applied field then interact to place a force on the conductor. This force must oppose the relative motion causing the induction of the emf otherwise additional emf would be induced. This would contravene the law of conservation of energy. Therefore the direction of the induced emf must always be such that the relative motion is opposed.

6.19.1.2 (a) Disc X will slow down due to the induction of eddy currents in the disc caused by the relative motion between the disc and the magnetic field. These eddy currents induce a second magnetic field which interacts with the applied field to produce a force which opposes the motion of the disc.

(b) Y will also slow down (for the same reason) but will rotate much longer than X. However, the eddy currents in Y will be smaller than those in X because the area of disc metal cutting the magnetic flux is smaller. Therefore the retarding force produced will also be smaller.

(c) The retarding forces in both cases must oppose the motion of the discs. If it acted in the direction of the motion this would result in the rotation of the discs accelerating – they would spin faster. This would contravene the law of conservation of energy, therefore the induced force (the Lenz's law forces) must oppose their motion and slow them down.

6.19.1.3 Whenever there is relative movement between a conductor and a magnetic field, there will be an emf induced in the conductor. The motion of the magnet through the coil induces an emf in the coil This induced emf induces a current which will induce a second magnetic field around the coil. The two magnetic fields will then interact to produce a force, which, by the law of conservation of energy must oppose the motion of the magnet through the coil.

In A, the motion of the south pole of the magnet is into the coil and will produce an emf which is clockwise in the coil and so as to produce a Lenz's law force upwards (to try to stop the magnet falling down).

In C, the motion of the north pole of the magnet is out the coil and will produce an emf which is anticlockwise in the coil so as to produce a Lenz's law force upwards to try to pull the magnet back upwards into the coil.

The readings on the meters in A and C are therefore in opposite directions.

In B, there is no change in the magnetic field experienced by the coil, so there is no induced emf. The reading on the ammeter is zero.

6.19.1.4 (a) Pendulum B will slow down and stop before pendulum C which will slow down and stop before pendulum A.

(b) In B and C the pendulum swing is damped because of the Lenz's law forces opposing their motion as they enter and leave the field (remember, Lenz's law is an electromagnetic statement of the law of conservation of energy). These forces arise because of the induced emf and current and second magnetic field as described by Faraday's law of induction.

B slows more than C because a larger area of metal cuts flux so the opposing forces will be larger.

A swings normally, slowing only due to friction and air resistance because there is no applied magnetic field and therefore no induction involved.

Module 7 The Nature Of Light

7.1.1.1 Maxwell:

- Calculated that the speed of propagation of an electromagnetic was the same as the speed of light.
- Proposed that light must be a wave in a medium which was the same cause of electrical and magnetic waves.
- Proposed that electricity, magnetism, and light could all be explained using the same theory in physics.
- Proposed that light was propagated by alternating electric and magnetic fields, which he believed would vibrate perpendicular to one another.

7.1.1.2 Electromagnetic radiation propagates by self-induced alternating electric and magnetic fields.

7.1.1.3 They all propagate using the same mechanism (by self-induced alternating electric and magnetic fields) and all travel at the speed of light.

7.1.1.4 (a) Hertz waves (now known as radio waves).
(b) Heinrich Hertz in 1887.

7.1.1.5 Gamma radiation
X-rays
Ultraviolet radiation
Visible light
Infra-red radiation
Microwaves
Radio waves
TV waves

7.2.1.1

Completed sentences
All electromagnetic waves can travel through a vacuum.
Electromagnetic waves all travel at the speed of light (3×10^8 m s^{-1}) in a vacuum – they slow down a little in other media.
Electromagnetic waves are self propagating alternating electric and magnetic fields.
Because the motion of the changing magnetic and electric fields are at right angles to the direction in which they carry energy, electromagnetic waves are also classified as transverse waves.
Because electromagnetic waves are really hard to draw, we usually draw them as transverse matter waves.
The flaw in doing this is that the energy carried by a transverse wave is indicated by the amplitude of the wave.
In electromagnetic waves, the energy is directly proportional to the frequency of the photons which make up the radiation.
The wavelength of an electromagnetic wave is the distance between the peaks of successive magnetic or electric field pulses.
We usually refer to the intensity of an electromagnetic wave rather than to its amplitude.
The intensity of an electromagnetic wave depends on the number of photons in the beam.
Each photon will have energy dependent on its frequency.
The period of an electromagnetic wave is the time for one wavelength to pass a given point.
The frequency of an electromagnetic wave is the number of wavelengths that pass a point each second.
The frequency of electromagnetic waves is measured in hertz (Hz).

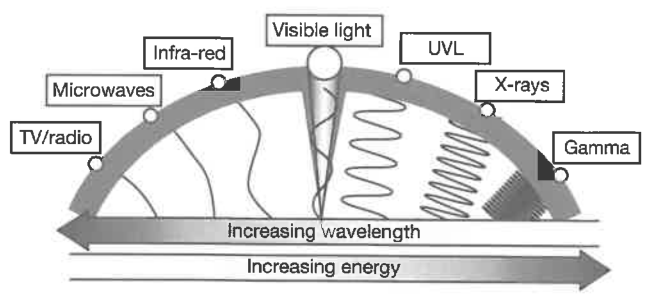
7.2.1.2 (a) Half a wavelength
(b) Wavelength
(c) Amplitude
(d) About 3.8×10^{-11} m
(e) 3
(f) 3
(g) 3×10^8 m s^{-1} because this is the speed of all electromagnetic waves in air.
(h) 7.89×10^{18} Hz
(i) Stays the same because the medium stays the same.
(j) Its wavelength would halve to maintain constant speed in the air.

7.2.1.3 The concept of electromagnetic radiation is difficult to visualise. For simplicity, accept it as oscillations in two perpendicular planes only – these planes representing the average of half its vibrations in a horizontal plane and half of its vibrations in a vertical plane (diagram right). In reality, the wave is composed of many sets of perpendicular planes of oscillation.

7.2.1.4 (a) Electromagnetic radiation is emitted from matter when excited electrons (electrons in higher energy levels than their normal position) fall back into their lower position. The energy they absorbed to excite them is released as electromagnetic radiation.
(b) It is a simple fact of physics that accelerating charges emit electromagnetic radiation (e.g. synchrotron radiation – see later). So electrons circling around the path inside a synchrotron, because they are continually emitting energy which can be harnessed and used in experiments.

7.2.1.5 (a) All electromagnetic radiations travel at 3×10^8 m s^{-1} in a vacuum.
(b) The radiation cannot be part of the electromagnetic spectrum because its speed in air is too low. However, the slower speed in the glass slab could be correct and the denser glass would decrease its speed.
(c) This is a bit of a trick question, because the bands in the electromagnetic spectrum are based on our use of the particular wavelengths in the band. A 'new band' would simply be the discovery of new uses for some wavelengths, not the discovery of new wavelengths.

7.2.2.1



7.2.2.2 A
7.2.2.3 B
7.2.2.4 C
7.2.2.5 D
7.2.2.6 B
7.2.2.7 D
7.2.2.8 C
7.2.2.9 A
7.2.2.10 C
7.2.2.11 D
7.2.2.12 B
7.2.2.13 A

7.2.2.14

Type of EMR	Use in society 1	Use in society 2
Gamma radiation	Treatment of certain types of cancer	Detection of flaws in industrial structures, pipes, slabs, beams etc
X-rays	Diagnosis of broken bones in bodies	Detection of foreign objects in bodies
UV radiation	Sterilisation of medical and other equipment	Tanning of bodies (not recommended)
Visible light	For sight	Optical communications
Infra-red	Heating objects	Remote controls
Microwaves	Heating/cooking foods	Communications
Radio waves	Communications	Entertainment
TV waves	Communication	Entertainments

7.3.1.1 Limitation was the lack of availability of accurate measuring instruments to measure times and distances, especially measuring such small intervals of time taken for light to travel from one point to another.

7.3.1.2 (a) Current accepted value is 299 792 458 m s^{-1}.

(b) Since 1983 the metre has been defined by international agreement as the distance travelled by light in a vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second. This makes the speed of light exactly 299 792 458 m s^{-1}.

7.3.1.3 Answer not given as this would discount the skill of researching the topic.

7.4.1.1 The composition of the filament or the type of gas used in the discharge tube.

The operating temperature of the source.

The pressure of gas in a discharge tube source.

7.4.1.2 Light sources which have filaments that get very hot will all usually produce continuous spectra, but low temperature vapour light sources such as mercury or sodium vapour lamps will produce light more consistent with their composition rather than their temperature.

7.4.1.3 (a) The term 'cool' refers to light sources which emit light towards the blue end of the spectrum, while warm or hot lights emit light which is closer to the red end of the spectrum.

(b) Cool light will be whiter in colour than warm light which will be more yellowish.

(c) X = cool
Y = warm

7.4.1.4 C

7.4.1.5

Spectrum X	Low pressure sodium vapour lamp. The spectrum is concentrated in the yellow wavelength region of the spectrum which eliminated all others. The high pressure sodium lamp, like all high pressure vapour sources will tend to have a broader spectrum.
Spectrum Y	Red LED – the spectrum is mainly in the red wavelength region of the spectrum and all the other sources listed (except the low pressure sodium lamp) would produce a wider spectrum.
Spectrum Z	This spectrum is the shape of a Planck curve and so is produced by a relatively hot source. It has its peak wavelength below red wavelength but does not extend significantly into the visible spectrum. It would be formed by the red hot iron rod.

7.4.1.6 When the power is turned on, current electrons move and collide with electrons and atoms within the filament of the light. These also start to move and as they move they emit electromagnetic radiation. The frequency emitted depends on the frequency of oscillation of the particles in the filament and a wide range of these oscillations produces the wide spectrum.

7.5.1.1 (a) Continuous
Emission
Absorption

(b) Continuous – All wavelengths (or frequencies) are present forming (in the case of the visible spectrum) a continuous, unbroken band of colour ranging according to ROYGBIV.

Emission – Mostly a black band with varying numbers of isolated coloured lines representing the spectrum of the particular element(s) present.

Absorption – A continuous band of colour with selected omissions of frequencies (depending on the element(s) involved) which will appear as isolated black lines in the band.

7.5.1.2 The isolated coloured lines in the emission spectrum will be the same frequencies as the black lines in the absorption spectrum.

7.5.1.3 (a) The spectrum formed from light from the Sun.

(b) To produce an absorption spectrum a quantity of the material (e.g. hydrogen gas) needs to be placed in the beam of (say) sunlight, and the resulting spectrum passed into the spectrometer. The hydrogen gas will absorb the frequencies determined by its electron structure and an absorption spectrum without these frequencies (i.e. black lines produced) will be formed. (*Note:* An emission spectrum cannot be formed from a continuous spectrum. It is formed by passing the light formed by burning the substance, or emitted from the very hot substance, through a spectrometer.)

7.5.1.4 (a) Continuous: All spectral lines appear in the spectrum; our eyes do not have the resolution to see them as separate lines – the spectrum appears continuous. Continuous spectra are emission spectra which involve emitted radiation from many elements such that all wavelengths are represented.

(b) Emission: Electromagnetic radiation is emitted as excited electrons fall back to lower energy levels causing photon emission to produce the emission spectrum lines – the rest of the spectrum is black. The few lines that do appear represent the energy values of the particular electron transfers for that element.

(c) Absorption: White light (all wavelengths) passes through a gas and photons of the energy representing energy transitions of the atoms of that gas, are absorbed – these energy values in the spectrum appear as black lines because they have been absorbed or removed from the beam of white light.

7.5.1.5 (a) Gustav Kirchhoff in 1859.

(b) The scientific research that followed in order to explain spectra was the beginning of quantum physics.

7.5.1.6 A = continuous spectrum

B = emission spectrum

C = absorption spectrum

7.5.1.7 (a) Short wavelength end is the left hand end (the blue end).

(b) High frequency end is also the blue end.

(c) Blue/violet end.

7.5.1.8 The hydrogen spectrum was the first spectrum to be analysed mathematically, leading to the Balmer equation, and this in turn, stimulated further research into the relationship between spectra and atomic structure.

7.5.1.9 The lines in the spectrum of an element become closer together as they approach the ultraviolet end of the spectrum, ending at the last line which is called the *convergence limit*. The energy of the convergence limit line gives us the ionisation energy of the element. For hydrogen the convergence limit is wavelength 364.6 nm.

7.5.1.10 (a)

Line	Actual λ (nm)	Balmer λ (nm)
$n = 3$	656.3	656.2
$n = 4$	486.1	486.1
$n = 5$	434.0	434.0
$n = 6$	410.2	410.1
$n = 7$	397.0	396.8

(b) See table.

(c) From the results in the table it would appear that the Balmer equation is valid for these predictions.

7.5.1.11 (a) The 434.01 nm line is in the blue part of the visible spectrum (you may have had to research this).

(b) Highest frequency = shortest wavelength, so the line to the far left of the spectrum as drawn would have the highest frequency.

(c) The line with the highest frequency is the line to the far left.

7.5.1.12 (a) A series in a spectrum is a series of emission lines for an excited electron falling from higher levels back to a specific level.

(b) It is in the visible light region of the spectrum.

(c) The Lyman – largest energy falls so highest frequencies, so shortest wavelengths.

7.5.1.13 (a) V, X and X and perhaps Z. All the spectral lines for these three elements appear in the mixture.

(b) While all the other lines for Z are present in the mixture, the double lines at the right hand end of the spectrum of Z are not in the mixture. Explanation – measurement error.

(c) The spectral lines from each are different, so they involve different energy transfers, so they must be from different energy levels within different atoms.

(d) Because supposedly no two sets of fingerprints are the same, and in the same way, no spectrum of any element or compound is the same as any other element or compound.

7.5.1.14 (a) Yes. All the spectral lines for hydrogen are in the spectrum from the star.

(b) There are additional spectral lines that are not part of the hydrogen spectrum.

7.5.1.15 (a) 1.8 eV

(b) 3.7 eV

(c) 3.9 eV emitted

(d) From $E = hf$, $E = 7.8 \times 10^{-19}$ J = 5.0 eV. This is not a quantised amount within the energy structure of mercury, so the electron will not move (it will not absorb the energy from the photon).

7.6.1.1 (a) The emission and absorption spectrum lines for any substance lie at exactly the same wavelengths/frequencies because they represent energy emitted by an excited electron falling to a lower quantum state or the same electron absorbing that energy to rise from the same lower quantum state to the same higher quantum state.

(b) (i) 589.9 nm = 3.3697×10^{-19} J = 2.1061 eV

(ii) 589.6 nm = 3.3714×10^{-19} J = 2.1071 eV

7.6.1.2 (a) Ground state is quantum state $n = 1$. This indicates that 10.38 eV would need to be added to ionise the atom.

(b) It has been the choice of the person drawing it to show energy values emitted as the electron falls from higher energy levels to lower energy levels.

(c) Emit – always emits energy when falling from higher to lower quantum states.

(d) Energy emitted = (–5.52) – (–1.57) = 3.95 eV = 6.32×10^{-19} J = 9.54×10^{14} Hz

(e) 10.38 eV

(f) From $E = \frac{hc}{\lambda}$, $\lambda = \frac{hc}{E}$ = 119.7 nm

7.6.1.3 (a) (i) $n = 3$ to $n = 2$ = 17 eV emitted

(ii) Then $n = 2$ to $n = 1$ = 91.8 eV emitted

(iii) Or $n = 3$ straight to $n = 1$ = 108.8 eV emitted

(b) (i) $n = 3$ to $n = 2$ = 17 eV emitted = 4.11×10^{15} Hz = 73.1 nm

(ii) Then $n = 2$ to n = 1 = 91.8 eV emitted = 2.22×10^{16} Hz = 13.5 nm

(iii) Or $n = 3$ straight to n = 1 = 108.8 eV emitted = 2.63×10^{16} Hz = 11.4 nm

(c) From $E = hf = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{143 \times 10^{-9}}$

= 1.39×10^{-18} J = 8.69 eV emitted

So initial level is 8.7 eV higher than $n = 2$ = –13.6 + 8.7 = 4.9 eV

So the electron fell from level $n = 5$.

(d) 5.54×10^{15} Hz = 3.67×10^{-18} J = 22.94 eV absorbed

This represents a transition from $n = 2$ to $n = 4$ (–30.6 + 22.94 = 7.7.66).

(e) 6.21×10^{15} Hz = 4.11×10^{-18} J = 25.7 eV emitted

This represents a transition from $n = 5$ to $n = 2$ (–30.6 + 4.9 = 25.7)

So, an excited electron has fallen from $n = 5$ to $n = 2$.

7.6.1.4 (a) X = continuous spectrum – full, unbroken spectrum of colours.

Y = absorption spectrum – continuous spectrum with black lines where frequencies characteristic of the elements concerned have been removed (absorbed by the gas).

Z = emission spectrum – the only lines present (coloured) are the lines for the wavelengths characteristic of the elements concerned.

(b) The spectral lines in each are at identical wavelengths/frequencies, but in the absorption spectrum they appear as black lines within a continuous spectrum because those wavelengths have been absorbed and are not there, whereas in the emission spectrum, they are the only lines present in the spectrum.

7.6.1.5 When the observer focuses on the light emitted from the top of the star (relative to the given diagram) this light will show a blue shift in the spectrum indicating that it is moving towards the observer.

When the observer focuses on the light emitted from the bottom of the star (relative to the given diagram) this light will show a red shift in the spectrum indicating that it is moving away from the observer.

Combining these two observations indicates that the star is rotating on its axis.

7.7.1.1 Diffraction involves a change in the direction of travel of waves as they pass through an opening or around the edge of a barrier in their path.

7.7.1.2 All types of waves undergo diffraction.

7.7.1.3 Classical physics would say that particles cannot diffract, but quantum physics recently has suggested that diffraction of single photons occurs.

7.7.1.4 (a) The wider the opening, the less the diffraction.

(b) The greater the wavelength, the greater the diffraction.

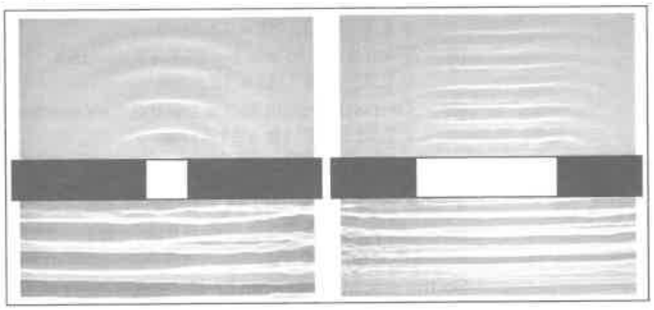
7.7.1.5 (a) If λ is small and w is large, the diffraction will be small – little diffraction.

(b) If λ is small and w is very small, the diffraction will be large – very circular wavefronts produced.

(c) If λ is very large and w is small, the diffraction will be large – very circular wavefronts produced.

(d) If λ is very small and w is small, the diffraction will be small – little diffraction.

7.7.1.6



7.7.1.7 (a) Y would have been formed by the red light since the width of the diffraction pattern is directly proportional to the wavelength of the radiation forming it. Red has longer wavelength than blue light.

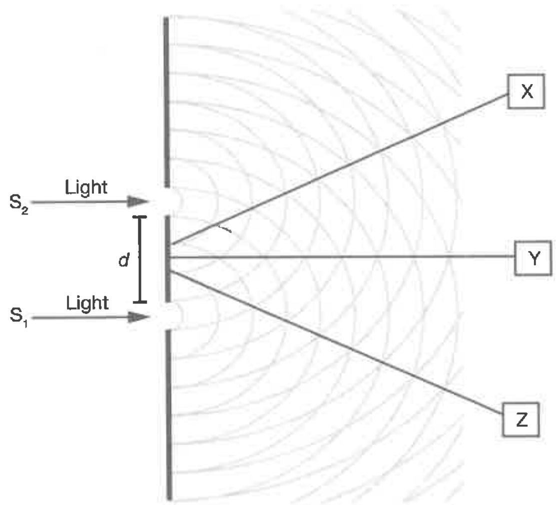
(b) In X the width of the slit would be wider than that producing Y because the width of the diffraction pattern is inversely proportional to the slit width.

7.8.1.1 (a) X = bright spot or band because it lies along an antinodal line representing constructive interference and therefore a bright position.

Y = bright position (same justification).

Z = bright position (same justification).

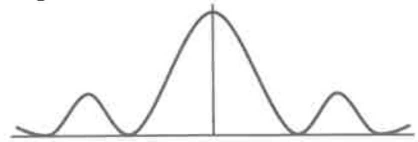
(b), (c)



(d) The pattern would be narrower – the bright and dark positions would be closer together.

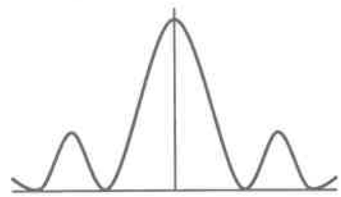
(e) The pattern would be wider – the bright and dark positions would be further apart.

7.8.1.2 (a) *Note:* Your diagram needs to be wider than the original.



(b) Lower frequency means longer wavelength and from the equation for double slit diffraction, $\Delta x = \frac{n\lambda L}{d}$, Δx is directly proportional to the wavelength, so the longer the wavelength, the wider the diffraction pattern.

(c) *Note:* Your diagram needs to be narrower than the original.



(d) From the equation for double slit diffraction, $\Delta x = \frac{n\lambda L}{d}$, Δx is inversely proportional to the distance between the slit holes, so the larger this distance, the narrower the diffraction pattern.

7.8.1.3 (a) One wavelength.

(b) From $\Delta x = \frac{n\lambda L}{d}$, $L = 33.3$ cm

(c) The distance between X and Y would decrease to 1.08×10^{-5} m.

(d) The distance between X and Y would double.

7.8.1.4 (a) The edges of solid objects are blurred due to edge diffraction. If the object is extremely small, then the diffraction patterns formed blur not just the edge, but effectively the entire image.

(b) The smaller the wavelength of the viewing 'light' the smaller the diffraction patterns formed, and the better the resolution of the image.

(c) The de Broglie wavelength of electrons is much smaller than the wavelength of visible light, so electron microscopes can image smaller objects with better resolution.

(d) Edge diffraction occurring as the light passes through the aperture to reach the recording medium (film, digital memory system) can decrease the resolution.

7.8.1.5 Because the point of the blade is thinner than other parts, the edge diffraction (which occurs at all the edges) is a higher proportion of the shadow at that point, and so it affects the resolution of the shadow more than at other points on the edges.

7.8.2.1 (a) In his experiment he placed a light source some distance behind a screen which had a pair of closely spaced pinhole slits in it. Light emerged from the pinholes and produced an interference pattern on a second screen.

(b) An interference pattern was produced on the screen.

(c) Young explained this pattern on the second screen by proposing that each slit acted as a point source of light and produced concentric waves travelling towards the second screen. He proposed that the waves from the two sources interfered with each other sometimes constructively (the bright lines) and sometimes destructively (the dark lines).

7.8.2.2 The sequence of bright and dark lines in the diffraction patterns were proposed to be due to the constructive and destructive interference of the light waves. Because particles would not interact in this way, the only possible explanation for the pattern was that the light consisted of waves.

7.8.2.3
(a) There would be a path difference of $n\lambda$.
(b) The path difference would be $(n - \frac{1}{2})\lambda$.
(c) Y must always be a bright spot because the geometry dictated that path lengths S_1Y and S_2Y are identical.
(d) The two beams would be in phase.
(e) The two beams are out of phase by half a wavelength or by 180°.
(f) The two beams would be partially out of phase and would form a 'grey' band in the pattern (in between bright and dull).

7.8.2.4
(a) The pattern is drawn to show the constructive interference of light beams whose path difference is an integral number of wavelengths (lighter areas) and the darker areas represent destructive interference of the beams from each slit, path difference $(n - \frac{1}{2})\lambda$.
(b) X and Y represent the beams forming the fourth bright line from the central maximum, so their path difference is
$4\lambda = 4 \times 632 = 2528$ nm $= 2.528 \times 10^{-6}$ m
(c) The statement is incorrect. Good results in this type of experiment require the two sources of light from the slits to be coherent – in phase – otherwise the whole concept of the $n\lambda$ and $(n - \frac{1}{2})\lambda$ path differences would be invalid.

7.8.2.5
Δx = distance between central maximum and the position on the diffraction pattern under consideration.
n = the number of the bright or dark spots from the central position.
λ = wavelength of the incident light used in the double slit experiment.
L = distance between the two screens used in the double slit experiment.
d = distance between the slits in a double slit experiment screen.

7.8.2.6
(a) The width of the diffraction pattern will decrease.
(b) The width of the diffraction pattern will increase.
(c) The width of the diffraction pattern will increase.
(d) The width of the diffraction pattern will decrease.

7.8.2.7
(a) X – higher frequency = shorter wavelength and from the equation, Δx directly proportional to wavelength.
(b) Y – again, from the equation Δx directly proportional to distance from screen.

7.8.3.1
(a) A diffraction grating is a tool used to separate the colour components of any light incident on it. It consists of a large number of parallel, closely spaced slits or grooves.
(b) If the slit width is 1.6 μm, then this corresponds to about $\frac{1}{1.6 \times 10^{-6}}$ = 625 tracks per mm.
(c) Slit spacing = $\frac{0.001}{800} = 1.26 \times 10^{-6}$ m = 1.67 μm

7.8.3.2 Compared to single, double, triple or more slit diffraction apparatus, a diffraction grating produces a spectrum which is more intense, much sharper with a much higher resolution.

7.8.3.3 From $m\lambda = d \sin\theta$
$\lambda = \frac{0.01}{4000} \sin 26°$
Therefore λ = 1096 nm

7.8.3.4
(a) Slit spacing = $\frac{0.001}{750} = 1.33 \times 10^{-6}$ m = 1.33 μm
(b) From $m\lambda = d \sin\theta$
$= \frac{0.001}{750} \sin 12°$
Therefore λ = 277 nm
(c) From $m\lambda = d \sin\theta$
$1 \times 450 \times 10^{-9} = \frac{0.001}{750} \sin\theta$
Therefore θ = 19.7°
(d) For the red light $750 \times 10^{-9} = \frac{0.001}{750} \sin\theta$
Therefore θ = 34.2°
For the violet light $400 \times 10^{-9} = \frac{0.001}{750} \sin\theta$
Therefore θ = 9.2°
Therefore angle of spread of the spectrum = 34.2 – 9.2 = 25°

7.8.3.5 From $m\lambda = d \sin\theta$
$= \frac{0.01}{15\,000} \sin 22.5°$
Therefore λ = 255 nm

7.8.3.6 From $m\lambda = d \sin\theta$
$3 \times 450 \times 10^{-9} = \frac{0.016}{8600} \sin\theta$
Therefore θ = 46.5°

7.8.3.7 If the two fifth order beams are separated by 80° then θ = 40°
Therefore, From $m\lambda = d \sin\theta$
$5 \times \lambda = \frac{0.03}{7500} \sin 40°$
Therefore λ = 514 nm which would be a green/blue (cyan) colour

7.8.3.8 From $m\lambda = d \sin\theta$
$2 \times 450 \times 10^{-9} = d \sin 28°$
Therefore d = 1.917 μm
Therefore number of lines in the grating = $\frac{0.03}{1.917 \times 10^{-6}}$ = 15 649

7.8.3.9
(a) From $m\lambda = d \sin\theta$
$620 \times 10^{-9} = d \sin 18°$
Therefore d = 2.0 μm
(b) From $m\lambda = d \sin\theta$
$620 \times 10^{-9} = (4.0 \times 10^{-6}) \sin\theta$
Therefore θ = 8.9°
(c) From $m\lambda = d \sin\theta$
$2 \times \lambda = (4.0 \times 10^{-6}) \sin 24°$
Therefore λ = 813 nm

7.8.3.10
(a) Slit spacing = $\frac{0.001}{500} = 2.0 \times 10^{-6}$ m = 2.0 μm
(b) From $m\lambda = d \sin\theta$
$= \frac{0.001}{500} \sin 18°$
Therefore λ = 618 nm

7.9.1.1 Light consists of very tiny particles known as 'corpuscles'.
These corpuscles on emission from the source of light travel in straight lines with high velocity.
When these particles enter the eyes, they produce images of the object or sensation of vision.
Corpuscles of different colours have different sizes.

7.9.1.2 Answers may vary – essentially, any property of light except interference and diffraction, e.g. reflection; refraction; light travels in straight lines; light travels though a vacuum.

7.9.1.3 Newton's reputation as a scientist and the fact that there was little experimental evidence to support the wave model for light were the two main factors in his favour.

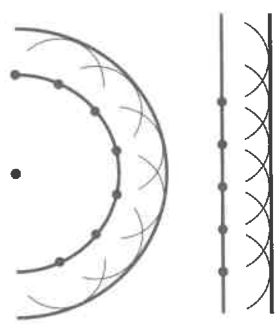
7.9.1.4
(a) Refraction refers to the change in speed that occurs when a wave motion passes a boundary and moves into a different medium.
(b) He proposed that gravitational attraction between the light particles and the particles of the medium (say glass) slowed the light particles down.
(c) He proposed that differing forces of gravitational attraction between the light particles and the particles of the medium (say glass) slowed the light particles down as they entered a more dense medium, and allowed them to speed up as they exited the medium.

7.9.1.5 He stated that particles travel in straight lines and will therefore go straight past the edge of an object whereas waves bend around objects and therefore light, if it was a wave, would not form shadows.

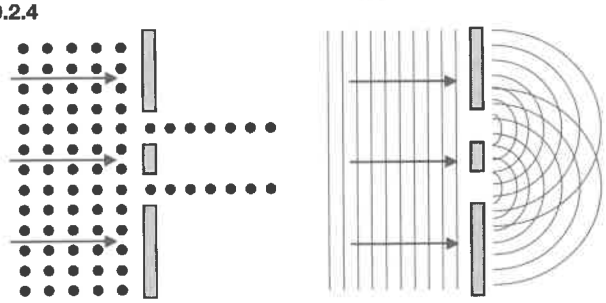
7.9.2.1
(a) Light is a form of *energy*.
(b) Light travels in the form of *waves* which vibrate up and down *perpendicular* to the direction of travel.
(c) A *medium* is necessary for the propagation of waves and space is filled with an imaginary medium called the *aether.*
(d) Each *point* in a source of light sends out waves in all directions in a hypothetical medium called the *aether*.
(e) Each point on the wavefront acts as a source of *wavelets* for the next wavefront.
(f) Light waves have very short *wavelength*.

7.9.2.2 Answers may vary – essentially, any property of light known at the time, e.g. reflection; refraction; light travels in straight lines; light travels though a vacuum; interference; diffraction.

7.9.2.3 Your diagrams should show circlets centred on each of the points on each wave, all having the same radius and lines of best fit drawn in to represent the next wave in the sequence



7.9.2.4



7.9.3.1
(a) Michael Faraday.
(b) Light was a high frequency electromagnetic vibration, which could propagate even in the absence of a medium such as the aether.
(c) James Clerk Maxwell.
(d) When studying electromagnetic radiation and light, Maxwell discovered, while working on mathematical equations to describe electrical phenomena, that self-propagating electromagnetic waves would travel through space at a constant speed, which happened to be equal to the previously measured speed of light. From this, Maxwell proposed, in 1873, that light was a form of electromagnetic radiation.

7.9.3.2
(a) Polarisation.
(b) In the electromagnetic model for light, light is considered to have many pairs of electric and magnetic fields oscillating at right angles to each other. We would refer to a light wave structured like this as being unpolarised. When a light wave is passed through a polariser, all the sets of field pairs are cut from the beam except those in one plane. The light is now polarised.
(c)

7.9.3.3 It cannot explain the threshold frequency in the photoelectric effect.

7.9.4.1
(a) Max Planck in 1900.
(b) He was trying to explain his observations with hot body radiations, usually referred to as his black body radiation experiments.
(c) Planck proposed that the radiations given off by hot objects were due to the oscillations of the particles of the matter and that these oscillations were quantised and that the particles carried discrete amounts of energy consistent with the formula $E = hf$, where f is the frequency of the oscillations of the particles of the matter. He called these packets of energy quanta.
(d) Einstein extended Planck's idea of quanta to cover all electromagnetic radiations and used it to explain the threshold frequency in the photoelectric effect (see later work). In explaining this, Einstein considered light photons to be discrete packets or particles of energy, called photons with quantised amounts of energy given by Planck's equation, $E = hf$.

7.9.4.2 The frequency of the light wave.

7.9.4.3
(a) All properties of light except *interference*, *diffraction* and *polarisation* can be explained using the particle model for light.
(b) All properties except the *threshold frequency* in the photoelectric effect can be explained by a wave model for light.
(c) Since neither model explained all light properties, *neither* model is correct and because we have no better idea at the moment, we accept both and retain a *dual model* for light.

7.9.4.4 The dual model considers light to be a wave for some properties and composed of particles for other properties because neither the wave nor the particle model can explain all light properties and we currently have no model that can.

7.10.1.1 (a) Polarisation occurs when unpolarised light waves are (for example) reflected from a polarising surface which results in the oscillations in the reflected rays occurring in a single plane.

(b) We represent an electromagnetic wave in a diagram which shows oscillations of the electric and magnetic fields in one set of perpendicular planes only.

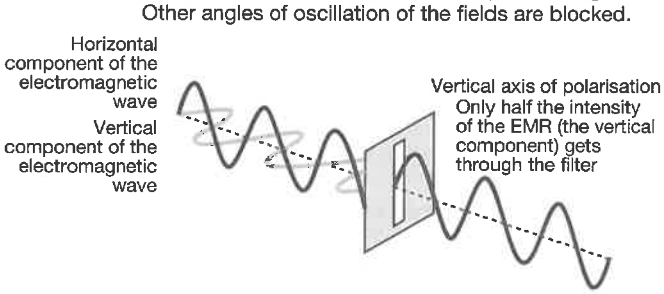
(c) If you could see an electromagnetic wave travelling towards you, then you would observe the oscillations of the fields in numerous planes of vibration, not just two planes at right angles. The wave is composed of many sets of perpendicular planes of oscillation, as represented. The fact that the waves can be polarised testifies to the existence of more than one set of vibrational axes.

(d) Because the correct model for electromagnetic radiation refers to many sets of perpendicular planes of oscillation of electric and magnetic fields, not just one set. During polarisation, many of these planes of radiation are removed from the ray.

7.10.1.2 The concept of unpolarised light is difficult to visualise. For simplicity, accept unpolarised light as oscillations in two perpendicular planes only – these planes representing the average of half its vibrations in a horizontal plane and half of its vibrations in a vertical plane.

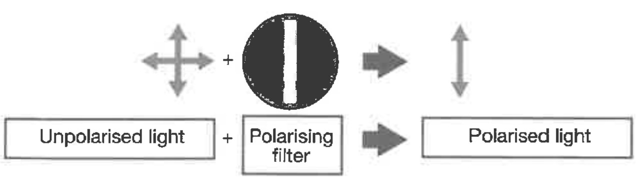
7.10.1.3 By using polaroid filters, by transmission, by reflection from a surface, by refraction and by scattering.

7.10.1.4 Polaroid filters are constructed such that they have (usually) horizontal bands built in which allows only the horizontal planes of the wave to pass through. Other angles of oscillation of the fields are blocked.



7.10.1.5 The left photo is the one using the filter. More detail can be seen in the photo as 'glare' from the light reflected from the water is eliminated.

7.10.1.6



7.10.1.7 A Vertically polarised light would be seen.
B Vertically polarised light would be seen.
C Vertically polarised light would be seen.
D No light would be seen.

7.10.2.1 The plane of polarisation is parallel to the reflecting surface.

7.10.2.2 (a) Pair X because the plane of polarisation of the lenses is the same as that of the reflected light, so the light will pass through the lenses.

(b) No light will pass through the lenses (you will not be able to see anything) because the axis of polarisation of the lenses is perpendicular to that of the reflected light.

7.10.2.3 They have been placed so that their axes of polarisation are perpendicular to each other.

7.10.2.4 (a) When light from the Sun strikes atoms and molecules in the atmosphere the atoms absorb some of its energy and some of their electrons start oscillating. These oscillations produce electromagnetic radiation which is partially polarised and scattered in all directions. This results in a 'glare' in the sky.

(b) The shorter wavelength components – blue and violet light because they have wavelengths closer in length to the size of the atmospheric particles.

7.10.2.5 Linear polarised waves can change their direction of polarisation many times as they collide with atmospheric particles and this can degrade the quality of the communications. Circular polarised waves are much more stable and reliable.

7.10.3.1

Beam	Intensity
A	I_0
B	0
C	I_0
D	I_0
E	I_0
F	$\text{Cos}^2\,50°\ I_0 = 0.41I_{0i}$

7.10.3.2 (a) Intensity passing through the first filter will be $I_1 = 0.5I_0$

(b) Intensity passing through the second filter $= I_2 = I_1\,(\cos 30°)^2 = 0.375\,I_0$

(c) Intensity passing through the third filter $= I_3 = I_2\,(\cos 30°)^2 = 0.375I_0\,(\cos 30°)^2 = 0.28I_0$

(d) Intensity passing through the third filter $= I_3 = I_2\,(\cos 60°)^2 = 0.375I_0\,(\cos 60°)^2 = 0.09I_0$

7.10.3.3 Intensity passing through the filter $= 9 = 45\,(\cos\theta)^2$
Therefore $(\cos\theta)^2 = 0.2$
Therefore $\cos\theta = 0.447$
So $\theta = 63.4°$

7.10.3.4 Intensity passing through the filter $= I_0\,(\cos 36°)^2 = 0.65.5I_0 = 65.5\%$

7.10.3.5 Intensity passing through the filter $= 200\,(\cos 15°)^2 = 186.6\ \text{W m}^{-2}$

7.10.3.6 Filters Y and Z cannot be next to each other because their polarising axes are at 90° to each other and so no light would be transmitted through the second one. This means that filter X must be in the middle. Therefore, maximum intensity will be transmitted when the filters are in the order Y-X-Z or Z-X-Y.
Considering the order as YXZ
Intensity through Y will be $0.5I_0$
Through X will be $0.5I_0\,(\cos^2 60°) = 0.125I_0$
Through Z will be $0.125I_0\,(\cos^2 30°) = 0.094I_0$
Considering the order as ZXY
Intensity through Y will be $0.5I_0$
Through X will be $0.5I_0\,(\cos^2 30°) = 0.375I_0$
Through Z will be $0.375I_0\,(\cos^2 60°) = 0.094I_0$
Therefore, either order will give maximum transmission.

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7.10.3.7 Intensity through the polariser will be $0.5I_o$
Through analyser 1 will be $0.5I_o(\cos^2 25°) = 0.41I_o$
Through analyser 2 will be $0.41I_o(\cos^2 25°) = 0.34I_o$

7.10.3.8 Let the angle between filter 1 and filter 2 be θ
Angle between filter 2 and filter 3 will be $90 - \theta$
Intensity therefore through the first filter $= 0.5I_o$
$= 64\ \text{W m}^{-2}$
Intensity through the second filter $= 64 \cos^2 \theta$
Intensity through the third filter $= 16$
$= 64 \cos^2 \theta(\cos^2 (90 - \theta))$
Therefore, $16 = 64 \cos^2 \theta \times \cos^2 90 - 64 \cos^2 \theta \times \cos^2 \theta)$)
$16 = 0 - 64 \cos^4 \theta$
Square root each side, $4 = -8 \cos^2 \theta$
Square root each side again, $2 = -2.828 \cos \theta$
Therefore $\cos \theta = -0.707$
Therefore $\theta = 45°$ or $135°$
It cannot be 135°
i.e. $\theta = 45°$

7.11.1.1 It was Planck's concept of quantum oscillations of the particles of matter to explain heat energy that stimulated Einstein to apply the idea to all electromagnetic radiation and then use it to explain the photoelectric effect, which could only be done if light was considered to be composed of particles with quantised amounts of energy.

7.11.1.2 It was Planck who coined the term quanta to explain why different materials gave the same energy emission graph when heated to the same temperatures. He imagined quanta as specific packets of energy associated with and emitted by specific oscillations of the atoms in hot substances.

7.11.1.3 Planck's black body radiation experiments were the start of a new branch of physics – quantum physics, and as such, were the foundation experiments for what has become perhaps the most far reaching and important branch of physics in terms of its power to explain atomic structures.

7.11.1.4 Planck's quanta were emitted by oscillating atoms. We now know that the emission is due to electrons which fall from higher to lower energy levels.

7.11.1.5 A (perfect) black body will absorb all radiation falling on it, increasing its temperature. It will then radiate this energy out again as its temperature falls to room temperature. The peak radiation it emits reflects the temperature it reaches as it absorbs energy.

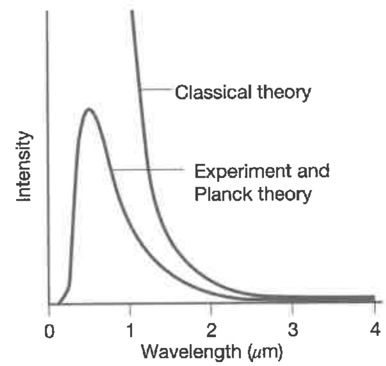
7.11.1.6 Planck's idea had the atoms inside the cavity oscillating back and forth and therefore emitting radiation in a similar way to a radio antenna. Like antennas, these oscillating atoms could also receive electromagnetic (in this case, heat) radiations from their surroundings – that is how the object got hot.

7.11.1.7 They observed that all hot materials, no matter what their composition, emitted radiations of varying wavelengths which depended not on the substance, but on the temperature of the substance. The peak radiation it emits reflects the temperature it reaches as it absorbs energy.

7.11.1.8 Energy associated with the oscillation of the atoms (electrons) can have only energy values consistent with the equation: $E = hf$, where h is Planck's constant $= 6.626 \times 10^{-34}$.

7.11.1.9 (a) The electromagnetic energy associated with the oscillation of the atoms was quantised. It could have only energy values consistent with the equation $E = hf$ where h is Planck's constant $= 6.626 \times 10^{-34}$. An atom could absorb or release 1 quantum of energy, or 2 quanta of energy or 200 quanta, but it could not absorb nor release 1.5 quanta of energy.
(b) Quanta of energy were absorbed or emitted only when an atom changed from one quantised energy level to a different quantised level. If the atom did not change quantum levels, it could neither absorb nor emit energy.

7.11.1.10 Classical theory predicts that the hotter a body, the higher the frequency (shorter the wavelength) of the radiation it will emit – which is what the peak of the experimental curve shows. However, the drop in intensity of very short wavelength radiation (at all temperatures) is not predicted by classical theory.



7.11.1.11 D
7.11.1.12 D
7.11.1.13 (a) C
(b) After years of debate as to whether light was particle or wave in nature, the evidence had swung firmly behind it being a wave (apart from the photoelectric effect, which could not be explained in terms of waves). Planck's quanta provided evidence for the particle nature believers and so rekindled the old debate.
7.11.1.14 (a) B
(b) As a continuous stream of energy rather than discrete 'bursts' or packets.
7.11.1.15 A
7.11.1.16 D
7.11.1.17 (a) D
(b) Classical physics would predict that the EMR emitted from a hot body would also depend on the type of material it was made of.
7.11.1.18 C
7.11.1.19 B
7.11.1.20 C
7.11.1.21 A
7.11.1.22 A
7.11.2.1 (a) A black body is an object that absorbs all incident electromagnetic radiation, regardless of frequency or angle of incidence.
(b) Black body radiation is the electromagnetic radiation emitted by a black body.
(c) Black body radiation produces a spectrum that is determined by temperature alone and not by the body's shape or composition and
The frequency of the peak radiation is proportional to the temperature of the back body.

7.11.2.2 Wien's displacement law states that there is an inverse relationship between the wavelength of the peak of the radiation curve of a black body and its temperature, or That the peak frequency of a black body radiation curve is proportional to the temperature of the black body.

7.11.2.3 (a) X – according to Wien's law, the shorter the wavelength of the peak radiation, the hotter the body.

(b) Z – because its highest peak wavelength indicates it is the coolest of the three stars shown.

7.11.2.4 (a) From $\lambda_{max} \times T = b = 2.898 \times 10^{-3}$

Maximum wavelength = $\frac{2.898 \times 10^{-3}}{2000} = 1.45\ \mu m$

(b) First we need to find the peak wavelength.

From the wave equation, $v = f\lambda$

$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{280 \times 10^9} = 1.071 \times 10^{-3}$ m

Then, using Wien's equation:

$1.071 \times 10^{-3} \times T = 2.898 \times 10^{-3}$

We get $T = 2.71$ K

7.11.2.5 From $\lambda_{max} \times T = b$

$1200 \times 10^{-9} \times T = 2.898 \times 10^{-3}$

So surface temperature = 2415 K

7.11.2.6 From $\lambda_{max} \times T = b$

$\lambda \times 300 = 2.898 \times 10^{-3}$ (remember the equation requires Kelvin = centigrade + 273)

So peak wavelength = 9.66×10^{-6} m = 9.66 μm

7.11.2.7 (a) From $\lambda_{max} \times T = b$

$\lambda \times 40\,000 = 2.898 \times 10^{-3}$

So $\lambda = 7.245 \times 10^{-8}$ m = 72.45 nm

(b) This wavelength is in the ultraviolet range (Eta Carinae is a double, blue supergiant).

7.11.2.8 (a) From $\lambda_{max} \times T = b$

$\lambda \times (15 + 273) = 2.898 \times 10^{-3}$

So $\lambda = 1 \times 10^{-5}$ m = 10 μm

(b) From $v = f\lambda$

$f = \frac{3 \times 10^8}{10 \times 10^{-6}} = 3 \times 10^{13}$ Hz

7.12.1.1 When light of an appropriate frequency is shone onto a metal surface, electrons are emitted from that surface.

7.12.1.2 (a) The energy of a single photon is $E = hf$, and this energy is partly used to break the electron away from its atom (the work function).

(b) Excess energy gives the photoelectron its kinetic energy ($KE = hf - \phi$).

(c) Photons of light below the threshold frequency did not carry sufficient energy, so no photoelectrons could be emitted regardless of the intensity of the light.

(d) As intensity of light of an appropriate frequency increased, photoemission increased as more photoelectrons could be emitted.

(e) Increased intensity of the light shining on an emitter meant more photons, but there is a limit to the number of electrons available on the surface of the emitter to be emitted.

7.12.1.3 Einstein's explanation of the photoelectric effect did not comply with the then accepted classical wave theory, and did not fit in with the wave properties exhibited by light (diffraction, interference).

7.12.1.4 Energy carried by photons is quantised according to $E = hf$, and in a collision with an electron, either all the energy is transferred to the electron, or none is transferred.

7.12.1.5 Einstein applied and expanded Planck's idea about quanta when he used them to explain the photoelectric effect. This added to the credibility of the idea of quanta (which wasn't widely supported in the scientific community because it went against classical theory) and widened the support for the theory in the scientific world. In addition, Einstein expanded quanta to apply to light and in this way opened the door for the development of the dual theory for light which we still accept. It was also Einstein's application of quanta that stimulated Bohr's mind to develop his solar system model of the atom. So, Einstein's application of quanta was important in two directions – it supported a newly developing idea and stimulated others.

7.12.1.6 C

7.12.1.7 (a) D

(b) Energy (the threshold energy, also known as the work function) is needed to break the electrons away from their valence orbits and it is this energy which is possessed by a photon having the threshold frequency. Higher frequencies provide additional energy which will appear as kinetic energy of the photoelectrons.

7.12.1.8 B

7.12.1.9 (a) A

(b) The ultraviolet light is obviously above the threshold frequency for the zinc and causes the photoemission of electrons from its surface. This reduces the charge on the electroscope.

7.12.1.10 C

7.12.1.11 (a) D

(b) Wave, or classical theory regarded light as a continuous stream of energy carried by a sinusoidal type transverse wave whereas quantum theory considers light as a continuous stream of particles called photons.

7.12.1.12 (a) It was the threshold frequency that classical wave theory was unable to explain. Classical theory predicted that electrons would absorb energy from continued collisions with photons below the threshold frequency until they accumulated enough energy to be emitted. This meant that photoelectrons would eventually be emitted at all frequencies – there would not be a threshold frequency. The existence of the threshold frequency can only be explained by considering light as composed of photons (particles) with discrete amounts of energy which, on collision is all transferred or none is transferred.

(b) The impact on the model for light was that the particle nature had to be included in any model. Since interference and diffraction effects cannot (at the moment) be explained using a particle model, the wave nature had to be retained also. So, scientists proposed the dual (wave/matter) model for the nature of light as the accepted model until something better is proposed.

7.12.2.1 B

7.12.2.2 C

7.12.2.3 D

7.12.2.4 B

7.12.2.5 D

7.12.2.6 A

7.12.2.7 C

7.12.2.8 C

7.12.2.9 B

7.12.2.10 (a) Classical theory would predict an ever increasing photocurrent as incident light intensity increased.

(b) Increased intensity means more photons, each with the same energy. Once every surface electron (assuming energy level is correct) has been hit, there are no further electrons available for the photocurrent to eject.

(c) This is the essence of the concept of quantum theory – that light exists as discrete particles with a specific amount of energy dependent on the frequency. The statement is a little ambiguous in that many more photons, each carrying the same amount of energy would provide a total amount of incident energy, but because of the quantum nature of the energy transfer, this is not a relevant way to look at it.

7.12.2.11 (a) The worry with Einstein's proposals was that they implied that light (and all other forms of electromagnetic radiation) consisted of particles – the photons. This did not sit well with classical wave theory, and did not fit in with the wave properties exhibited by light (diffraction, interference).

(b) Einstein's application of quantum theory to explain the photoelectric effect gave support to that theory and increased its credibility in the eye of other scientists.

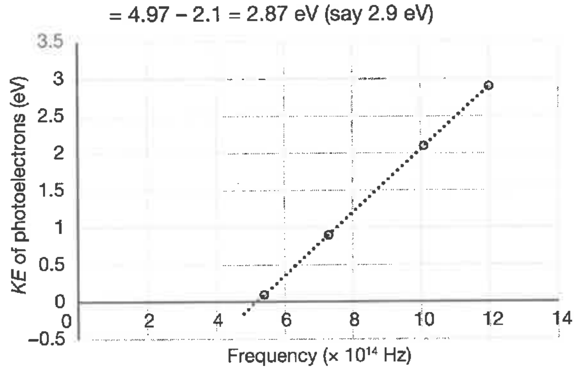
7.12.3.1 (a) Using the data for blue light,
Energy of blue photon = hf
$= 7.3 \times 10^{14} \times 6.626 \times 10^{-34}$
$= 4.84 \times 10^{-19}$ J
= 3.0 eV
Work function = energy of photon – *KE* electrons
= 3.0 – 0.90 = 2.1 eV

(b) For UV1,
Work function = energy of photon – *KE* electrons
= 4.2 – 2.1 = 2.1 eV

(c) No current will be emitted by the red light as the energy of the red photons is below the threshold energy.

(d) Work function = 2.1 eV = 3.36×10^{-19} J
So, from $E = hf$, threshold frequency
$f = 5.07 \times 10^{14}$ Hz

(e) For the red light, there is no photoemission, so their *KE* is not relevant.
For UV2, energy of photon = 4.97 eV
So maximum *KE* of the photoelectrons
= 4.97 – 2.1 = 2.87 eV (say 2.9 eV)



(f) Planck's constant = $\frac{E \text{ (in joules)}}{f}$ = gradient
$= \frac{4.64 \times 10^{-19} - 0}{12 \times 10^{14} - 5.1 \times 10^{14}} = 6.72 \times 10^{-34}$ J s

(g) About 5.1×10^{14} Hz compared to 5.07×10^{14} Hz

(h) 2.5 eV

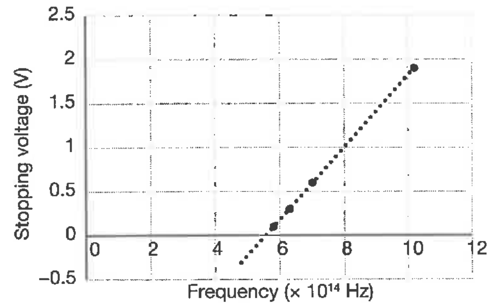
7.12.4.1 (a)

Incident light	Frequency of incident light (× 10¹⁴ Hz)	Energy of incident photons (eV)	Stopping voltage (V)	Maximum kinetic energy of photoelectrons (eV)	Work function (eV)
Red	4.8	1.98	0	0	NA
Yellow	5.3	2.19	0	0	NA
Green	5.8	2.40	0.1	0.1	2.30
Blue	6.3	2.61	0.3	0.3	2.31
Violet	7.0	2.90	0.6	0.6	2.30
UV	10.2	4.22	1.9	1.9	2.32

(b) The stopping voltage gives the kinetic energy of the photoelectrons in eV and if this value is subtracted from the photon energy, the value for the work function is obtained.

(c) See table for values, average value = 2.31

(d)



(e) The energy of the red and yellow photons is below the threshold energy for the emitter, so there are no photoelectrons emitted, therefore no stopping voltage.

(f) Energy of photon = work function + *KE* electrons
Energy of a photon with frequency 8×10^{14} Hz
$= 2.32 + 1.0 = 3.32$ eV $= 5.31 \times 10^{-19}$ J
Therefore Planck's constant = $\frac{E}{f} = \frac{5.31 \times 10^{-19}}{8 \times 10^{14}}$
$= 6.64 \times 10^{-34}$ J s

7.12.5.1 (a) The stopping potential gives the value of the kinetic energy of photoelectrons in eV. This, when subtracted from the energy of the incident photons provides the work function of the emitter.

(b) The negative value means the applied potential is being used as a retarding potential, slowing the rate at which the photoelectrons flow from emitter to receiver. The photocurrent increases as the retarding potential decreases because the electrons are being slowed less. At $V = 0$, the current represents the flow of photoelectrons as emitted.

(c) When the applied potential is positive, the electrons emitted are attracted towards the receiver more quickly and more directly (they are emitted in all directions) so the photocurrent increases to its maximum value at Y.

(d) Current is number of electrons passing a point per second. The current is limited by the maximum number of electrons that can be emitted from the surface. When all atoms are emitting electrons, no more are available, so the current has reached a maximum or saturation value.

7.12.5.2 (a) Line of best fit will cross the x-axis at frequency $= 5.2 \times 10^{14}$ Hz which is the threshold frequency which represents an energy value of $E = hf = 3.45 \times 10^{-19}$ J $= 2.15$ eV

(b) 450 nm $= 6.67 \times 10^{14}$ Hz
Interpolating from the graph, KE = about 0.7 eV

(c) Planck's constant = gradient $= \dfrac{3.44 \times 10^{-19}}{4.7 \times 10^{14}}$
$= 7.32 \times 10^{-34}$ J s

(d) Their hypothesis is wrong. The frequency of 4×10^{14} Hz is below the threshold frequency, and no photoemission will occur regardless of the intensity.

7.12.5.3 C

7.12.5.4 D

7.12.5.5 A

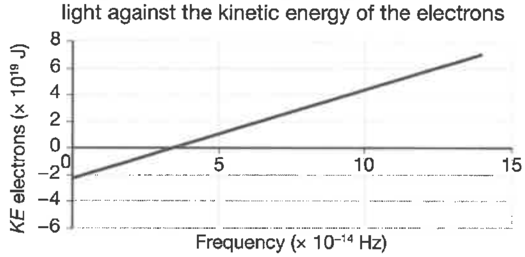
7.12.5.6 C

7.12.5.7 B

7.12.5.8 (a)

Frequency of incident light (Hz)	Energy of incident photon (J)	Stopping voltage (V)	Kinetic energy of electrons (J)
4.0×10^{14}	2.65×10^{-19} J	0.06	9.60×10^{-21} J
6.0×10^{14}	3.98×10^{-19} J	1.0	1.60×10^{-19} J
8.0×10^{14}	5.30×10^{-19} J	1.81	2.90×10^{-19} J
1.0×10^{13}	6.63×10^{-19} J	2.56	4.10×10^{-19} J
1.2×10^{13}	7.95×10^{-19} J	3.56	5.70×10^{-19} J
1.4×10^{13}	9.28×10^{-19} J	4.38	7.00×10^{-19} J

(b) Draw a graph of the frequency of the incident light against the kinetic energy of the electrons

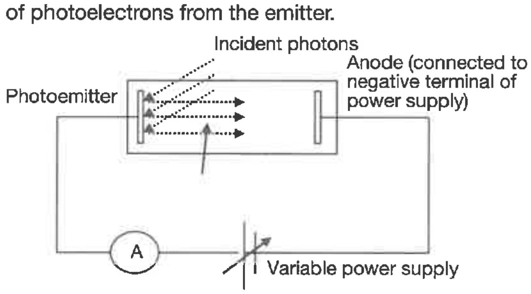


(c) From x-axis intercept, threshold frequency = about 3.3×10^{14} Hz

(d) From y-axis intercept, work function = about 2.2×10^{-19} J

(e) From graph gradient, $h = 6.57 \times 10^{-34}$ J s

7.12.5.9 Stopping voltage is the reverse potential applied across the electrodes in a CRT to stop the emission of photoelectrons from the emitter.



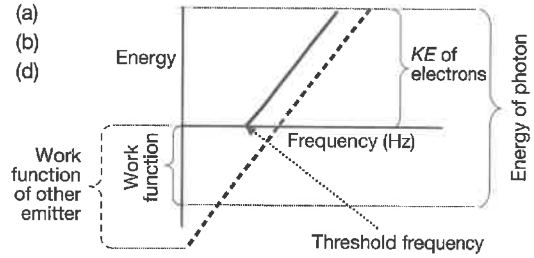
Photoelectrons stopped by negative charge on anode

7.12.5.10 The stopping voltage enables the kinetic energy of the electrons to be calculated ($KE = qV_{stopping}$), and if this is subtracted from the energy of the photon ($E = hf$), then the work function is found. Using $E = hf$ again enables the threshold frequency to be calculated.

7.12.5.11 C

7.12.5.12 The diagram shows a typical graph obtained from an experiment on the photoelectric effect.

(a)
(b)
(d)



(c) Planck's constant (h)

7.12.6.1 The wave model cannot explain the threshold frequency. If the incident light onto a photoemitter was composed of waves, then the supply of energy to the surface would be continuous and electrons would continually absorb energy until they eventually reached the amount needed to break away from their atoms.

7.12.6.2 The classical wave model suggests that photoelectrons will be emitted from the surface at any frequency, electrons taking longer to absorb the required energy at low frequencies, and therefore not being emitted instantaneously. So if the wave model was correct, there would be delayed emission at frequencies below the threshold frequency.

7.12.6.3 Wave theory would predict higher kinetic energy of photoelectrons if intensity is increased. In wave theory, increased intensity means higher energy available for photoelectrons. The particle theory regards increased intensity as more photons each having the same energy and each other, so, while more photoelectrons would be emitted, they would all have the same KE.

7.12.6.4 This cannot be explained by wave theory. Wave theory would predict an increase in the KE of photoelectrons with increasing intensity of incident light whereas, because the energy of the photons is related to their frequency, increased intensity simply means more photons each with the same energy.

7.13.1.1 The energy released by a hot object is due to the oscillation of its atoms.

7.13.1.2 $E = hf = \dfrac{hc}{\lambda}$

7.13.1.3 6.626×10^{-19} J $= 4.14$ eV

7.13.1.4 (a) D
(b) 1.66×10^{-19} J

7.13.1.5 B

7.13.1.6 D

7.13.1.7 D

7.13.1.8 D

7.13.1.9 From $E = \dfrac{hc}{\lambda}$, $E = \dfrac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{475 \times 10^{-9}}$
$= 4.18 \times 10^{-19}$ J $= 2.62$ eV

7.13.1.10 (a) Energy in joules $= 4.6 \times 1.6 \times 10^{-19}$
$= 7.36 \times 10^{-19}$ J

(b) From $E = hf$, $f = \dfrac{7.36 \times 10^{-19}}{6.626 \times 10^{-34}} = 1.11 \times 10^{15}$ Hz

(c) From $c = f\lambda$, $\lambda = \dfrac{c}{f} = \dfrac{3 \times 10^{8}}{1.11 \times 10^{15}} = 270$ nm

(d) UVL

7.13.2.1 (a) 3.74×10^{-18} J
(b) 5.625 V
(c) 5.64×10^{12} Hz

7.13.2.2 (a) 3.5×10^{14} Hz
(b) 9.6×10^{-20} J
(c) Original photon has a wavelength = 857 nm, so the new photon has a higher frequency, therefore carries more energy, therefore photoelectrons will be emitted with more energy.

7.13.2.3 (a) A
(b) 2.8 eV

7.13.2.4 A

7.13.2.5 (a) A
(b) Energy of the photon = hf
$= 6.626 \times 10^{-34} \times 2 \times 10^{15}$
$= 1.325 \times 10^{-18}$ J $\div 1.6 \times 10^{-19}$
= 8.2825 eV – the work function (= 4.5 eV)
= 3.78 eV
= kinetic energy of the released electrons.

7.13.2.6 Energy of photon $= \frac{hc}{\lambda} = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{300 \times 10^{-9}}$
$= 6.626 \times 10^{-19}$ J $\div 1.6 \times 10^{-19} = 4.14$ eV
KE of electrons is 3.0 eV, so work function must be 4.14 – 3.0 = 1.14 eV.

7.13.2.7 C

7.13.2.8 B

7.13.2.9 (a) From the graph, the threshold frequency is 2.5×10^{14} Hz, so, from $\Phi = hf_o$
$= 6.626 \times 10^{-34} \times 2.5 \times 10^{14}$
$= 1.66 \times 10^{-19}$ J (= 1.04 eV)
(b) 4.8×10^{-19} J = 3.0 eV, therefore stopping voltage will be 3.0 V.

7.13.2.10 (a) From $E = hf_o$, where f_o = threshold frequency,
$E = 6.626 \times 10^{-34} \times 4.4 \times 10^{14}$
$= 2.92 \times 10^{-19}$ J
= 1.82 eV
(b) Einstein's explanation of the photoelectric effect is that light consists of packets of discrete particles called photons. The amount of energy carried by each photon is proportional to the frequency of the light and during collisions with electrons they transfer all their energy to the electron (provided it equals or exceeds the work function). Excess energy above the work function will appear as *KE* of the photoelectrons.
Light of a higher frequency consists of photons with greater energy to give to each electron. Accordingly light of a higher frequency will produce electrons with a greater maximum *KE*.

7.13.3.1 D

7.13.3.2 A

7.13.3.3 C

7.13.3.4 (a) B
(b) The red light frequency is obviously below the threshold frequency of the top of the electroscope. Using a higher frequency light source could solve this problem.

7.13.3.5 D

7.13.3.6 (a) UVL – current will increase – UVL has a higher frequency (more energy) than blue light.
(b) Green light – current will decrease – green light has a lower frequency (less energy) than blue light.
(c) Red light – current will decrease or may even reduce to zero if frequency of the red light is below the threshold frequency – red light has a lower frequency (less energy) than blue light.

7.13.3.7 B

7.13.3.8 The stopping voltage for a mixed frequency beam will be determined by the highest frequency component in the beam. for white light, this will be blue light. Hence the stopping voltages will be the same.

7.13.3.9 D

7.13.3.10 A

7.13.3.11 (a) C
(b) Energy is directly proportional to frequency, therefore it is inversely proportional to wavelength, i.e. C.

7.14.1.1 (a) A frame of reference is a system of coordinates in which we make measurements and observations.
(b) Inertial and non-inertial frames of reference.
(c) Inertial frames of reference are frames which have zero acceleration, non-inertial frames of reference are accelerating and experience inertial forces.

7.14.1.2 (a) The principle of relativity states that the laws of motion hold in all frames of reference, but in an inertial frame of reference no observation or experiment can be made *inside* the frame to determine whether or not the frame is at rest or moving with constant velocity. Reference must be made to some object outside the frame of reference to determine this.
(b) Because the motion of an inertial frame cannot be detected from within the frame, the principle of relativity can be used to distinguish between inertial and non-inertial frames of reference.

7.14.1.3 (a) Stationary frames.
Frames moving with constant velocity.
Frames in constant motion, circular orbits.
(b) The complication here is that the Earth is also spinning on its axis, and this motion can be detected without making observations outside the frame of reference of the Earth (see Foucault pendulum). For this reason, it is technically not an inertial frame, but the acceleration due to this rotation is essentially negligible for most simple considerations, and can therefore be ignored.

7.14.1.4 (a) Inertial frame of reference.
(b) Inertial frame of reference.
(c) Inertial frame of reference.
(d) Non-inertial frame of reference.
(e) Non-inertial frame of reference.
(f) Non-inertial frame of reference.
(g) Inertial frame of reference.

7.14.1.5

	(a) Explanation	(b) Frame of reference
(i)	Train is either stationary or moving with constant velocity	Inertial frame of reference
(ii)	Train is turning to the right	Non-inertial frame of reference
(iii)	Train is turning to the left	Non-inertial frame of reference
(iv)	Train is accelerating forwards	Non-inertial frame of reference
(v)	Train is braking	Non-inertial frame of reference

7.14.1.6 (a) D
(b) You are moving backwards and the comet is stationary.
You, and the comet are moving backwards, but you are moving much faster than the comet.

7.14.1.7 (a) C
(b) While an observer inside an inertial frame of reference cannot detect whether the system is moving or not, the absence of any inertial forces acting on suspended objects will indicate that the system is not accelerating and is therefore an inertial frame of reference.

7.14.1.8 The principle of relativity states that the laws of physics hold in all frames of reference but indicate that constant motion cannot be detected in an inertial frame of reference without reference to some point outside the frame. The principle of relativity does not hold in a non-inertial frame of reference.

7.14.1.9 D

7.14.1.10 (a) C

(b) Because a satellite in a stable orbit is falling freely under the influence of gravity and there are therefore no reaction forces acting, there is no way its movement can be detected without reference to an outside point. It is therefore an inertial frame of reference.

7.14.1.11 D

7.14.2.1 (a) All motion is relative – the principle of relativity holds in all situations.

The speed of light is constant regardless of the observer's frame of reference.

(b) The aether model must be wrong.

(c) The aether was 'invented' to account for the particle nature of light and it would therefore affect the speed of light. If the speed of light is constant, then the particle theory in Newtonian terms must also be wrong (light is composed of quantum particles which do not obey the laws of classical physics) and therefore there is no need for the concept of the aether.

7.14.2.2 Einstein showed that when a material body lost energy (either by radiation or heat) of amount E, its mass decreased by the amount $\frac{E}{c^2}$. This led to the famous mass-energy equivalence formula: $E = mc^2$.

7.14.2.3 Minkowski realised that Einstein's special theory of relativity could best be understood in a four-dimensional space, now known as the 'Minkowski space time', in which time and space are not separated entities but connected in a four-dimensional space time continuum. Einstein recognised the importance of Minkowski's space time concept and used it for his work on the foundations of general relativity.

7.14.2.4 B

7.14.2.5 (a) C

(b) (D) – Nothing can travel faster than the speed of light (3×10^8 m s^{-1})

7.14.2.6 C

7.14.2.7 (a) A

(b) If the speed of light is constant as proposed, then light must be independent of any aether. So, there is no need for an aether to exist to carry light energy. Note that the statements do not prove the non-existence of the aether.

7.14.2.8 D

7.14.2.9 D

7.15.1.1 In his first thought experiment Einstein wondered: 'Suppose I am sitting in a train travelling at the speed of light. If I hold a mirror in front of me, will I see my reflection?'

He contemplated two possibilities:

1. No. If the train is travelling at the speed of light, light from his face would not reach the mirror in order to be reflected back. By not being able to see his reflection, he would know that the train was travelling at the speed of light without having to refer to an outside point. This violates the principle of relativity.
2. Yes. This means that light would travel at its normal speed relative to the train. This does not violate the principle of relativity. However, it also means that, relative to a stationary observer outside the train, light would have to travel at twice its usual speed!

On the basis of not violating the principle of relativity, he decided that he must see his image and proposed the consistency of the speed of light, and the non-constant nature of time.

7.15.1.2
- Length and time can no longer be regarded as separate concepts.
- In order to define an object's position we must consider four coordinates in the space time continuum – three dimensions of space and time (Minkowski's proposal).
- A new standard of length had to be defined.

7.15.2.1 The principle of simultaneity which states that events that are simultaneous in one frame of reference may not be seen as simultaneous from a different frame of reference.

7.15.2.2 (a) In this thought experiment Einstein imagined a light on the ceiling of a moving train shining onto a mirror on the floor. The light reflects from the mirror and travels back to the ceiling to a detector that records the time of its arrival. Two observers watch what happens – one inside the train, the other outside the train.

(b) Einstein's mathematics showed that the time for the light to reflect and return to the source was shorter for the observer inside the train (the observer at rest relative to the event) than for the observer outside the train (the observer in motion relative to the train).

(c) Einstein concluded that time in a moving frame of reference always passes more slowly than time in any other frame of reference.

(d) This effect is known as time dilation.

(e) $t_v = \gamma t_o = \dfrac{\Delta t}{\sqrt{1 - \frac{v^2}{c^2}}}$

7.15.2.3 (a) Imagine an observer on Earth looking at the clock on a spaceship travelling away from him at constant speed. The clock on the spaceship will be seen to be running more slowly than his clock on Earth. By the same principle, the astronaut on the spaceship will observe the clock on Earth to be running slower than his clock on the ship.

(b) The term 'the event' refers to what is happening relative to the observer, and this depends on which observer is being considered. For example, for the observer on Earth, 'the event' is the spaceship moving away from Earth.

For the astronaut in the spaceship, 'the event' is the Earth moving in the opposite direction away from him.

(c) t_o is always the time measured on the clock which is stationary relative to 'the event'. For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the spaceship moving away from him, so the clock in the spaceship, which is moving along with the spaceship, is at rest relative to the spaceship. The clock on the spaceship therefore records t_o.

(d) t_v is always the time measured on the clock which is moving relative to 'the event'. For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the spaceship moving away from him, so the clock on Earth is moving relative to the spaceship. The clock on the spaceship therefore records t_v.

(e) The confusing aspect of time dilation is that it works both ways as outlined in the answers above. For both observers, the clock in front of them seems to be running faster than the clock in the other frame of reference That is, more time will pass on the clock in their frame of reference (t_v) that on the clock in the other frame of reference (t_o). In other words $t_v > t_o$. So to remember this, this author teaches that the person making the observation is always watching TV – the time on his clock is t_v!

7.15.2.4 Time can no longer be considered as a fundamental quantity.

In order to correctly define an object's position in space we need to consider four coordinates in the space-time continuum – the three dimensions of space itself, and time.

A new standard of both time and length needed to be found that was not affected by the motion of the observer.

7.15.2.5 (a) Diagram X is from the frame of reference of the observer inside the train.

Diagram Y is from the frame of reference of the observer outside the train.

(b) For X, $c = \frac{2L}{t}$

For Y, $c = \frac{2D}{t}$

(c) The speed of light is constant regardless of the frame of reference of the observer.

(d) For the observer inside the train, $c = \frac{2L}{t}$

For the observer outside the train, $c = \frac{2D}{t}$

But, because the speed of light is constant, then

$\frac{2L}{T} = \frac{2D}{t}$

However, D is a greater distance than L, so for these quotients to be equal, the time measured by the observer outside the train must be greater than the time measured by the observer inside the train.

That is, Time outside train > time inside train

Or, as Einstein put it $t_v > t_o$

7.15.3.1 (a) By definition, t_o is always the time measured on the clock which is *stationary* relative to 'the *event*'.

(b) For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the *spaceship moving away from him*.

(c) Therefore the clock in the spaceship, which is moving along with the spaceship, is at rest *relative* to the spaceship.

(d) The clock on the spaceship therefore records t_o.

(e) The clock on the desk next to the Earth observer is therefore measuring t_v and his clock is in *relative motion* to 'the *event*'.

(f) Therefore, according to the observer on *Earth*, the clock on the spaceship will be running m*ore slowly* than his clock on Earth.

7.15.3.2 (a) The same definition holds – t_o is always the time measured on the clock which is *stationary* relative to 'the *event*'.

(b) In this example, for the observer on the spaceship comparing times of clocks on Earth and in the spaceship, 'the event' is the *Earth moving away from the spaceship*.

(c) Therefore the clock on *Earth*, which is moving with the Earth, is at *rest relative* to the Earth.

(d) The clock on *Earth* therefore records t_o.

(e) The clock on the desk next to the *astronaut*, is therefore measuring t_v and his clock is in *relative motion* to 'the event'.

(f) Therefore, according to the observer on the *spaceship*, the clock on the Earth will be *running more slowly* than his clock on the spaceship.

7.15.3.3 This phrase is designed to help students distinguish between t_o and t_v. Because t_v is always the time measured on the clock belonging to the person making the observations, then let the observer be watching TV!

7.15.3.4 (a) The event is the spaceship moving away from Earth

(b) The pilot in the spaceship

(c) t_v

7.15.3.5 (a) The event is the Earth receding away from the spaceship

(b) The observer on the Earth

(c) t_v

7.15.3.6 (a) The spaceship moving relative to him

(b) The Martian's clock

(c) The Martian's clock

(d) The spaceship clock

(e) The Martian's clock

7.15.3.7 (a) Spaceship Y moving towards him

(b) Captain X's clock

(c) Captain X's clock

(d) Captain Y's clock

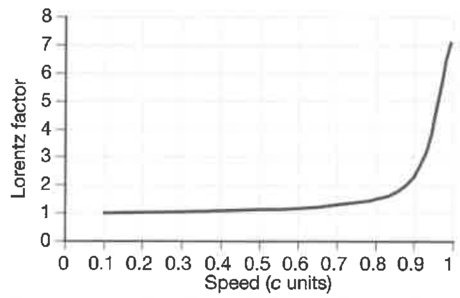
(e) Captain X's clock

7.15.4.1 A light clock is a device in which time is measured by dividing the distance light travels from a source to a mirror where it is reflected and then travels back to the source by the speed of light. In other words, $t = \frac{d}{c}$. This time, if measured by an observer in the same frame of reference as the clock it is known as proper time.

7.15.4.2

Speed of ship (c)	Lorentz factor
0.1	1.005
0.3	1.048
0.5	1.155
0.7	1.400
0.9	2.294
0.99	7.089

7.15.4.3 (a)

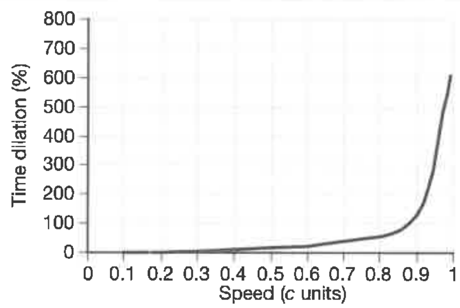


(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 *c*.

7.15.4.4

Time on spaceship (s)	Speed of ship (c)	Lorentz factor	Length of 1 second on spaceship as perceived by observer on Earth	Time dilation effect (%)
1	0.1	1.005	1.005	0.5
1	0.3	1.048	1.048	4.8
1	0.5	1.155	1.155	15.5
1	0.7	1.400	1.400	40.0
1	0.9	2.294	2.294	129.4
1	0.99	7.089	7.089	608.9

7.15.4.5 (a)



(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 *c*.

7.15.4.6 (a) Astronauts see this as ≈ 2.18 years.
(b) Time recorded on Earth = (4.5 ÷ 0.9) = 5 years

7.15.4.7 (a) 7.79 hours
(b) 8.21 hours

7.15.4.8 Speed of the meson is 0.99 *c*.

7.15.4.9 (a) 11.55 hours
(b) 8.7 hours

7.15.4.10 0.503 s

7.15.4.11 4.9 s

7.15.4.12 5.45 s

7.15.4.13 0.94 *c*

7.15.4.14 (a) 3×10^8 m s^{-1}
(b) 3×10^8 m s^{-1}
(c) (i) 3×10^8 m s^{-1}
(ii) 3×10^8 m s^{-1}

7.15.4.15 (a) 2.8×18^8 s (8.88 years)
(b) 2.2×18^8 s (6.98 years)
(c) Proper time is time measured by the observer who is at rest relative to the event, which in this case is the astronaut. Note that both observers however would consider their time to be the correct time.
(d) The biological age of the astronaut will be less because of time dilation despite the fact that the astronaut will experience various forces and accelerations during the trip.

7.15.4.16 (a) 40 years
(b) 36.66 years
(c) 14.66 light years
(d) 0.4 *c*

7.15.5.1 The answer to this depends on your concept of 'stationary observer' as there is probably no absolute state of not moving since all parts of the Universe are moving as it expands. However, if we consider this observer to be stationary relative to the Solar System, then he would notice a small time dilation for Earth (due to its orbital motion) and a larger time dilation effect for time on the spaceship as the spaceship would also be moving faster relative to this observer.
(Note that if you take the observer as stationary relative to Earth – a less correct assumption – then you would get no time dilation on Earth and some time dilation on the spaceship.)

7.15.5.2 (a) B
(b) Both observers are in inertial frames of reference and are moving relative to each other, so both observers will detect a time dilation effect in the clocks of the other person.

7.15.5.3 D

7.15.5.4 (a) B
(b) Both observers are in inertial frames of reference and are moving relative to each other, so both observers will detect a time dilation effect in the clocks of the other person.

7.15.5.5 C

7.15.5.6 C

7.15.5.7 (a) A
(b) Both pulse rate and heartbeat would be slower due to the time dilation effect.

7.15.5.8 (a) D
(b) Because they are both moving *relative to each other* they will both notice a time dilation effect. Each person will observe that time passes more slowly in the other person's frame of reference. So, 5 seconds in their frame of reference will be observed to be less than 5 seconds in the other frame of reference.

7.15.5.9 C

7.15.5.10 B

7.15.5.11 C

7.15.5.12 A

7.15.6.1 Proper length is the length measured by an observer at rest to the object.

7.15.6.2 (a) 1.5 m
(b) $L = \gamma L_0$
(c) *L* will be shorter because the desk is moving relative to Jenny, so length contraction will occur for her.

7.15.6.3 0.53 *c*

7.15.6.4 (a) Its pilot – 100 m.
(b) An observer on the space platform – 60 m.
(c) The pilot – 150 m.
(d) An observer on the space platform – 250 m.

7.15.6.5 (a) 0.66 *c*
(b) 0.87 *c*

7.15.6.6 (a) 116 189.5 km
(b) 96.82 m

7.15.6.7 (a) 38 m (Speed is too slow for a significant relativistic effect.)
(b) 250 km
(c) 250 km

7.15.6.8 (a) 1 hour
(b) 1.67 hours
(c) 8.64×10^8 km
(d) 1.44×10^9 km
(e) 167 m
(f) 100 m

7.15.6.9 124.9 m
7.15.6.10 293.6 m
7.15.6.11 137.5 m
7.15.6.12 D
7.15.6.13 B
7.15.6.14 B
7.15.7.1 C
7.15.7.2 (a) A
(b) 120 m high by 120 m deep by 72 m long – the length contraction is only in the direction of the motion of the object.

7.15.7.3 (a) B
(b) 50 m – (The length contraction is only in the direction of the motion.)

7.15.7.4 C
7.15.7.5 C
7.15.7.6 D
7.15.7.7 D
7.15.7.8 A
7.15.7.9 C
7.15.7.10 A
7.15.7.11 B
7.15.7.12 D
7.15.7.13 B
7.15.8.1 (a) Using $\gamma = \sqrt{\left(1-\frac{v^2}{c^2}\right)} = \frac{1}{\sqrt{\left(1-\frac{0.8^2}{1^2}\right)}} = 1.67$

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 150\sqrt{\left(1-\frac{(0.8\ c)^2}{c^2}\right)}$
$= 150 \times 0.6 = 90$ m

(c) $t = \frac{90}{(0.8 \times 3 \times 10^8)} = 3.75 \times 10^{-7}$ s

(d) $t = \frac{150}{(0.8 \times 3 \times 10^8)} = 6.25 \times 10^{-7}$ s

(e) 9.109×10^{-31} kg

(f) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = \frac{(9.109 \times 10^{-31})}{\sqrt{\left(1-\frac{(0.8\ c)^2}{c^2}\right)}}$
$= 1.521 \times 10^{-30}$ kg

(g) Graph will be the usual exponential graph.

7.15.8.2 (a) Astronaut will notice no changes. He is at rest relative to his frame of reference.
(b) Astronaut's body will appear to be thinner in the direction of movement, his mass will be relativistically increased, and his pulse rate will be slower due to the perceived time dilation effect as observed by the Earth observer.

7.15.8.3 (a) $v = \frac{15.8}{16} = 0.9875\ c$

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 16\sqrt{\left(1-\frac{(0.9875\ c)^2}{c^2}\right)} = 2.52$ years

(c) Being in the spaceship, the length of journey itself is not in the astronaut's frame of reference so it will be contracted to 2.49 light years. Travelling at 0.9875 c, the ship will cover this distance in 2.52 years.

7.15.8.4 The astronaut will consider that time is passing normally for him. An Earth observer would perceive the astronaut's time as passing more slowly

7.15.8.5 No, it is not correct. The patient will be in the same frame of reference as the spaceship and so will experience time passing as normal. The disease will run its course as if he was still on Earth with time passing normally (to him).

7.15.8.6 (a) $t = \frac{s}{t} = \frac{4.2}{0.6} = 7$ years

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 7\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 5.6$ years

(c) 4.2 light years

(d) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 4.2\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 3.36$ light years

(e) 5.6 years

(f) Being in the spaceship, the length of journey itself is not in the astronauts' frame of reference so it will be contracted to 3.36 light years. Travelling at 0.6 c, the ship will cover this distance in 5.6 years.
Observers on Earth, measuring 7 years as passing in the spaceship's frame of reference will record the astronauts journey time as 5.6 years.

7.15.8.7 (a) 200 m

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 200\sqrt{\left(1-\frac{(0.4\ c)^2}{c^2}\right)} = 183.3$ m

(c) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 2\sqrt{\left(1-\frac{(0.4\ c)^2}{c^2}\right)} = 1.833$ km

(d) 2.0 km

7.15.8.8 (a) $t = \frac{10.5}{0.75} = 14$ years

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 14\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)} = 9.26$ years

(c) $t = 2 \times 14 = 28$ years
(d) $t = 2 \times 9.26 = 18.52$ years

7.15.8.9 (a) $t = \frac{s}{v} = \frac{100}{(0.75 \times 3 \times 10^8)} = 4.44 \times 10^{-7}$ s

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = (4.44 \times 10^{-7})\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)}$
$= 2.94 \times 10^{-7}$ s

(c) 100 m

(d) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 100\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)} = 66.14$ m

(e) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = (1.673 \times 10^{-27})\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)}$
$= 2.529 \times 10^{-27}$ kg

(f) 1.673×10^{-27} kg

7.15.8.10 (a) 500 m

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 500\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 400$ m

(c) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 1600\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 1280$ m

(d) 1600 m

(e) 3000 kg

(f) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = 3000\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 3750$ kg

(g) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)}$; $500 = 1600\sqrt{\left(1-\frac{v^2}{c^2}\right)}$;

$1-\frac{v^2}{c^2} = 0.098$; $\frac{v^2}{c^2} = 0.9023$; $v = 0.95\ c$

7.15.8.11 (a) $v = \frac{(v_A + v_B)}{\left(1+\frac{v_A v_B}{c^2}\right)} = \frac{(0.6\ c + 0.8\ c)}{\left(1+\left(\frac{0.6\ c \times 0.8\ c}{c^2}\right)\right)} = 0.95\ c$

(b) c *Note:* The velocity of EM radiation (the signal) is always c.

(c) c

(d) c

(e) c

(f) c

(g) c

7.16.1.1 In 1972 four ultra accurate atomic clocks were placed on fast planes (flying at one millionth the speed of light). After two days of continuous flight (two around the world in different directions) the time shown by the airborne clocks differed (by nanoseconds!) from that shown by a synchronised clock left on Earth. However, questions were asked about the accuracy of the experiment and the Nobel Committee has chosen not to recognise it as experimental proof.

7.16.1.2 Muons are elementary particles created by cosmic rays in the Earth's atmosphere at an altitude of about 9 km.

At the speed they travel, 99.7 per cent of the speed of light, the muons should reach sea level in 16 to 31 microseconds (depending on the altitude at which they form), far longer than the time it takes them to decay and 'disappear'. Therefore, theoretically, they should never be detected at sea level. However, they are detected at sea level and so, in their frame of reference must take only about 2.2 μs to travel from the upper atmosphere to the surface. For them, the distance of 9 km contracted to 1.26 km.

7.16.1.3 The relativistic mass increase of particles accelerated to near light speeds in particle accelerators has been shown frequently. If the speed of the particles only is used to calculate conservation of energy data in high energy collisions, the law would seem to be disobeyed. However, when relativistic mass increases are considered, energy conservation is shown to occur.

7.16.1.4 The Michelson-Morley experiment was designed to detect the motion of the aether relative to the Earth. Their hypothesis was that because the aether was the medium that carried light, then the speed of light relative to Earth would vary if the speed of the aether relative to Earth varied, so the speed of light relative to Earth from different directions would be different. Their null result can be taken as evidence for the consistency of the speed of light.

7.16.2.1 Half-life refers to the time it takes a quantity, such as the mass of a radioactive particle or a number of muons to reduce to half its initial mass or number.

7.16.2.2

Time (μs)	Number of half-lives	Number of muons
0	0	1 000 000
2.2	1	500 000
4.4	2	250 000
6.6	3	125 000
8.8	4	62 500
11.0	5	31 250
13.2	6	15 625
15.4	7	7612
17.6	8	3806
19.8	9	1903
22.0	10	951
24.2	11	475
26.4	12	237
28.6	13	118

7.16.2.3 (a) 656 m

(b) 46.95 μs

(c) 21.34 half-lives

(d) 0

7.16.2.4 (a) 20.1 μs

(b) About 6030 m

(c) 2.32

(d) About 200 000

7.16.2.5 (a) About 1530 m

(b) 5.1 μs

(c) 2.32

(d) About 200 000

7.16.2.6 The calculations based on the equations of special relativity which predict the proportion of muons reaching the surface and the observations which show the predictions to be correct provide one of the strongest pieces of evidence to support the theory.

7.17.1.1 Rest mass is the mass of an object when it is at rest.

7.17.1.2 Because the mass of an object increases as its speed increases.

7.17.1.3 The mass of an object is affected if it is moving. At all speeds, mass increases according to Einstein's relativistic mass equation. So mass cannot be regarded as a fundamental quantity – it changes according to the speed of the object.

7.17.1.4 9.214×10^{-31} kg

7.17.1.5 2.788×10^{-27} kg

7.17.1.6 (a) 0.745 c

(b) (1×10^{-7})%

7.17.1.7 (a) 9.16×10^{-31} kg

(b) 2.92×10^{-30} kg

(c) 0.8 c

7.17.1.8 (a) From $W = qV = \frac{1}{2}mv^2$

$1.6 \times 10^{-19} \times 5 \times 10^5 = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

From which $v = 1.326 \times 10^8$ m s^{-1} = 4.2×10^8 m s^{-1}

(b) This velocity is impossible because it exceeds the speed of light.

7.17.1.9 (a) Negligible (don't even bother working it out).
(b) Negligible (ditto).
(c) 34.2%

7.17.1.10 0.999885 c (Do not round to 1.0 c, as this would make the mass of the electron infinite.)

7.17.1.11 (a) 2.3×10^{-14} J
(b) 3.49×10^{-14} J

7.17.1.12 (a) Newtonian physics will give (i.e. ignoring relativistic increases in mass that occur) gain in kinetic energy = 6.56×10^{-15} J
Repeating the calculation using relativistic effect at 0.4 c we get

Work done = $\frac{1}{2} \times 9.94 \times 10^{-31} \times (0.4 \times 3 \times 10^8)^2$

= 7.2×10^{-15} J which is a more correct answer.

(b) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 1.52 \times 10^{-30} \times (0.8 \times 3 \times 10^8)^2 - \frac{1}{2} \times 9.94 \times 10^{-31} \times (0.4 \times 3 \times 10^8)^2$

$= 4.4 \times 10^{-14} - 7.2 \times 10^{-15} = 3.7 \times 10^{-14}$ J

(c) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 6.46 \times 10^{-30} \times (0.99 \times 3 \times 10^8)^2 - \frac{1}{2} \times 1.52 \times 10^{-30} \times (0.8 \times 3 \times 10^8)^2$

$= 2.85 \times 10^{-13} - 4.4 \times 10^{-14} = 2.4 \times 10^{-13}$ J

(d) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 2.04 \times 10^{-29} \times (0.999 \times 3 \times 10^8)^2 - \frac{1}{2} \times 6.46 \times 10^{-30} \times (0.99 \times 3 \times 10^8)^2$

$= 9.16 \times 10^{-13} - 2.85 \times 10^{-13} = 6.3 \times 10^{-13}$ J

(e) (Comparing answer (b) to answer (a) – for the same increase in speed, i.e. 0.4 c, 3.6 times as much work must be done. Comparing answer (c) to answer (b) – to increase the speed by 25%, 9.6 times as much work must be done. Comparing answer (d) to answer (c) – to increase the speed by 0.1%, 2.5 times as much work must be done (note that if we multiply this by 250 = 25% ÷ 0.1%. we get 2.5 × 250 = 625 so although it is only 2.5 times as much work for a 0.1% increase, it represents an equivalent amount 625 times larger than the previous amount for the 25% increase.)
These figures therefore show an exponential increase in the amount of energy needed to increase the speed of an object by very small amounts as it approaches the speed of light, suggesting that an infinite amount of energy may be needed to reach the speed of light, further suggesting that we cannot reach it, let alone exceed it.

7.17.1.13 (a) 1.0×10^5 eV
(b) $W = qV = 1.6 \times 10^{-14}$ J
(c) Work done = kinetic energy gained = 1.6×10^{-14} J
So velocity = 1.874×10^8 m s^{-1} (= 0.625 c)
(d) 0.625 c
(e) 9.11×10^{-31} kg
(f) 1.17×10^{-30} kg

7.17.1.14 (a) Relativistic mass of X = 2.09125×10^{-27} kg
Relativistic mass of Y = 3.83812×10^{-27} kg
Difference = 1.74689×10^{-27} kg
(b) Newtonian kinetic energy X = 2.710×10^{-11} J
Newtonian kinetic energy Y = 6.098×10^{-11} J
Difference = 3.388×10^{-11} J
(c) Relativistic kinetic energy X = 3.3878×10^{-11} J
Relativistic kinetic energy Y = 1.399×10^{-10} J
Difference = 1.0602×10^{-10} J
(d) X since it is the slower speed.
(e) Y because relativistic effects are exponential as speed approaches the speed of light, and Y will be much closer to that speed than X.

7.17.2.1 (a) C
(b) The mass of particles in accelerators increases as their speed increases. JJ Thomson also found proof of this in his cathode ray oscilloscope experiments in the 1880s.

7.17.2.2 (a) D
(b) Never. If an object exists it must have mass. (Let's not confuse this simple concept by talking about neutrinos!)

7.17.2.3 D
7.17.2.4 B
7.17.2.5 C
7.17.2.6 B
7.17.2.7 B
7.17.2.8 B
7.17.2.9 C
7.17.2.10 A
7.17.2.11 (a) B
(b) Relativistic mass effects are greater at higher speeds, so the increase in mass of the spaceship will be larger from 0.8 c to 0.9 c than from 0.6 to 0.7 c (it will be larger at 0.8 c than at either 0.6 c and 0.7 c anyway), so the constant thrust will have less effect at the higher speeds. The acceleration of Y will therefore be less than the acceleration of X.

7.17.3.1 (a)

Speed (c)	Classical momentum ($\times 10^{-22}$)	Relativistic momentum ($\times 10^{-22}$)	Relativistic momentum compared to classical momentum
0.10	0.273	0.276	1.005
0.25	0.683	0.706	1.034
0.50	1.36	1.57	1.115
0.75	2.05	3.10	1.51
0.99	2.71	19.2	7.08
0.999	2.730	61.1	22.38
0.9999	2.733	193.2	70.72
0.99999	2.733	611.1	223.60
0.999999	2.733	1932.5	707.1

(b) Almost the same for the first 4 – low speed but rising exponentially for the speeds near c.
(c) The mass is increasing at the expense of speed so c will never be attained.

7.17.3.2 Gamma factor at 0.235 c = 1.0288
Gamma factor at 0.47 c = 1.1329
Therefore relativistic momentum increases by $\frac{1.1329}{1.0288}$
= 1.1 times larger

7.17.3.3 (a) They will have the same momentum at low speeds, but at speeds which are a significant proportion of the speed of light, particle B will have the higher momentum. At the higher speeds the gamma factor is larger, so the relativistic mass is larger as well as the speed being larger, so the relativistic momentum will be larger at higher speeds.
(b) Relativistic momentum of A = $\gamma m_o.v$
= 1.115 × 2 × 0.5 = 1.115 units
Relativistic momentum of B = $\gamma m_o.v$
= 1.034 × 4 × 0.25 = 1.034 units
(c) Relativistic momentum of A = $\gamma m_o.v$
= 1.667 × 40 × 0.8 = 53.34 units
Relativistic momentum of B = $\gamma m_o.v$
= 1.091 × 80 × 0.4 = 34.91 units

7.17.3.4 0.866 c

7.17.3.5 (a) 4.73×10^{-22} kg m s^{-1}
(b) 2.367×10^{-22} kg m s^{-1}
(c) At a speed of 0.866 c, the gamma factor is 2.0 which means the relativistic momentum is twice the classical momentum.

7.18.1.1 Einstein's explanation of this is that when an object is moving (at any speed), the energy used to accelerate the mass also changes its mass. At high speeds, while the energy still changes the mass of the object, not all of it results in an increase in speed. He put forward a new concept for the total energy of an object: $E_{total} = KE + m_oc^2$.

7.18.1.2 1.508×10^{-10} J

7.18.1.3 C

7.18.1.4 (a) B
(b) Total energy = kinetic energy due to the movement + rest energy = $\frac{1}{2}mv^2 + mc^2$

7.18.1.5 (a) B
(b) The rest energy of an electron cannot be zero as it has mass.

7.18.1.6 (a) A
(b) This mass is smaller than that of an electron, so only possible if there is some subatomic particle smaller than the electron (and there are plenty of those!) – however, your answer must give this proviso to be correct.

7.18.1.7 C

7.18.1.8 (a) C
(b) The same amount. One kilogram of any element will produce the same amount of energy.

7.18.1.9 (a) A
(b) The gradient would be constant and equal to c^2.

7.18.1.10 (a) A
(b) As the speed of an object increases, its mass increases, and so does the force needed to accelerate it. At speeds approaching the speed of light, the mass increases towards infinity, so the force needed to accelerate it to a higher speed also increases towards infinity. We cannot have an infinite force, therefore we cannot accelerate the mass beyond the speed of light.

7.18.1.11 (a) D
(b) The rest mass of an object can never be zero – mass can never be zero.

7.18.1.12 (a) B
(b) No, because the rest mass is the mass when it is at rest and it can never be moving slower than zero.

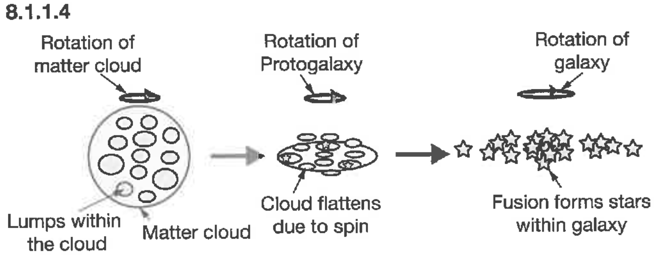
Module 8 From the Universe To the Atom

8.1.1.1
(a) The Big Bang produced an enormous amount of energy which expanded outwards.
(b) As the Universe cooled, the energy condensed to simple particles first, then to more complex particles.
(c) The first particles formed were the fundamental particles, the leptons, neutrinos and quarks.
(d) The formation of mass particles allowed the gravitational force to take effect on them.
(e) Gravity collected the newly forming particles together to form 'lumps' within the developing Universe.
(f) As the temperature fell, quarks combined to form matter hadrons and antimatter hadrons.
(g) The initial hadrons were mainly protons and neutrons, as isolated particles.
(h) This explains the huge amounts of hydrogen in the Universe.
(i) The formation of these hadrons required the strong nuclear force to come into play.
(j) The charged leptons resulted in the electromagnetic force.
(k) The next phase is thought to have been the annihilation of hadrons and antihadrons as they combined.
(l) This annihilation released leptons and energy in the form of gamma rays.
(m) However, due to an excess of matter over antimatter, some matter hadrons remained.
(n) These hadrons gravitated towards each other forming dense collections of molecules of hydrogen.
(o) The energy produced by the annihilation was enough to allow fusion of some hydrogen into heavier nuclei.
(p) The main nuclei formed initially by this fusion were deuterium, helium and lithium.
(q) Over the next few hundred thousand years enough matter accumulated to form stars and galaxies.
(r) The Universe as we know it started to form.

8.1.1.2 The Big Bang event.

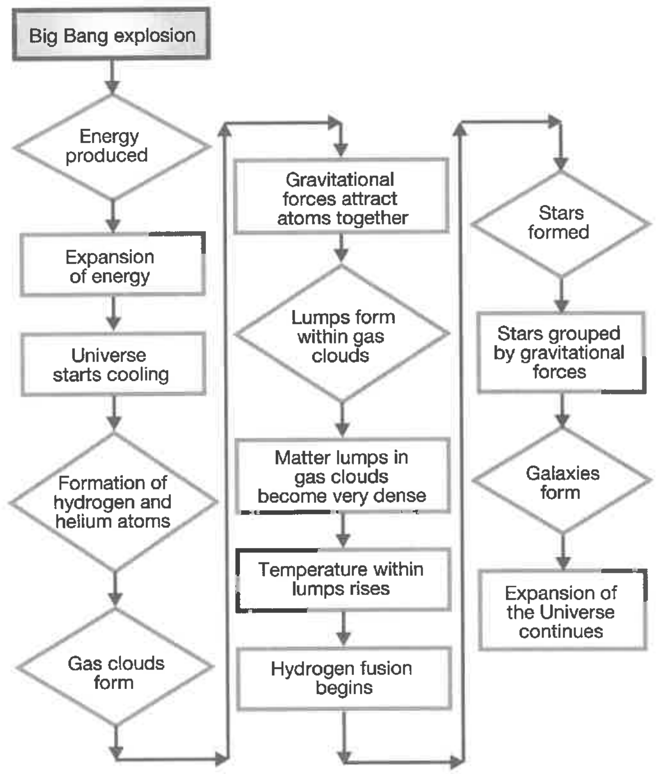
8.1.1.3
(a) The term lumpy' refers to the composition of the Universe as being pockets of matter (in some cases antimatter) isolated in space with huge distances between each pocket of matter.
(b) The Big Bang produced both matter and antimatter, with matter in excess. Wherever matter and antimatter coexisted, they annihilated each other resulting in the empty spaces. The 'lumps' are the left over matter (or antimatter) which was not near any antimatter (or matter).
(c) Gravitational attraction of the matter within each lump formed denser clumps of matter.
(d) The galaxies and the stars that compose them.

8.1.1.4



8.1.1.5
(a) Like all accepted theories in science, the Big Bang theory explains more observations than rival theories and makes more accurate predictions of observations than Astronomers have been making in modern times.
(b) Their idea was that the energy was generated due to the gravitational forces compressing the matter into the centre of the stars.
(c) Almost all life on Earth is dependent either directly or indirectly on the photosynthesis that occurs in plants, and the energy that runs photosynthesis comes from the Sun.

8.1.1.6



8.1.2.1
(a) It shows us that the Big Bang event produced the energy that produced matter which became more complex as time from the Big Bang event increased. We could say that the formation of matter was directly related to the time passing since the Big Bang event.
(b) The diagram assumes that time is measured relating to the Big Bang event, perhaps assuming that time did not exist before the event.

8.1.2.2 This is more difficult because the diagram assumes the existence of a 'unified force' which is thought to be a single force encompassing the four fundamental forces. As matter stated to form and become more complicated, the separate forces started to become independent of the others – they acted in their own right – so perhaps we could say that the appearance of these separate forces was directly related to the formation of the particles of matter.

8.1.2.3 Time and the size of the Universe are directly related. As time passes, the Universe gets larger.

8.1.2.4 Indirectly related. As time passes the temperature of the Universe decreases.

Science Press

8.1.2.5 (a) 10^{-43} seconds

(b) The fermions – the fundamental particles, quarks and electrons and neutrinos (and their antimatter equivalents).

8.1.2.6 (a) Around 10 seconds after the Big Bang.

(b) Leptons and gamma radiation.

(c) The energy produced added to the energy produced by the Big Bang and enabled the expansion of the Universe to continue.

8.1.2.7 The temperature of the Universe had to cool sufficiently to allow the developing matter to attract (gravitational forces) and form atoms pressed close enough together for the fusion to commence.

8.1.3.1 (a) The red shift in light from distant galaxies shows that the Universe is expanding no matter in which direction we look. Calculations show that galaxies further away from us are moving faster. This data supports the idea of the Big Bang explosion in that this is exactly the way pieces of a hand grenade or an exploding bomb move after they explode.

(b) The Universe is composed of about 25% helium and 75% hydrogen. Calculations show that if the Universe began with a big bang, then these elements would have formed in these proportions. This supports the Big Bang idea.

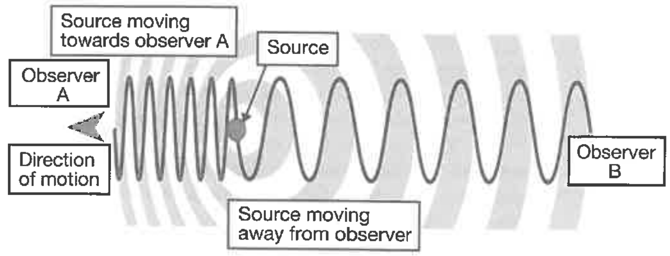
(c) Hotter, larger stars produce heavier elements in the fusion reactions that occur in their cores, and that all stars (except dwarfs) fuse hydrogen to form helium. If the 25% helium in the Universe had been formed in this way, then most stars would be much hotter than they are because of the amount of nuclear fusion of hydrogen required to produce it. In addition, older stars would have less helium than younger stars (due to its conversion to heavier elements). However, they don't. Again, the calculations which lead to these results also favour a Big Bang event

(d) If the Universe started with a big bang, then it is getting older every year. We should be able to see signs of this. Light from galaxies far away from us has taken billions of years to reach us. This light should provide evidence to show these galaxies are different from ours (being much younger) and from other, closer galaxies. This evidence is found. At large distances from us, many galaxies are radio galaxies – they emit radiation in the radio frequencies, and contain many more blue stars. Blue stars are very hot, and have a much shorter life span than stars like the Sun. These two observations give evidence of younger galaxies, supporting the ageing concept.

(e) An exciting development in physics is the link between high speed particle physics and cosmology, the study of how the Universe began. As scientists built bigger and better particle accelerators and collided particles with more and more energy they realised that the particles they were producing could have been those which existed when these types of energies existed in the Universe. They started linking their ideas about the structure of matter to the conditions which they thought existed just after the 'Big Bang'. While astronomers were hypothesising from time zero forwards, particle physicists started working backwards from now. They both arrived at the same points.

(f) George Gamow, a former student of Friedmann, predicted in 1948 that if the Universe started with a highly energetic explosion, then the remnants of the energy associated with that explosion should be able to be detected as a 'background radiation' of wavelength of about 1 mm throughout all of space. He estimated that the expansion of the Universe would have resulted in its cooling down to about 3 kelvins. This has been found to be correct.

8.1.3.2



8.1.3.3 The Big Bang should be considered as an 'event' rather than an actual explosion. An explosion implies the existence of matter which is hurled into space. The Big Bang theory says that nothing existed before the 'event'. Space did not exist. What happened was the space was formed and started expanding outwards, carrying with it, the matter and energy associated with the 'event'. How the matter and energy was produced is not accounted for. What happened in the 10^{-43} seconds before the appearance of the fundamental particles is not known (yet). Remember, that while space continues to expand, the galaxies within space do not. They maintain their relative sizes and shapes.

8.2.1.1 Advances in technology, specifically developments in telescopes, including lenses and reflecting mirrors and spectrographs.

8.2.1.2 (a) Einstein's mathematics on the laws of gravity and special relativity actually predicted the expansion of the Universe. This was the first time this had been considered.

(b) Instead of trusting his mathematics and searching for more evidence, Einstein seems to have let his personal belief that the Universe was stationary influence his mathematics to the point that he introduced a constant into his work so that the mathematics supported his belief.

8.2.1.3 (a) The optical Doppler effect is the red or blue shift in the spectrum of light from distant galaxies when their emission spectrum is compared to a stationary emitter, like our Sun.

(b) Vestro Slipher, was an astronomer working at the Lowell Observatory in Arizona. He examined the spectrum of light produced by spiral nebulae (he did not know these were different galaxies).

(c) The red shift is produced by galaxies that are moving away from us. The blue shift is caused by galaxies moving towards us.

(d) Any frequency of electromagnetic radiation will be subject to frequency shifts if the emitter is moving relative to an observer. Sound also undergoes an audio Doppler effect.

(e) The frequency of sound emitted by the sirens of ambulances, police, fire trucks increases as they come towards us, decreasing as they pass and go away from us.

(f) Galaxy X is stationary relative to Earth. Its spectrum is the normal reference spectrum.
Galaxy Y is showing a red shift due to its motion away from Earth.
Galaxy Z is showing a blue shift due to its motion towards Earth.

8.2.1.4 In 1922, Friedmann, a Russian physicist read Einstein's work and how he had solved the problem of an expanding Universe by introducing the cosmological constant. Friedmann considered this had been an error, and set about solving Einstein's equations without the constant. He found that they predicted either an expanding or contracting Universe. With no other evidence to back him up, he favoured an expanding Universe in which both space and time are curved.

8.2.1.5 Hubble's discoveries were to revolutionise ideas on the structure of the Universe. He discovered that not all stars belonged to the Milky Way Galaxy and discovered over 20 new galaxies awakening people to the fact that the Universe was very much larger than previously thought. He applied the idea of the red shift to his new galaxies and discovered that they were all moving away from Earth, no matter in which direction he looked. So while Friedmann proposed the expansion of the Universe, Hubble proved it. Hubble went further to show that the further away from us galaxies are, the faster they are moving away, and that this is a mathematically direct relationship. This data enabled more accurate calculations of the age of the Universe.

8.2.1.6
(a) Edwin Hubble's
(b) From the equation, average speed $= \frac{\text{distance}}{\text{time}}$

Therefore $D = vt$

From the graph,

Gradient = Hubble's constant H_0
= velocity ÷ distance to galaxy
$= \frac{v}{D}$

From which $D = \frac{v}{H_0}$

Equating the two equations for distance:

$vt = \frac{v}{H_0}$

Dividing both sides by v, we get t, so that t, the age of the Universe, is given by:

$t = \frac{1}{H_0} \approx 15.6$ billion years

8.2.1.7 The Big Bang does not consider the 'creation' of this initial energy, only its evolution after creation.

8.3.1.1 Einstein's explanation of this is that when an object is moving (at any speed), the energy used to accelerate the mass also changes its mass. At high speeds, while the energy still changes the mass of the object, not all of it results in an increase in speed. He put forward a new concept for the total energy of an object:

$E_{total} = KE + m_0c^2$

8.3.1.2 1.508×10^{-10} J

8.3.1.3
(a) A
(b) The gradient would be constant and equal to c^2.

8.3.1.4
(a) Rest mass refers to the mass of an object when it is at rest.
(b) Because Einstein's work and observations of particles in accelerators have shown that the mass of an object increases as its speed increases.
(c) The rest energy of a mass is its energy equivalence when it is stationary.

8.3.1.5 C

8.3.1.6
(a) B
(b) Total energy = kinetic energy due to the movement + rest energy $= \frac{1}{2}mv^2 + mc^2$

8.3.1.7
(a) B
(b) The rest energy of an electron will be zero when it is at absolute rest.

8.3.1.8
(a) A
(b) This mass is smaller than that of an electron, so only possible if there is some subatomic particle smaller than the electron (and there are – plenty of those!) – however, your answer must give this proviso to be correct.

8.3.1.9 C

8.3.1.10
(a) C
(b) The same amount. One kg of any element will produce the same amount of energy.

8.3.1.11
(a) D
(b) No. Mass is the amount of matter in an object – this cannot be zero.

8.3.1.12
(a) B
(b) No. Rest mass is the mass of an object when it is stationary – it cannot move slower than stationary!

8.3.1.13 In a nuclear reaction, the mass of the products is usually less than the mass of the reactants. The difference, called the mass defect, is the mass converted to energy during the reaction. The amount of energy released can be calculated using the Einstein equation.

8.3.2.1
(a) Mass of reactants $= 4 \times 1.67325 \times 10^{-27}$ kg
$= 6.693 \times 10^{-27}$ kg
(b) Mass of products $= 6.645 \times 10^{-27}$ kg
(c) Mass defect $= 6.693 \times 10^{-27} - 6.645 \times 10^{-27}$
$= 0.048 \times 10^{-27}$ kg
(d) $E = mc^2 = 0.048 \times 10^{-27} \times 9 \times 10^{16}$
$= 4.32 \times 10^{-12}$ J

8.3.2.2
(a) Number of fusions $= \frac{4 \times 10^{26}}{4.32 \times 10^{-12}}$
$= 9.26 \times 10^{37}$ per second
(b) Note that there are 4 hydrogen atoms used in every fusion, therefore mass of hydrogen fused
$= 4 \times 9.26 \times 10^{37} \times$ mass of hydrogen atom
$= 1.67325 \times 10^{-27}$ kg
$= 6.198 \times 10^{11}$ kg
= about 620 million tonnes
(c) Mass of helium-4 produced
$= 6.645 \times 10^{-27} \times 9.26 \times 10^{37}$ kg
$= 6153 \times 10^{12}$ kg
= about 615 million tonnes
(d) The loss in mass of the Sun each second
= about 5 million tonnes
(e) The mass lost by the Sun each year
$= 5 \times 365.25 \times 24 \times 3600$
$= 1.58 \times 10^{8}$ million tonnes
(f) Percentage mass lost each year
$= \frac{1.58 \times 10^{17}}{2 \times 10^{30}} \times 100 = 7.9 \times 10^{-12}$ %
(g) Sun will last, at this rate
$= 2 \times 10^{30}$ kg ÷ 5 million tonnes
$= 2 \times 10^{30} \div 1.58 \times 10^{17}$
$= 1.27 \times 10^{13}$ years
$= 1.27 \times 10^{4}$ billion years
(h) Long before this time, about 5 billion years from now, the Sun's concentration of hydrogen in its core will be insufficient to maintain hydrogen fusion. At this stage, gravitational collapse will not be counteracted by the thermal expansion due to the fusion reactions, so the Sun will shrink in on itself and then, when the pressure and temperature rises sufficiently, helium fusion will commence. The Sun will then expand extremely rapidly producing a red giant.
(i) Mass 4.5 billion years ago
$= 2.0 \times 10^{30} + (4.5 \times 10^{9} \times 1.58 \times 10^{17})$
$= 2.00071 \times 10^{30}$ kg
(j) Percentage of mass lost in 4.5 billon years
$= 0.036\%$

8.4.1.1 When atoms are excited they emit electromagnetic radiation of characteristic wavelengths. This radiation can be split into its component wavelengths which can then be detected using photographic or similar plates. The pattern formed on the photographic plate is called a spectrum.

8.4.1.2 (a) Continuous
Emission
Absorption

(b) Continuous – All wavelengths (or frequencies) are present forming (in the case of the visible spectrum) a continuous, unbroken band of colour ranging according to ROYGBIV

Emission – Mostly a black band with varying numbers of isolated coloured lines representing the spectrum of the particular element(s) present.

Absorption – A continuous band of colour with selected omissions of frequencies (depending on the element(s) involved) which will appear as isolated black lines in the band.

8.4.1.3 The coloured lines in the emission spectrum will be the same frequencies as the black lines in the absorption spectrum.

8.4.1.4 (a) The spectrum formed from light from the Sun.

(b) To produce an absorption spectrum a quantity of the material (e.g. hydrogen gas) needs to be placed in the beam of (say) sunlight, and the resulting light passed into the spectrometer. The hydrogen gas will absorb the frequencies determined by its electron structure and an absorption spectrum without these frequencies (i.e. black lines produced) will be formed. (Note that an emission spectrum cannot be formed from a continuous spectrum. It is formed by passing the light formed by burning the substance, or emitted from the very hot substance, through a spectrometer.)

8.4.1.5 (a) Continuous: All spectral lines appear in the spectrum; our eyes do not have the resolution to see them as separate lines – the spectrum appears continuous. Continuous spectra are emission spectra which involve emitted radiation from many elements such that all wavelengths are represented.

(b) Emission: Electromagnetic radiation is emitted as excited electrons fall back to lower energy levels causing photon emission to produce the emission spectrum lines – the rest of the spectrum is black. The few lines that do appear represent the energy values of the particular electron transfers for that element.

(c) Absorption: White light (all wavelengths) passes through a gas and photons of the energy representing energy transitions of the atoms of that gas, are absorbed – these energy values in the spectrum appear as black lines because they have been absorbed or removed from the beam of white light.

8.4.1.6 (a) Gustav Kirchhoff in 1859.

(b) The scientific research that followed in order to explain spectra was the beginning of quantum physics.

8.4.1.7 A = continuous spectrum
B = emission spectrum
C = absorption spectrum

8.4.1.8 (a) Short wavelength end is the left hand end (the blue end).

(b) High frequency end is also the blue end.

(c) Blue/violet end.

8.4.1.9 (a) A black body is a theoretical object which absorbs all radiation falling on it, and later re-emits that radiation.

(b) The continuous spectrum from a black body would be like the spectrum of the Sun.

8.5.1.1 Planck's work on the radiations from hot bodies suggested that the wavelength (or frequency) of the peak radiation indicated the temperature of the radiating body. He found that all hot objects, regardless of composition, had the same peak radiation wavelength for the same temperatures. Astronomers applied this idea to the radiation curves from stars and developed the mathematics (e.g. Wien's law) to determine surface temperature and intensity of emitted radiation.

8.5.1.2 (a) X then Y the Z

(b) Z then Y then X

(c) Z then Y then X

(d) (i) X = towards red end of spectrum, perhaps red or orange

(ii) Y = towards middle of spectrum, perhaps yellow

(iii) Z = towards blue end of spectrum, perhaps blue or blue/white

8.5.1.3 (a) Peak radiation wavelength = 500 nm

Therefore from $\lambda_{max} T = b$

$500 \times 10^{-9} \times T = 2.898 \times 10^{-3}$

Therefore $T = 5796$ K

(b) Most probable colour is yellow as this is about the same surface temperature as our Sun.

8.5.1.4 (a) It is an intensity/frequency graph rather than an intensity/wavelength graph.

(b) U – it has the highest peak frequency.

(c) P – it has the lowest peak frequency.

(d) S – it has radiation frequency about 6×10^{14} Hz which is wavelength about 600 nm which is the same as our Sun.

(e) No – she is incorrect. Star T has a higher peak radiation frequency than S and will therefore be hotter than S.

8.5.2.1 (a) The black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature, or

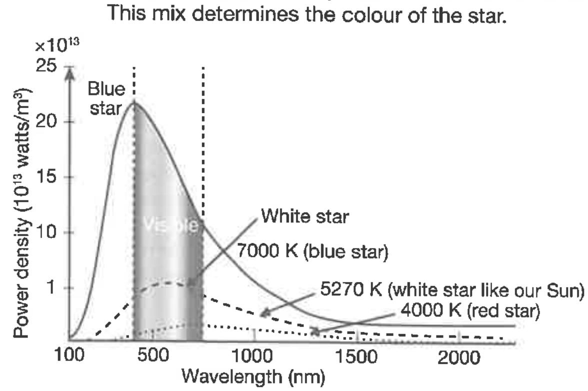
As the temperature of a black body rises, the Planck curve of the emitted radiation shifts to a higher frequency, the peak intensity indicating the surface temperature of the body.

(b) $T = \dfrac{\text{constant}}{\lambda_{peak}}$

(constant = 2.8977729×10^{-3} m K)

(c) The Kelvin or absolute scale.

8.5.2.2 The higher the frequency range of the emitted radiation, the less red and more blue radiation from the visible spectrum is present in the Planck curve. This mix determines the colour of the star.



8.5.2.3 From $T = \dfrac{\text{constant}}{\lambda_{peak}}$

$= \dfrac{2.8977729 \times 10^{-3}}{500 \times 10^{-9}} = 5795.5\text{ K} = 5522.5.5°\text{C}$

8.5.2.4 An analysis of the black body radiation curve from a star will determine its peak radiation frequency. This can be substituted into Wien's equation to determine the surface temperature of the star.

8.5.2.5 From $T = \dfrac{2.8977729 \times 10^{-3}}{\lambda_{peak}}$

$\lambda_{peak} = \dfrac{2.8977729 \times 10^{-3}}{2.7} = 1.07\text{ mm}$

8.5.2.6 From $T = \dfrac{\text{constant}}{\lambda_{peak}}$

$= \dfrac{2.8977729 \times 10^{-3}}{675 \times 10^{-9}} = 4293\text{ K} = \text{about } 4300\text{ K}$

8.5.2.7 (a) X will be hotter than Y. It has peak radiation wavelength shorter than Y, therefore peak frequency higher than Y, therefore temperature higher than Y.

(b) Temperature X $= \dfrac{2.8977729 \times 10^{-3}}{6 \times 10^{-6}} = 483\text{ K}$

Temperature Y $= \dfrac{2.8977729 \times 10^{-3}}{6 \times 10^{-6}} = 414\text{ K}$

8.5.2.8 From $T = \dfrac{2.8977729 \times 10^{-3}}{4.5 \times 10^{-3}} = 0.64\text{ K} = -272.4\text{ C}$

8.5.2.9 From $T = \dfrac{2.8977729 \times 10^{-3}}{\lambda_{peak}}$

$\lambda_{peak} = \dfrac{2.8977729 \times 10^{-3}}{4500} = 643.9\text{ nm}$

8.5.2.10 (a) The line has been drawn so that it connects the peak wavelengths of the radiation curves, the point on the curves that indicates their surface temperatures. Its gradient is negative, indicating that there is an inverse relationship between the peak wavelength and the maximum intensity of the radiation intensity at the peak wavelength. Wien's displacement law states that the black body radiation curve for different temperature peaks at a wavelength inversely proportional to the temperature of the star.

(b) If we assume that the two vertical dashed lines represent the visible spectrum of light, then the Sun would be the star whose peak frequency was closest to the centre of these two lines. That is, star Q.

(c) Star S

(d) Star P

(e) None of the radiations from star U are in the visible spectrum, so it is unable to be seen.

8.6.1.1 An H-R diagram is a plot of the luminosity of stars against their temperature, which also represents their colour ranges and spectral classes.

8.6.1.2 That the stars were arranged in obvious patterns and groups on the diagram.

8.6.1.3 Both colour and spectral class are determined by the temperature of the star.

8.6.1.4 Main sequence stars can have luminosities across the whole range. Red giants tend to have luminosities ranging from 100 times that of the Sun to 1000 times that of the Sun. Their luminosity is greater than their temperature would indicate, but their surface area is huge. White dwarfs have luminosities ranging about equal, to 10 000 times less than that of the Sun. Given their temperatures, these luminosities compare to equal temperature main sequence stars. This is due to their very small size.

8.6.1.5 White dwarfs range (approximately) between 6000 K and 40 000 K, red giants from 2500 K to 6000 K, and supergiants from 2500 K to 25 000 K.

8.6.1.6 For main sequence stars, the more luminous they are, the more massive they are. White dwarfs are the least massive of the stars.

8.6.1.7 (a) Main sequence stars

(b) Blue giants

(c) Red supergiants

(d) Red giants

(e) White dwarfs

(f) Red dwarfs

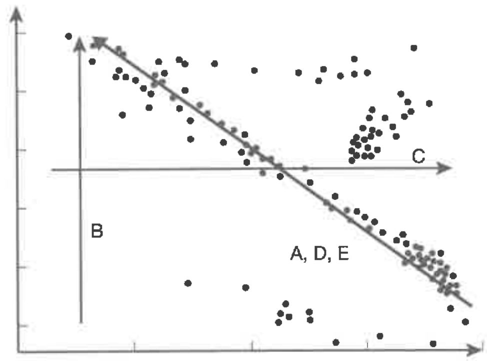
(g) (i) At E (ii) At A

(iii) At H (iv) At C

(v) At A (vi) At E

(h) At G

8.6.1.8



8.6.2.1 A main sequence star.

8.6.2.2 Red giant stars are more luminous than our Sun – they give out much more total energy – but, they are also much cooler than the Sun. Therefore they must be significantly larger.

8.6.2.3

Star type	Energy producing process(es)
Main sequence	Hydrogen fusion
Red giant	Helium fusion
Red supergiant	Helium fusion
Blue supergiant	Helium fusion
Red dwarf	Hydrogen fusion (they are main sequence stars)
White dwarf	No energy source, only radiating energy due to temperature

8.6.2.4 A temperature of around 10^7 K at the core of a star is required to initiate hydrogen fusion. Below this, stars will simply be radiating energy indicative of their surface temperature. They will have no internal fusion energy source.

8.6.2.5 (a) Main sequence stars are all characterised by producing energy by core hydrogen fusion.

(b) Red giants and larger, hotter stars will have a core which provides energy through helium fusion.

(c) All main sequence stars, regardless of size, produce energy by hydrogen fusion.

(d) If the mass of a non main sequence star is greater than 5 solar masses, then carbon fusion and fusion of heavier elements will occur at the core with helium and hydrogen fusion continuing in the outer core layers.

8.6.2.6 The size of a star is determined by the equilibrium that exists between the thermal expansion caused by heat energy generated at its core, known as radiation pressure (expanding its size), and gravitational forces which contract its mass towards the centre. When these two factors balance each other, the size of the star is constant.

8.6.2.7 Hotter main sequence stars are hotter because they are fusing more core hydrogen more rapidly than cooler stars. They will therefore deplete their core hydrogen more quickly and change to helium fusion, which takes them off the main sequence in terms of classification.

8.6.2.8 Because of their small size, not as much helium collects in a central core, because much of it is carried by convection currents towards the surface and space. Because of this they will burn a larger proportion of their hydrogen before the helium concentration in their core increases to the point that hydrogen fusion ceases and helium fusion starts and therefore before leaving the main sequence.

8.6.2.9 When hydrogen fusion stops in a main sequence star, there is less radiative pressure to counteract gravity, so it shrinks inwards, compressing the high concentration helium in its core. This causes the core temperature to rise, and when it reaches around 10^8 K, a sudden, massive fusion of core helium occurs releasing in an instant more energy than that produced normally by the Milky Way Galaxy. This huge release of energy is known as the 'helium flash'. After commencing helium fusion in this way, the star then expands rapidly, cools, and helium fusion continues at a 'normal' rate.

8.6.3.1 The gas cloud must be sufficiently dense and be sufficiently massive so that high gravitational forces are exerted in its core, producing the pressure and temperature required to initiate fusion.

8.6.3.2 A nebula.

8.6.3.3 As the particles in a nebula move closer together under gravitational attraction (referred to also as accretion of particles) their temperature increases and the number of ionised particles therefore increases. The system will acquire its own luminosity and a protostar is formed. Further accretion occurs and the pressure and temperature at the centre of the protostar becomes large enough to strip all atoms of their electrons and a central plasma is formed. When the temperature rises sufficiently, hydrogen fusion commences. A main sequence star is born.

8.6.3.4 Its mass.

8.6.3.5 Protostars with less than 0.08 solar masses do not have enough mass to develop the pressures and temperatures needed to initiate hydrogen fusion. They will simply contract to a brown dwarf. Protostars with masses greater than 100 solar masses develop so much internal temperature and pressure that they blow apart and eject enormous amounts of matter thereby disrupting the formation of a star.

8.6.3.6 Its mass. Stars with masses between 4 and 8 solar masses will form red supergiants. Less than 4 solar masses results in red giants.

8.6.3.7 In a red giant helium is fused. If the mass is less than 0.5 solar masses, then the helium core does not fuse and is surrounded by a shell of hydrogen fusion. If the mass is between 0.5 and 5 solar masses, the red giant will contract until the temperature and pressure rises enough to start fusing helium. Above 5 solar masses it is thought that the star fuses different elements in 'shells' (neon, oxygen, carbon, silicon) with the core forming iron.

8.6.3.8 The star, probably a red supergiant, fuses elements higher than helium in shell burning and explodes as a supernova. The core matter collapses to form a neutron star.

8.6.3.9 Neutron stars have a strong magnetic field and stars rotate rapidly. Charged particles accelerated in the large magnetic field produce directed beams of radiation which sweep across Earth and can be detected.

8.6.3.10 The core density of a star is limited by a quantum effect known as electron degeneracy. Essentially, contraction of a star cannot continue past the point where electrons are packed as closely together as they can be. This sets an upper limit on the mass of a star that can simply degenerate into a white dwarf. This limit is the Chandrasekhar limit.

8.6.3.11 Stars with masses less than 8 solar masses usually end up as white dwarfs, because they eject most of their mass into space as they nova in the final stage of their life as a red giant. The core mass left is usually under the Chandrasekhar limit.

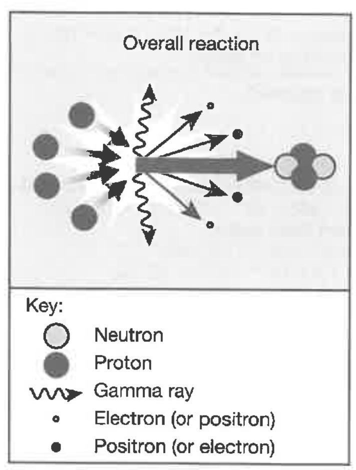
8.6.3.12 (a) (i) Red giant.
(ii) White dwarf.
(b) Hydrogen concentration in its core will have reduced significantly as it has fused to form helium. Core fusion of helium will commence, producing more energy which causes it to expand.
(c) The luminosity will increase as its surface area increases.
(d) F is the region on the H-R diagram where white dwarfs are found and the Chandrasekhar limit suggests that stars with masses less than 1.4 solar masses will become white dwarfs.

8.6.3.13 (a) Star Q will most likely become a white dwarf, while P will become a neutron star or a black hole.
(b) Its position on the H-R diagram would suggest P has a much greater mass than this. However, if in the process of becoming a red supergiant and maybe a supernova, if it loses enough mass it could end as a white dwarf.

8.7.1.1
A ^1_1H
B ^3_2He
C ^1_1H
D ^7_4Be
E ^4_2He
F ^1_1H
G ^8_4Be
H ^8_4Be
I 2^4_2He

8.7.1.2 (a) $^0_{-1}e + ^0_1\bar{e} \to \gamma$
(b) Antielectron

8.7.1.3 (a)



(b) $4^1_1H \to ^4_2He + 2^0_1\bar{e} + 2v_e + 2\gamma$
(c) The energy given out.

8.7.1.4 Main sequence stars are the stars that fuse hydrogen as their main source of energy – that is the reason for their classification. Stars larger in size than the Sun have core temperatures which are too high for the PP reactions and they fuse hydrogen via the CNO cycle.

8.7.1.5 C

8.7.1.6 D

8.7.1.7 A

8.7.1.8

Step 1: $^1_1H + ^1_1H \rightarrow ^2_1H + ^0_1\bar{e} + v$

Step 2: (W) $^2_1H + ^1_1H \rightarrow ^3_2He + \gamma$

Step 3: (X) $^3_2He + ^4_2He \rightarrow ^7_4Be + \gamma$

Step 4: (Y) $^7_4Be + ^0_{-1}e \rightarrow ^7_3Li + v$

Step 5: (Z) $^7_3Li + ^1_1H \rightarrow ^4_2He + ^4_2He$

Particle	Mass (u)
^1_1H	1.007825
^2_1H	2.014102
^3_2H	3.016029
^4_2H	4.002603
^7_4Be	7.016929
^7_3Li	7.016003
$^0_{-1}e$	0.0005486
$^0_{+1}e$	0.0005486

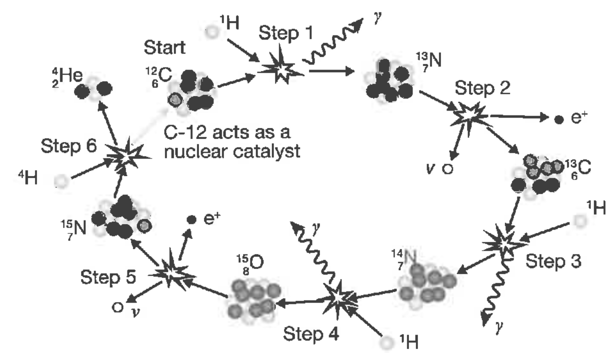
8.7.1.9

(a) Reaction 1: 0.0009994 u
Reaction 2: 0.005898 u
Reaction 3: 0.001703 u
Reaction 4: 0.0014746 u
Reaction 5: 0.018622 u

(b) Total mass defect for the 5 reactions is 0.0257478 u

(c) Total mass defect is equivalent to 23.98 MeV (= mass defect × 931.494)

8.7.2.1 (a), and (b) and (c)



8.7.2.2

Step 1: Nuclear equation	Step 2: Nuclear equation
$^{12}_6C + ^1_1H \rightarrow ^{13}_7N + \gamma$ **Mass defect** = 13.005738 – (12.000000 + 1.007825) = 0.002087 u = 0.002087 × 1.660 × 10^{-27} = 3.4644 × 10^{-30} kg **Energy released (MeV and J)** = 0.002087 × 931.494 = 1.944 MeV = 1.944 × 10^6 × 1.6 × 10^{-19} = 3.11 × 10^{-13} J **Check** $E = mc^2$ = 3.4644 × 10^{-30} × 9 × 10^{16} = 3.11 × 10^{-13} J (Difference = rounding off errors)	$^{13}_7N + ^{13}_6C \rightarrow ^0_1\bar{e} + \nu_e$ **Mass defect** = (13.003355 + 0.0005486) – 13.005738 = 0.001834 u = 0.001834 × 1.660 × 10^{-27} = 3.0451 × 10^{-30} kg Energy released (MeV and J) = 0.001834 × 931.494 = 1.71 MeV = 1.71 × 10^6 × 1.6 × 10^{-19} = 2.73 × 10^{-13} J **Check** $E = mc^2$ = 3.0451 × 10^{-30} × 9 × 10^{16} = 2.74 × 10^{-13} J (Difference = rounding off errors)
Step 3: Nuclear equation $^{13}_6C + ^1_1H \rightarrow ^{14}_7N + \gamma$ **Mass defect** = 14.003074 – (13.003355 + 1.007825) = 0.008106 u = 0.008106 × 1.660 × 10^{-27} = 1.35456 × 10^{-29} kg **Energy released (MeV and J)** = 0.008106 × 931.494 = 7.55 MeV = 7.55 × 106 × 1.6 × 10^{-19} = 1.21 × 10^{-12} J **Check** $E = mc^2$ = 1.35456 × 10^{-29} × 9 × 10^{16} = 1.22 × 10^{-12} J (Difference = rounding off errors)	**Step 4: Nuclear equation** $^{14}_7N + ^1_1H \rightarrow ^{15}_8O + \gamma$ **Mass defect** = 15.003056 – (14.003074 + 1.007825) = 0.007843 u = 0.007843 × 1.660 × 10^{-27} = 1.30194 × 10^{-29} kg **Energy released (MeV and J)** = 0.007843 × 931.494 = 7.31 MeV = 7.306 × 10^6 × 1.6 × 10^{-19} = 1.17 × 10^{-12} J **Check** $E = mc^2$ = 1.30194 × 10^{-29} × 9 × 10^{16} = 1.17 × 10^{-12} J (Difference = rounding off errors)
Step 5: Nuclear equation $^{15}_8O + ^{15}_7N \rightarrow ^0_1\bar{e} + \nu_e$ **Mass defect** = (15.000109 + 0.0005486) – 15.003056 = 0.0023984 u = 0.0023984 × 1.660 × 10^{-27} = 3.98134 × 10^{-30} kg **Energy released (MeV and J)** = 0.0023984 × 931.494 = 2.23 MeV = 2.23 × 10^6 × 1.6 × 10^{-19} = 3.57 × 10^{-13} J **Check** $E = mc^2$ = 3.98134 × 10^{-30} × 9 × 10^{16} = 3.58 × 10^{-13} J (Difference = rounding off errors)	**Step 6: Nuclear equation** $^{15}_7N + ^1_1H \rightarrow ^{12}_6C + ^4_2He$ **Mass defect** = 12.000000 + 4.002603 – (15.000109 + 1.007825) = 0.005311 u = 0.005311 × 1.660 × 10^{-27} = 8.84946 × 10^{-30} kg **Energy released (MeV and J)** = 0.005311 × 931.494 = 4.95 MeV = 5.88 × 10^8 × 1.6 × 10^{-19} = 9.41 × 10^{-13} J **Check** $E = mc^2$ = 8.84946 × 10^{-30} × 9 × 10^{16} = 7.96 × 10^{-13} J (Difference = rounding off errors)

8.8.1.1 (a) D
(b) It enabled them to observe the cathode rays for a much longer period of time.

8.8.1.2 (a) B
(b) Cathode rays, beta particles.

8.8.1.3 (a) A
(b) Waves cannot be charged, so if cathode rays are charged, then they must be exhibiting particle nature.

8.8.1.4 (a) B
(b) Cathode rays were deflected by magnetic fields and this indicated they must be charged, and therefore must be particles as waves cannot be charged. However, their apparent non-deflection by electric fields indicated to these scientists that cathode rays were not charged, and therefore could be waves.

8.8.1.5 (a) D
(b) It showed that they were charged and therefore could not be waves – they must be particles.

8.8.1.6 (a) D
(b) He succeeded in deflecting them by an electric field (better equipment than previous scientists) and so proved that they were charged and therefore had to be particles as electromagnetic waves cannot carry a charge.

8.8.1.7 (a) C
(b) Thomson in his experiment to determine the ratio of charge to mass of cathode rays. He was able to produce a much stronger electric field and a better vacuum and showed that they were deflected by electric fields.

8.8.1.8 A

8.8.1.9 C (Energy can be transferred by cathode rays.)

8.8.1.10 (a) A
(b) If they were charged particles then they should have been deflected by both magnetic and electric fields. Apparent non-deflection by electric fields left open the idea that perhaps they were waves and that the experiment with magnetic fields was wrong.

8.8.1.11 B

8.8.1.12 (a) D
(b) They are blocked or absorbed by solid objects.

8.8.1.13 (a) D
(b) They are negatively charged.

8.8.1.14 B

8.8.1.15 D

8.8.1.16 C

8.8.1.17 C

8.8.1.18 (a) A
(b) They are not electromagnetic, they do not produce high voltage electric fields, they do have mass and therefore they are affected by gravitational fields, they can be refracted but these tubes do not show this, they are electrons, but these tubes do not show this.

8.8.1.19 (a) B
(b) B and C – modern tubes have stronger electric fields and better vacuums and so deflection by electric fields can be detected.

8.8.2.1 A cathode ray tube consists of an evacuated glass tube with an electrode at each end (usually). The cathode is often photoemitting.

8.8.2.2 (a) The vacuum tube.
(b) It allowed the cathode rays to travel further and therefore be observed for a longer period of time.

8.8.2.3 According to the scientists of the 1800s, the Maltese cross tube, the deflection by magnetic fields and the paddle wheel tube all indicated cathode rays were particles.

8.8.2.4 The tube with the electric plates (which did not cause a deflection in cathode ray beams) confused scientists of the 1800s, and caused them to suspect cathode rays could be waves.

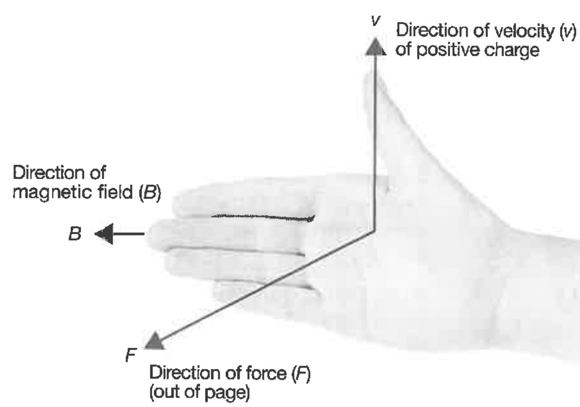
8.8.2.5 If magnetic fields deflected them, this indicated they were charged and therefore particles (waves cannot be charged). However, when their (not strong enough) electric fields did not deflect (deflection was too small to be seen), this started them thinking that maybe the rays were uncharged and perhaps waves.

8.8.2.6

Discharge tube	Observations	Conclusions drawn from each observation
Maltese cross	1. Cast a sharp shadow of the cross on the end of the tube. 2. Rays were blocked by the cross.	Rays travelled in straight lines. Rays were absorbed by the metal in the cross.
Fluorescent display	1. Fluorescent line was straight. 2. Line glowed on the screen. 3. Beam was deflected by a magnetic field.	Rays travelled in straight line. They caused fluorescence. They were charged, and therefore must be particles.
Paddle wheel	1. Caused the paddle wheel to move.	Have momentum, therefore must have mass, therefore must be particles.
Electric plates	1. Ray not deflected. 2. Rays travel in straight line.	Rays not charged, perhaps waves. Travel in straight lines.

8.8.2.7 (a) The bottom plate is positive.
(b) Magnetic field would need to be vertically out of the page.
(c) The cathode is electrode A.

8.9.1.1 By using the right hand rule – your diagram should label the extended fingers as the direction of magnetic field, your thumb as the direction of motion of positive charge and the direction in which the palm of your hand points as the direction of the force on the charged particles.



8.9.1.2 Uniform circular motion.

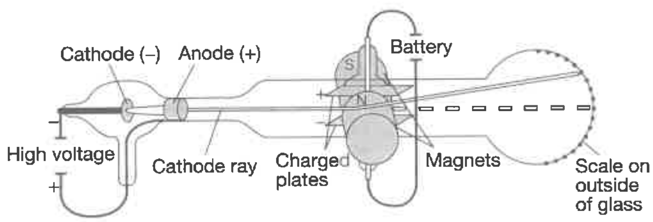
8.9.1.3 Because a charged particle moving in a magnetic field undergoes uniform circular motion, the force acting on it must also be a centripetal force – hence the magnetic force equation can be equated to the equation for centripetal force.

8.9.1.4 Thomson found the ratio to be about 1800 times greater than that of a hydrogen ion. From this, because neither charge nor mass could be found, he could conclude that:

- The charge on cathode rays was 1800 times larger than the charge on a hydrogen ion; or
- The mass of cathode ray particles was 1800 times less than that of a hydrogen ion.

From these results, Thomson assumed that the charge on them was similar in size to that on a hydrogen ion and calculated their mass to be 9.11×10^{-31} kg. He also assumed they were the particles predicted by George Stoney in 1894 to be part of an atom and responsible for electricity.

8.9.1.5 Thomson used the apparatus shown, deflecting the cathode rays either up or down by the parallel plates D and E, then cancelling this deflection using the magnetic field produced by the coils.



The electric force on the particles could be represented by:

$F_E = qE = \frac{qV}{d}$

And the magnetic field by:

$F_B = bqv = \frac{mv^2}{r}$

The velocity of the charges could be found knowing that, when they passed through the electric and magnetic fields undeflected, so:

$F_E = qE = F_B = Bqv$ and $v = \frac{E}{B}$

Also, the work done by the electric field in deflecting the cathode rays is given by:

$W = qV = = \frac{1}{2}mv^2 = \frac{\frac{1}{2}mE^2}{B^2}$

Rearranging these we get:

$\frac{q}{m} = \frac{E^2}{2VB^2}$

Since E, B and V are all measurable quantities, Thomson was able to calculate the ratio of the charge to mass of cathode rays.

8.9.1.6 (a) 8×10^4 V m^{-1}
(b) 4.0 T
(c) 1.31×10^{-15} kg

8.9.1.7 (a) B
(b) He calculated the speed of the cathode rays by equating the two forces acting on them. $F = qE = Bqv \sin\theta$, and hence $v = \frac{E}{B}$.

8.9.1.8 A (*Note:* Both q and m are constants so any choice with either of these in it (all the incorrect ones) must be wrong. In the experiment, Thomson had various strength magnetic fields which caused a deflection of the cathode rays (that is, the radius of curvature depended on the magnetic field strength). He then adjusted the electric field to cancel the deflection caused by the magnetic field (i.e. the strength of the electric field depended on the magnetic field strength)).

8.9.1.9 C

8.9.1.10 D

8.9.1.11 B

8.9.1.12 C (The forces on the electron due to the magnetic field and the electric field must be equal in magnitude and opposite in direction for the electron to pass straight through. Therefore from $Bqv = \frac{qV}{d}$, V calculates at 200 V and must be directed down the page (electron moves against an electric field) since the magnetic field will deflect the electron downwards (RHPR).)

8.9.1.13 A

8.9.1.14 B

8.9.1.15 A

8.9.1.16 B From $Bqv = qE$, $B = \frac{E}{v} = \frac{400}{100} = 1.33$
From $Bqv = \frac{mv^2}{r}$ (having measured r), $\frac{q}{m} = \frac{E}{rB^2}$

8.10.1.1 (a) The purpose of the oil drop experiment was to determine the charge on an electron.

(b) A closed chamber with transparent sides was fitted with two parallel metal plates to provide an upward force on the charged oil drops due to the electric field between them. An atomiser sprayed a fine mist of oil droplets into the top portion of the chamber which were charged by hitting them with ionising radiation. Gravity pulls the drops downwards and some passed through a small hole in the top metal plate. The electric field was varied until the upward and gravitational forces were in balance. The charge on the drop was calculated.

(c) The electric force on each oil drop is given by $F = \frac{qV}{d}$.
The gravitational force on each drop is $F = mg$.
If the voltage is adjusted so that the downward motion of the drops due to gravity is balanced by an upward electric field force, then we have:
$F_E = F_G = mg = \frac{qV}{d}$
Therefore $q = \frac{mgd}{V}$

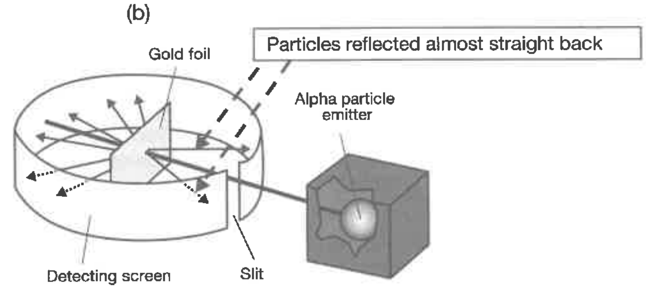
8.10.1.2 He documented all his results and proposed that the lowest common denominator of them indicated the minimum possible charge, and therefore the charge on the electron.

8.11.1.1 The scattering of alpha particles by a thin gold foil.

8.11.1.2 The alpha particles were produced by the decay of a sample of radioactive radium and were directed through a vacuum and on to a thin gold foil which caused the scattering. The positions of the scattered particles were seen as small flashes of light, which were detected using a microscope that could be rotated around the foil. The alpha particle scattering was usually only one or two degrees.

8.11.1.3 (a) Geiger and Marsden obtained scattering at very large angles and it appeared that some alpha particles bounced straight back from the sheet of gold foil.

(b)



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8.11.1.4 Rutherford proposed that atoms were mainly empty space and had a dense, central 'nucleus' which contained most of the mass.

8.12.1.1 Rutherford's model had a small nucleus which contained most of the mass of the atom and carried a positive charge, with negatively charged electrons orbiting around it. (*Note*: Some resources do not credit Rutherford as giving the nucleus a positive charge.)

8.12.1.2 Rutherford fired alpha particles at a very thin gold sheet and observed the different amounts of scattering that occurred as the particles were reflected from or passed through the foil. His analysis of the scattering pattern led to the formulation of the model.

8.12.1.3 B

8.12.1.4 (a) A

(b) Models must be able to explain all observations. The fact that Rutherford's model did not explain spectral lines (among other things) meant that it was not a correct model.

8.12.1.5 (a) A

(b) Chemical symbol $^{4}_{2}He$, common symbol α.

8.12.1.6 (a) C

(b) The target sheet needed to be thin to allow the possibility of alpha particles passing through it and the nuclei needed to be large so that they would withstand the collisions of alpha particles.

8.12.1.7 V = electron orbit for gold atom

W = alpha particle path deflected through foil

X = gold atom nucleus

Y = undeflected alpha particle

Z = alpha particle reflected backwards

8.12.1.8 C

8.12.1.9 A

8.12.1.10 B

8.13.1.1 Limitation 1: Rutherford proposed that the electrons revolve around the nucleus in fixed paths called orbits. According to Maxwell and the theory of electromagnetism, accelerated charged particles emit electromagnetic radiations and hence an electron revolving around the nucleus should emit electromagnetic radiation. This radiation would carry energy from the motion of the electron which would come at the cost of shrinking of orbits. Ultimately the electrons would collapse in the nucleus.

Limitation 2: Rutherford's model described the electrons in an atom as orbiting the nucleus, but it did not describe these orbits in any way, nor indicate how many electrons might occupy each orbit.

Limitation 3: One of the main stimuli driving scientists to study atomic structure was their desire to explain spectral lines. Rutherford's model went no further towards a solution to this problem. It offered no explanation for spectral lines.

8.13.1.2 With the limited and developing knowledge of the structure of the atom, it is acceptable that Rutherford's findings did not allow a more sophisticated model. It was only after Planck's quantum theory and Einstein's application of this to explain the threshold frequency in the photoelectric effect, that Bohr was able to build on Rutherford's model. However, while explaining spectra and the partial distribution of electrons around an atom, Bohr's model still could not account for stable orbits.

8.14.1.1 Rutherford's experiments in 1919 where he bombarded nitrogen with alpha particles were the first observed artificially induced nuclear transformation. His analysis of this work led him to the prediction that a neutral particle, with a mass equal to that of a proton, must be part of the nucleus. He named this particle the neutron.

8.14.1.2 (a) Rutherford suggested that the difference in the mass and atomic number could be explained by the existence of this neutron consisting of a proton and an electron joined together – a neutral proton-electron double.

(b) Quantum theory suggested that the energy involved in maintaining the electron in the nucleus, combined with a proton or not, was so large that it would make all nuclei unstable and unable to exist. In addition, observed atomic spectra were inconsistent with the proton-electron proposal. It was thought that the presence of 'nuclear electrons' would produce hyperfine splitting in the spectral lines of elements but no lines like this were observed.

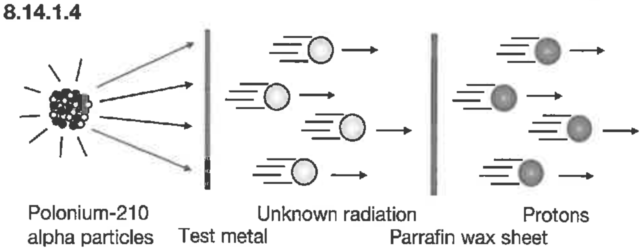
8.14.1.3 (a) Bothe and Becker in 1931.

(b) Bothe and Becker found that if the very energetic alpha particles emitted from a small amount of radioactive polonium fell onto a light element, like beryllium, a highly energetic and penetrating radiation was produced.

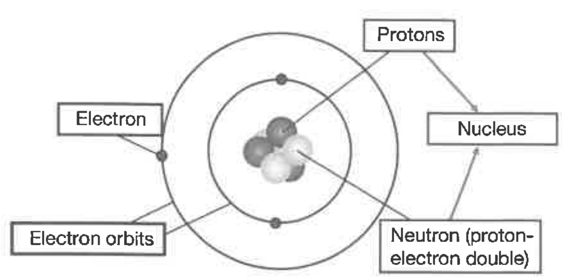
(c) Irène Joliot-Curie and Frédéric Joliot in Paris repeated this experiment and observed that if the Bothe and Becker radiation fell on paraffin, or any other hydrogen-containing compound, it ejected protons of very high energy.

(d) Using the laws of conservation of momentum and energy, he found that the new radiation had to be uncharged particles with about the same mass as the proton – he proposed that they were neutrons.

8.14.1.4



8.14.1.5



8.15.1.1 Planck's work on black body radiation and his explanation of his observations by proposing the idea of quanta of energy, and Einstein's application of this to the photoelectric effect were directly responsible for Bohr's interest in the idea of quanta.

8.15.1.2 (a) Balmer.

(b) Balmer developed a mathematical equation to describe the hydrogen spectrum. On seeing this equation, Bohr's developing ideas of quanta and how to apply the idea to atomic structure 'became clear'.

8.15.1.3 Bohr's model of the atom was a solar system model with electrons orbiting the nucleus in stable orbits around a central positively charged nucleus. The number of electrons able to fit into each successive orbital could not exceed $2n^2$ where n was the number of the orbital from the nucleus.

8.15.1.4 (a) Postulate 1: Electrons in an atom exist in stable, circular orbits.

Postulate 2: Electrons in stable orbits do not emit electromagnetic radiation.

Postulate 3: Electrons absorb or emit specific quanta of energy when they move from one stable energy level to another.

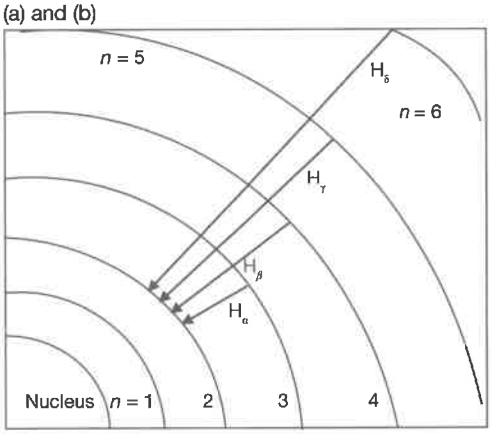
(b) Postulates are stated conditions in a theory or model that must be true if the theory or model is to work or to explain what it is developed to explain. In a way, postulates assume conditions that the theory either cannot explain or show to be fact.

(c) Postulates in Bohr's model were needed to cover the things that classical physics would indicate was a flaw in the model. For example, if electrons are in circular orbits, then, according to classical physics, they are accelerating and should therefore be emitting radiation all the time, losing energy and spiralling into the nucleus – i.e. an atom would not be stable on this model if classical physics held true.

8.15.1.5 An electron has an angular momentum that is an integral multiple of (h = Planck's constant).

8.15.1.6 One of the considered limitations of the Bohr model was that it was a mixture of classical and quantum physics and many scientists did not like this. However, being the first model to apply quantum physics to atomic structure, its development was very significant.

8.15.1.7 (a) and (b)



8.15.1.8 (a) C

(b) The strength of every new scientific theory lies in two areas – its ability to explain observed phenomena but particularly its ability to predict further discoveries. Bohr's model led to the development of the Rydberg equation which was used to predict other spectral series for hydrogen. Their discovery gave great credibility to Bohr's model.

8.16.1.1 The hydrogen spectrum was the first spectrum to be analysed mathematically, leading to the Balmer equation, and this in turn, stimulated further research into the relationship between spectra and atomic structure.

8.16.1.2 The lines in the spectrum of an element become closer together as they approach the ultraviolet end of the spectrum, ending at the last line which is called the convergence limit. The energy of the convergence limit line gives us the ionisation energy of the element. For hydrogen the convergence limit is wavelength 364.6 nm.

8.16.1.3 (a)

Line	Actual λ (nm)	Balmer λ (nm)
$n = 3$	656.3	656.2
$n = 4$	486.1	486.1
$n = 5$	434.0	434.0
$n = 6$	410.2	410.1
$n = 7$	397.0	396.8

(b) See table.

(c) From the results in the table it would appear that the Balmer equation is valid for these predictions.

8.16.1.4 (a) The 434.01 nm line is in the blue part of the visible spectrum (you may have had to research this).

(b) Highest frequency = shortest wavelength, so the line to the far left of the spectrum as drawn would have the highest frequency.

(c) The line with the highest frequency = line to the far left.

8.16.1.5 (a) A series in a spectrum is a series of emission lines for an excited electron falling from higher levels back to a specific level.

(b) It is in the visible light region of the spectrum.

(c) The Lyman – largest energy falls so highest frequencies, so shortest wavelengths.

8.16.2.1 (a) V, X and X and perhaps Z. All the spectral lines for these three elements appear in the mixture.

(b) While all the other lines for Z are present in the mixture, the double lines at the right hand end of the spectrum of Z are not in the mixture. Explanation – measurement error.

(c) The spectral lines from each are different, so they involve different energy transfers, so they must be from different energy levels within different atoms.

(d) Because supposedly no two sets of fingerprints are the same, and in the same way, no spectrum of any element or compound is the same as any other element or compound.

8.16.2.2 (a) Yes. All the spectral lines for hydrogen are in the spectrum from the star.

(b) There are additional spectral lines that are not part of the hydrogen spectrum.

8.16.2.3 (a) 1.8 eV

(b) 3.7 eV

(c) 3.9 eV emitted

(d) From $E = hf$, $E = 7.8 \times 10^{-19}$ J = 5.0 eV. This is not a quantised amount within the energy structure of mercury, so the electron will not move. (It will not absorb the energy from the photon.)

8.16.2.4 (a) The emission and absorption spectrum lines for any substance lie at exactly the same wavelengths/frequencies because they represent energy emitted by an excited electron falling to a lower quantum state or the same electron absorbing that energy to rise from the same lower quantum state to the same higher quantum state.

(b) (i) 589.9 nm = 3.3697×10^{-19} J = 2.1061 eV

(ii) 589.6 nm = 3.3714×10^{-19} J = 2.1071 eV

8.16.2.5 (a) Ground state is quantum state $n = 1$. This indicates that 10.38 eV would need to be added to ionise the atom.

(b) It has been the choice of the person drawing it to show energy values emitted as the electron falls from higher energy levels to lower energy levels.

(c) Emit – always emits energy when falling from higher to lower quantum states.

(d) Energy emitted = (–5.52) – (–1.57) = 3.95 eV = 6.32×10^{-19} J = 9.54×10^{14} Hz

(e) 10.38 eV

(f) From $E = \frac{hc}{\lambda}$, $\lambda = \frac{hc}{E}$ = 119.7 nm

8.16.2.6 (a) (i) $n = 3$ to $n = 2$ = 17 eV emitted

(ii) Then $n = 2$ to $n = 1$ = 91.8 eV emitted

(iii) Or $n = 3$ straight to $n = 1$ = 108.8 eV emitted

(b) (i) $n = 3$ to $n = 2$ = 17 eV emitted = 4.11×10^{15} Hz = 73.1 nm

(ii) Then $n = 2$ to $n = 1$ = 91.8 eV emitted = 2.22×10^{16} Hz = 13.5 nm

(iii) Or $n = 3$ straight to $n = 1$ = 108.8 eV emitted = 2.63×10^{16} Hz = 11.4 nm

(c) From $E = hf = \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{143 \times 10^{-9}}$

= 1.39×10^{-18} J = 8.69 eV emitted

So initial level is 8.7 eV higher than $n = 2$ = –13.6 + 8.7 = 4.9 eV

So the electron fell from level $n = 5$

(d) 5.54×10^{15} Hz = 3.67×10^{-18} J = 22.94 eV absorbed

This represents a transition from $n = 2$ to $n = 4$ (–30.6 + 7.65 = 22.95 eV) (Difference due to rounding off errors in data)

(e) 6.21×10^{15} Hz = 4.11×10^{-18} J = 25.7 eV emitted

This represents a transition from $n = 5$ to $n = 2$ (–30.6 + 4.9 = 25.7)

So, an excited electron has fallen from $n = 5$ to $n = 2$

8.17.1.1 (a) It only predicts the spectral line values for hydrogen accurately, and not for atoms with more than one electron.

(b) It does not explain why lines in the hydrogen spectrum are not all the same intensity nor the same thickness and sharpness.

(c) It does not explain why the spectral lines can be split into 3 fine lines by a strong magnetic field (Zeeman effect).

(d) It does not explain why spectral lines can be split into many (up to 15 hyperfine lines (anomalous Zeeman effect).

(e) It is a mixture of classical and quantum physics.

8.17.1.2 Possible reasons include interactions between electrons, the shielding effect of inner electrons, the orbits being non-circular, stronger attraction of electrons to nuclei which are more positive than the hydrogen nucleus.

8.17.1.3 (a) Some lines in the hydrogen spectrum are of higher intensity (brightness) than others.

(b) It was thought that these could be due to orbits being slightly elliptical rather than circular, so some electron jumps are more probable within an energy level than others.

8.17.1.4 (a) The Zeeman effect is the splitting of spectral lines into multiple lines (usually three) by strong magnetic fields.

(b) If a very strong magnetic field is applied, the spectral lines are split further, sometimes up to 15 lines.

8.17.1.5 (a) B

(b) It s the only one with one electron.

8.17.1.6 A

8.17.1.7 (a) D

(b) Quanta represent specific amounts of energy and the energy differences between electron orbits also represent specific energy differences. In fact, the two ideas are identical – Planck's quanta are the electron energy level differences.

8.17.1.8 C

8.17.1.9 C

8.17.1.10 B

8.17.1.11 (a) D

(b) The 'quantised' part of this expression refers to the specific amounts of energy (quanta) involved in the movement of electrons between energy levels. The 'condition' refers to the fact that the idea of quanta must apply if the model is to explain observed phenomena like the spectra of elements.

8.17.1.12 (a) A

(b) The Bohr model used the idea of quanta of energy but applied it to electrons which he still regarded in classical physics ideas as particles.

8.17.1.13 (a) A

(b) It was the first to have a central nucleus and the electrons in orbit around it.

8.17.1.14 (a) D

(b) Not necessarily, but if it is correct, then there are adjustments to be made so that it applies to all atoms. A model which predicts for only one atom must be at least incomplete.

8.17.1.15 (a) A

(b) A continuous spectrum implies electrons with all possible energy values, whereas Bohr's model allows electrons only specific (quantised) energy values, with all other values not allowed. The Bohr model can only result in line spectra.

8.17.1.16 A

8.18.1.1 (a) De Broglie proposed that if waves could be considered as having particle properties, then moving particles could be considered as having wave properties, such as a wavelength given by $\lambda = \frac{h}{mv}$.

(b) De Broglie used the idea of electrons as waves to propose that the allowed electron orbits were those that fitted standing waves into them.

(c) De Broglie's idea was purely theoretical – almost 'tongue in cheek' – it had no observations to suggest it and no experiments to support it at the time it was proposed.

(d) De Broglie was a little known scientist at the time of his matter waves proposal which was considered 'bizarre' by many scientists of the time. It was not well accepted.

(e) His equation $mvr = \frac{nh}{2\pi}$ included mass (a classical concept) and Planck's constant (a quantum concept).

8.18.1.2 Now that electrons could be thought of as having a wavelength, then Bohr's stable orbit could be accounted for if each orbit was an integral number of electron wavelengths in circumference. If so, each electron wave would superimpose on itself and interfere constructively making the orbital stable.

8.18.1.3 C

8.18.1.4 (a) A

(b) De Broglie's explanation of stable electron orbits was that their circumference was composed of an integral number of wavelengths of the electron wave and thus self-supporting standing waves were set up.

8.18.2.1 (a) From Planck's equation and the general wave equation $v = f\lambda$, $E = hf = \frac{hc}{\lambda} = mc^2$

Therefore $\frac{h}{\lambda} = mc$

This is the relationship for electromagnetic radiation, but de Broglie proposed it also applied to quantum (or any other) particle moving at velocity v.

Therefore, for a particle of matter, $\frac{h}{\lambda} = mv$ = momentum = p

Therefore $\frac{h}{\lambda} = mv = p$

(b) For a stable orbit, the circumference of the electron orbit has to be an integral number of electron wavelengths.

So $n\lambda = 2\pi r$

But $\lambda = \frac{h}{p} = \frac{h}{mv}$

Therefore $2\pi r = \frac{nh}{mv}$

Or, rearranging, $mvr = \frac{nh}{2\pi}$

8.18.2.2 4.0×10^{-10} m

8.18.2.3 (a) B

(b) The de Broglie idea is really a quantum idea and quantum physics really only applies to particles which have very, very, very small masses. Quantum physics is really not compatible with 'real' sized objects.

8.18.2.4 From $\lambda = \frac{h}{mv} = 1.33 \times 10^{-36}$ m

8.18.2.5 From $\lambda = \frac{h}{mv} = 9.7 \times 10^{-10}$ m

8.18.2.6 From $\lambda = \frac{h}{mv} = 2.20 \times 10^{-15}$ m

8.18.2.7 From $\lambda = \frac{h}{mv} = 1.58 \times 10^{-8}$ m

8.18.2.8 From $\lambda = \frac{h}{mv}$, $v = h/m\lambda = 0.035$ m s^{-1}

8.18.2.9 From $\lambda = \frac{h}{mv} = 1.49 \times 10^{-36}$ m

8.18.2.10 From $\lambda = \frac{h}{mv} = 2.76 \times 10^{-35}$ m

8.18.2.11 From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 1.347 \times 10^{6}$ m s^{-1}

8.18.2.12 From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 9419$ m s^{-1}

8.18.2.13 From $\lambda = \frac{h}{mv} = 1.32 \times 10^{-13}$ m

8.18.2.14 From $\lambda = \frac{h}{mv} = 3.68 \times 10^{-34}$ m

8.18.2.15 From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 0.125$ m s^{-1}

8.18.2.16 Their wavelengths will be in ratio $\lambda_e : \lambda_p = 1836 : 1$ (the inverse ratio of their masses).

8.18.2.17 $\lambda_X : \lambda_Y = 1 : 2$ (inverse ratio of their speeds)

8.18.2.18 (a) C

(b) Wavelength of the proton would be larger since λ is proportional to m^{-1}.

8.18.2.19 (a) C

(b) Since wavelength is inversely proportional to mass, the electron, with the smaller mass will have the larger wavelength.

8.18.2.20 (a) A

(b) $X : Y = \frac{h}{4 \times 1} : \frac{h}{4 \times 2} = \frac{h}{4} : \frac{h}{2} = 1 : 2$

8.18.2.21 A

8.18.2.22 (a) From $\lambda = \frac{h}{mv} = 1.9779 \times 10^{-15}$ m

(b) From $\lambda = \frac{h}{mv} = 1.9803 \times 10^{-15}$ m. This is larger due to the smaller mass of the proton.

8.18.2.23 For X, wavelength = 6.601×10^{-14} m

For Y, wavelength = 3.300×10^{-14} m

So, ratio is 2 : 1 since speed of Y is twice that of X

8.18.2.24 From $\lambda = \frac{h}{mv}$, for X, $\lambda = \frac{h}{4}mv$

For Y, $\lambda = \frac{h}{m2v}$

So, ratio X : Y = 1 : 2

8.18.2.25 (a) De Broglie wavelength is inversely proportional to mass

Therefore $\lambda_{proton} : \lambda_{neutron} = m_{neutron} : m_{proton}$

$= 1.67 \times 10^{-27} : 1.66 \times 10^{-27} = 167 : 166$

(b) De Broglie wavelength is inversely proportional to momentum

Therefore $p_{neutron} : p_{rroton} = \lambda_{proton} : \lambda_{neutron} = 1 : 1$

8.19.1.1 Schrödinger developed a quantum model of the atom based on the existence of electron clouds, using mathematics based on wave mechanics. Like Heisenberg, he rejected specific orbits for electrons as particles and proposed mathematical probabilities for the position of his electron clouds.

8.19.1.2 Heisenberg's model was also a quantum model but based on matrix mathematics. He also dismissed the idea of electrons as particles preferring to model them as electron matter waves.

8.19.1.3 Schrödinger's model was more readily accepted because scientists did not understand the mathematics used by Heisenberg.

8.19.1.4 Their decision was invalid. Not understanding is no scientific rationale for rejecting a proposal.

8.19.1.5 Heisenberg had two separate contributions to atomic structure. Firstly he developed mathematical equations which explained and predicted the electron energy levels in the Bohr atom. Secondly, he later proposed in his uncertainty principle that if we know the accurate position of an electron, then we cannot know its momentum (and vice versa).

8.19.1.6 Measurements of certain systems cannot be made without affecting the systems in some way. In quantum physics, the observer effect would say that looking at a quantum particle will change the nature of the quantum particle. We therefore have to be careful in drawing conclusions from observations made especially of subatomic particles. The uncertainty principle actually states a fundamental property of quantum systems, and is not a statement about the process of making actual measurements of properties of position and momentum. According to the uncertainty principle, the changes in the system may occur whether or not any observation is being made – it is a property of the system rather than the observation.

8.19.1.7 (a) D

(b) Any new scientific idea that can be developed from different points of view is immediately stronger than if put forward without such corroborating evidence. Even though the evidence was mathematical, the fact that the equations could be derived from two different approaches gives support to the basic ideas in those equations.

8.20.1.1 (a) Gravitational force, electrostatic force, strong nuclear force, weak nuclear force.

(b) The strong nuclear force, the gravitational force.

(c) Gravitational force – force of attraction between all nucleons.

Electrostatic force – force of repulsion between protons.

Strong nuclear force – force of attraction between all nucleons.

Weak nuclear force – holding proton and electron together in neutron.

8.20.1.2 (a) There are two forces we know about, gravitational and electrostatic, given by the following formulas.

$$F_G = \frac{Gm_1m_2}{r^2} \quad \text{and} \quad F_E = \frac{Kq_1q_2}{r^2}$$

Where $G = 6.673 \times 10^{-11}$
$K = 9 \times 10^9$
m = mass of proton = 1.673×10^{-27} kg
q = charge on proton = 1.6×10^{-19} C
r = distance between protons in a nucleus = 1.0×10^{-15} m

(b) 1.87×10^{-34} N

(c) 230.4 N

(d) 1.23×10^{36} times greater

(e) Repulsive force would be greater the higher the number of protons. If 15 protons, then each proton would repel each other proton with a force of 230.4 N. The total repulsive force would be $230.4 \times 15^2 = 51\ 840$ N.

(f) There must be a force to overcome the electrostatic force of repulsion between protons if nuclei are to be stable.

8.20.1.3 (a) The larger the nucleus, the more protons the strong nuclear force has to hold together, so the more it has to 'divide itself' to do that job. There will be a limit to its ability to hold increasing numbers of protons together.

(b) No. There is only one proton in the nucleus of a hydrogen atom, so none of the three forces come into play in a hydrogen atom nucleus.

8.20.1.4 Repulsive force would be much greater in the nucleus with 30 protons (factorial 30 compared to factorial 20). It would be logical to conclude that the nucleus would be less stable than the nucleus with 20 protons.

8.20.1.5 The larger the nucleus, the more protons the strong nuclear force has to hold together, so the more it has to 'divide itself' to do that job. There will be a limit to its ability to hold increasing numbers of protons together, and this obviously occurs at atomic number 90.

8.20.1.6 The diagram shows how the forces between nucleons in a nucleus varies with their distance apart, and compares this with the strength of the Coulomb repulsive force between like charges particles.

8.20.1.7 (a) Attractive.

(b) Difficult to extrapolate from the graph, but assume it is asymptotic, so attractive.

(c) Repulsive.

8.20.1.8 (a) Fermi.

(b) It was proposed that beta decay resulted from the breakdown of a neutron into an electron and a proton and therefore there must be a force holding these two together in the neutron. Gravity was too weak to do this and both the electromagnetic and strong nuclear forces do not affect electrons. A new force – the weak nuclear force was proposed.

8.20.2.1 (a) If any nucleus is to stay together and not burst apart due to the electrostatic repulsions there must be another force. We call this force the strong nuclear force.

(b) A = average distance between nucleons
B = electrostatic force of repulsion between protons
C = strong nuclear force

(c) Holds all nuclear particles together, whether charged or uncharged.
Is much stronger than electrostatic forces.
Is attractive over only a very small distance (about 10^{-15} m).
Becomes repulsive at small distances (less than the diameter of a nucleon).

8.20.2.2 The strong nuclear force in particular requires ideal distances between the protons. If the distance between protons is too small then the strong nuclear force is repulsive. If the average separation of protons is too large, then the strong nuclear force is too weak to hold them together. The neutrons help create these ideal distances. If there are too few neutrons, or too many neutrons, the nucleus becomes unstable. Large nuclei have many neutrons which increase the distance between protons thereby making the atoms unstable.

8.20.3.1 (a) The decaying nucleus emits an alpha particle which is a helium nucleus, $({}^4_2He)^{2+}$. The mass number of the nuclide decreases by 4 and the atomic number by 2.

(b) The nucleus emits an electron and an electron antineutrino. The atomic number increases by 1 as a neutron decays, but the mass number stays the same because the neutron decay also results in the formation of an additional proton.

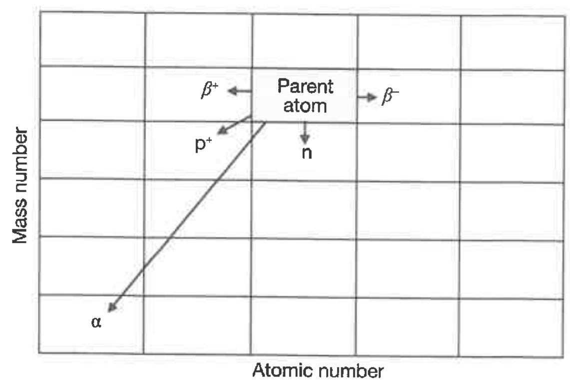
(c) A neutron is ejected from the nucleus. Atomic number does not change, mass number decreases by 1.

(d) The nucleus emits a positron (a positively charged electron) and an electron neutrino as a proton decays. Atomic number decreases by 1, mass number stays the same as a neutron is also formed.

(e) A proton is ejected from the nucleus. Both atomic number and mass number decrease by 1.

(f) Note that gamma rays usually accompany alpha and beta decay, but not always. It depends on the particular decay and the amount of energy involved. There is no rule for predicting gamma rays in any particular decay reaction.

8.20.3.2



8.20.3.3 (a)

Decay reaction	General equation for reaction
Alpha	${}^A_ZX \rightarrow {}^{A-4}_{Z-2}X + {}^4_2He$
Beta	${}^A_ZX \rightarrow {}_{Z+1}{}^{A}X + {}^{0}_{-1}e + {}^0_0\overline{v}$ (Note that beta decay is always accompanied by an antineutrino)
Positron	${}^A_ZX \rightarrow {}_{Z-1}{}^{A}X + {}^{0}_{+1}e + {}^0_0v$ (Note that positron decay is always accompanied by a neutrino)
Proton	${}^A_ZX \rightarrow {}^{A-1}_{Z-1}X + {}^1_1p$ (or ${}^1_1H$)
Neutron	${}^A_ZX \rightarrow {}^{A-1}_{Z}X + {}^1_0n$

(b) Gamma rays usually accompany alpha and beta decay, but not always. It depends on the particular decay and the amount of energy involved. There is no rule for predicting gamma rays in any particular decay reaction.

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8.20.3.4 A

8.20.3.5 C

8.20.3.6 D

8.20.3.7 A

8.20.3.8 B

8.20.3.9 C

8.20.3.10 B

8.20.3.11 (a) D

(b) The atomic bombs produced by the Manhattan Project during World War II.

8.20.3.12 (a) B

(b) Isotopes are atoms of the same element which have different numbers of neutrons and therefore different masses. Atomic mass is a measure of the average mass of the atoms of a particular element and the isotopes result in non-integral averages.

8.20.3.13 Nuclear decay, transformation, reaction, fission.

8.20.3.14 A nuclear transmutation occurs when an atomic nucleus is split into two smaller nuclei (nuclear fission) or when two nuclei are fused to form a larger nucleus (nuclear fusion).

8.20.4.1 (a) If any nucleus is to stay together and not burst apart due to the electrostatic repulsions there must be another force. We call this force the strong nuclear force.

(b) Holds all nuclear particles together, whether charged or uncharged.

Is much stronger than electrostatic forces.

Is attractive over only a very small distance (about 10^{-15} m).

Becomes repulsive at small distances (less than the diameter of a nucleon).

8.20.4.2 The strong nuclear force requires ideal distances between the protons. If the distance is too small then the strong nuclear force is repulsive. If the average separation of protons is too large, then the strong nuclear force is too weak to hold them together. The neutrons help create these ideal distances. If there are too few neutrons, or too many neutrons, the nucleus becomes unstable. Large nuclei have many neutrons which increase the distance between protons thereby making the atoms unstable.

8.20.4.3 The concept of entropy is that 'things in nature seek their lowest energy state'. In their lowest energy state, things are most stable and less likely to change. Applying this to atoms, stable atoms have low energy states while unstable atoms will try and become stable by getting to a lower energy state. They will typically do this by emitting some form of radioactivity and change in the process.

8.20.4.4 The strong nuclear force in particular requires ideal distances between the protons. Remember, if the distance between protons is too small then the strong nuclear force is repulsive. The neutrons help create these ideal distances. If there are too few neutrons, or too many neutrons, the nucleus becomes unstable.

8.20.4.5 If an atom has more than 82 protons in the nucleus, there is no arrangement of neutrons that can produce more attractive forces than repulsive forces. Therefore, all isotopes of elements beyond lead are radioactive. Their only route to stability is to reduce the overall size of the nucleus.

8.20.4.6 Science still does not completely understand why certain isotopes are more stable than others. There are theories based on observations of stable and unstable isotopes, but no real understanding of why. This is just another, unexplained observation.

8.20.4.7 (a) Binding energy refers to the energy bound up in the strong nuclear force holding the nucleons together in the nucleus.

(b) Elements between mass number 50 and 82 are the most stable, having the highest binding energy per nucleon.

(c) For nuclei with fewer than 50 nucleons, the average distance between them is smaller than ideal, so the strong nuclear force is not as strong. For atoms with atomic mass 82, the number of nucleons is larger than ideal so, on average, they are further apart than ideal, so again, the strong nuclear force is weaker.

(d) No. It simply indicates relative stability, not absolute stability or instability.

8.20.4.8 (a) The line of stability indicates the stable isotopes of the elements.

(b) Above the line of stability, the neutron/proton is higher than that indicated in more stable nuclei, so nuclear decay would be most likely to occur to reduce the number of neutrons and increase the number of protons in order to approach the line of stability – hence beta decay.

(c) Below the line of stability, the neutron/proton is lower that indicated in more stable nuclei, so nuclear decay would be most likely to occur to reduce the number of neutrons to approach the line of stability – hence positron decay.

(d) All nuclei in this area (mass number greater than 82) are too large to be stable, and would therefore be most likely to decay in a way which reduces their size – i.e. nuclear fission, or by releasing an alpha particle (or both).

(e) The graph is only an indicator of trends, not of absolute information.

8.20.5.1

Radiation	Charge	Mass	Penetrating power	Ionising power	Path through electric field	Path through magnetic field	What is it?
Alpha	2+	4 amu	Very low	Very high	Parabolic towards negative	Circular	Helium nucleus
Beta	−1	Very low	Low	High	Parabolic towards positive	Circular	Electron
Gamma	None	None	Very high	Low	Unchanged	Straight	Electromagnetic radiation

8.20.5.2 (a) C
(b) Chemical symbol = He^{2+}, common symbol = α

8.20.5.3 C

8.20.5.4 A

8.20.5.5 (a) C
(b) Beta particles, being electrons, have only about one eight thousandth of the mass of an alpha particle, so their impact on a surface is much less than that of an alpha particle (assuming velocity is the same).

8.20.5.6 C

8.20.5.7 A

8.20.5.8 D

8.20.5.9 B

8.20.5.10 A

8.20.5.11 (a) X = alpha particle
Y = gamma ray
Z = beta particle
(b) Alphas, having more mass, will have a path with greater radius. Gammas, with no charge, will pass through undeflected.

8.20.5.12 D

8.20.5.13 A = alpha particle
B = beta particle
C = gamma ray
D = alpha particles (helium nuclei)
E = beta particles (electrons)
F = gamma radiation

8.20.5.14

Radiation	Charge	Penetrating power	Ionising power	Path through electric field	Path through magnetic field	What is it?
X	None	Very high	Very low	Undeflected	Undeflected	Gamma
Y	Positive	Very low	Very high	Towards negative potential	Deflected indicating positive charge	Alpha
Z	Negative	Low	Low	Towards positive potential	Deflected indicating negative charge	Beta

8.21.1.1 B

8.21.1.2 A

8.21.1.3 (a) D
(b) Superscript numbers represent the mass number of the atoms of the elements and subscript numbers represent the atomic numbers of the elements.

8.21.1.4 (a) C
(b) Emission of an alpha particle removes two protons from the atom involved, so Y will have an atomic number 2 less than X.

8.21.1.5 (a) B
(b) Lead is two places below polonium on the periodic table as required by the emission of an alpha particle.

8.21.1.6 (a) C
(b) Emission of a beta particle results in an increase of 1 in atomic number, so the next element on the periodic table (polonium) is the correct element.

8.21.1.7 (a) A
(b) Mass number must be 222 and atomic number 85.

8.21.1.8 (a) D
(b) With the loss of an alpha particle, X must have an atomic mass 4 less (207) and an atomic number 2 less (81).

8.21.1.9 (a) A
(b) Antineutrinos are usually emitted along with beta particles in nuclear transformations.

8.21.1.10 (a) D
(b) Two successive beta decays will increase the atomic number of the element by 2, therefore element 92 is formed – uranium.

8.21.1.11 (a) C
(b) Mass number decreases by 28 which indicates that 7 alpha particles have been released. This would decrease the atomic number by 14, but it has only decreased by 10, so 4 betas must have been released.

8.21.1.12 (a) B
(b) Decay involves ${}_{-1}^{0}e$ and ${}_{2}^{4}He$ which decreases the mass number by 4, and decreases the atomic number by 1.

8.21.1.13 D

8.21.1.14 D

8.21.1.15 C

8.21.1.16 A

8.21.1.17 C

8.21.1.18 B

8.21.1.19 C

8.21.1.20 B

8.22.1.1 The half-life of a radioisotope is the time required for one half of the amount of the isotope to degrade into a more stable material.

8.22.1.2 (a) $100\ s^{-1}$
(b) 9.00 pm
(c) 2

8.22.1.3 (a) $200 \div 2 \div 2 \div 2 \div 2 \div 2 = 6.25$
(b) $5 \times 8.04 = 40.2$ days
(c) The thorium would have the greater activity because it has the longer half-life.
(d) For the thorium, 50 days = 2.8 half-lives
Therefore fraction remaining = 0.1436
For the iodine, 50 days = 6.22 half-lives
Therefore fraction remaining = 0.0136
So activity thorium : activity iodine = 10.5 times greater

8.22.1.4 $\frac{2.00\ \text{mg}}{128.0\ \text{mg}} = 0.015625$ of the sample remains
Therefore, from $\left(\frac{1}{2}\right)^n = 0.015625$
$n \log 0.5 = \log 0.015625$
$n = \frac{\log 0.015625}{\log 0.5} = 6$
$\frac{24\ \text{days}}{6\ \text{half-lives}} = 4.00$ days (the length of the half-life)

8.22.1.5 $\frac{5.00}{100.0} = 0.05$ (decimal fraction remaining)
$\left(\frac{1}{2}\right)^n = 0.05$
$n = 4.32$ half-lives
$36.0\ \text{hours} \times 4.32 = 155.6$ hours

8.22.1.6 Fraction remaining = 0.25
Therefore $\left(\frac{1}{2}\right)^n = 0.25$
$n = 2$
Therefore time = 24.52 years

8.22.1.7 40.2 days = 5 half-lives
Therefore fraction remaining = $0.03125 = \left(\frac{1}{(2^n)}\right)$
0.3125% remaining

8.22.1.8 Fraction remaining = 0.625

Therefore $\left(\frac{1}{2}\right)^n = 0.625$

$n = 0.68$

Therefore time = 0.68 × 18.72 = 12.7 days

8.22.1.9 Recognise $\frac{1}{4}$ as a fraction associated with 2 half-lives (from $\left(\frac{1}{2}\right)^2 = \frac{1}{4}$)

3.82 days × 2 = 7.64 days

8.22.1.10 In 24 hours, the sample goes from 100% to 95%

$\left(\frac{1}{2}\right)^n = 0.95$

$n \log 0.5 = \log 0.95$

$n = 0.074$

$\frac{24 \text{ hrs}}{0.074} = 324$ hrs = one half-life

8.22.1.11 Fraction remaining = $\frac{(5.20 \times 10^6)}{(5.32 \times 10^9)}$

$= 9.77 \times 10^{-4}$

Therefore $\left(\frac{1}{2}\right)^n = 9.77 \times 10^{-4}$

$n = 10$

Therefore time = 301.7 years

8.22.1.12 99% lost = 1% remaining = 0.01

Therefore $\left(\frac{1}{2}\right)^n = 0.01$

$n = 6.64$

Therefore time = 95 days

8.22.1.13 (a) $\frac{159 \text{ days} \times 24 \text{ hrs}}{\text{day} \times 60 \text{ min/hour}} = 228960$ min

228960 min × (3.4×10^{13} disintegrations per 26 min)

$= 2.994 \times 10 \times 10^{17}$ total disintegrations in 159 days

$\frac{2.994 \times 10 \times 10^{17}}{3.25 \times 10^{18}} = 0.0921$

9.21% has disintegrated

(b) 0.9079 is the decimal fraction of the substance remaining since 0.0921 has gone away

$\left(\frac{1}{2}\right)^n = 0.9079$

$n \log 0.5 = \log 0.9079$

$n = 0.139$ half-lives

$\frac{159 \text{ days}}{0.139} = 1144$ days

8.22.1.14 (a) This represents 11 half-lives, so $\frac{100}{(2^{11})}$ = fraction remaining = 0.0488

(b) The carbon-14 dating limit lies around 58 000 to 62 000 years (10 to 11) half-lives because the amount of C-14 remaining after this time is too small to measure accurately.

8.22.1.15 0.22 per cent of K-40 remains

$\left(\frac{1}{2}\right)^n = 0.22$

$n \log 0.5 = \log 0.22$

$n = 2.18$

Total elapsed time = (2.18) (1.27×10^9)

$= 2.77 \times 10^9$ yrs = age of the sample

8.22.1.16 Sample is 3.8 parts by mass Ar and 1 part K, so original sample contained 4.8 parts K and zero parts Ar.

Therefore the fraction of K-40 that remains = 0.20833

So $\left(\frac{1}{2}\right)^n = 0.20833$

Therefore $n = 2.263$

Total elapsed time = (2.263) (1.27×10^9) = 2.87×10^9 yrs

8.22.1.17 Fraction of C-14 remaining:

$\frac{6.00}{13.6} = 0.4411765$

$\left(\frac{1}{2}\right)^n = 0.4411765$

$n = 1.18057$

Time elapsed = 5730 yr × 1.18057 = 6765 yrs

8.22.1.18 Fraction of C-14 remaining = $\frac{0.109}{0.296} = 0.368243$

$\left(\frac{1}{2}\right)^n = 0.368243$

$n = 1.441269$

5730 yr × 1.441269 = 8258 yrs

8.22.1.19 Fraction of C-14 remaining = 0.300

Half-lives have elapsed = $\left(\frac{1}{2}\right)^n = 0.300$

$n = 1.737$

Time elapsed = 5730 yr × 1.737 = 9953 yrs

8.22.1.20 Half-lives elapsed = $\frac{11\ 430}{5730} = 1.9947644$

Fraction remaining = $\left(\frac{1}{2}\right)^{1.9947644} = x = 0.25091$

C-14 present in the past = $\left(\frac{0.060 \text{ mg}}{0.25091}\right) = \left(\frac{x}{1}\right)$

$x = 0.239$ mg

8.22.1.21 Half-lives elapsed = $\frac{12\ 900 \text{ yr}}{5730 \text{ yr}} = 2.2513$

Fraction remaining = $\left(\frac{1}{2}\right)^{2.2513} = x = 0.21$

Counts remaining = 15.3 × 0.21 = 3.2

8.22.1.22 Fraction remaining = $\frac{9.58}{15.3} = 0.6261438$

$\left(\frac{1}{2}\right)^n = 0.6261438$

$n \log 0.5 = \log 0.6261438$

$n = 0.675434$

Determine number of years:

5730 years × 0.675434 = 3870 years

8.22.1.23 $\frac{10\ 000 \text{ yr}}{5730 \text{ yr}} = 1.7452$ half-lives

$\left(\frac{1}{2}\right)^{1.7452} = 0.2983$ = fraction remaining

15.3 times 0.2983 = 4.56 counts min^{-1}

8.22.1.24 (a) B

(b) B

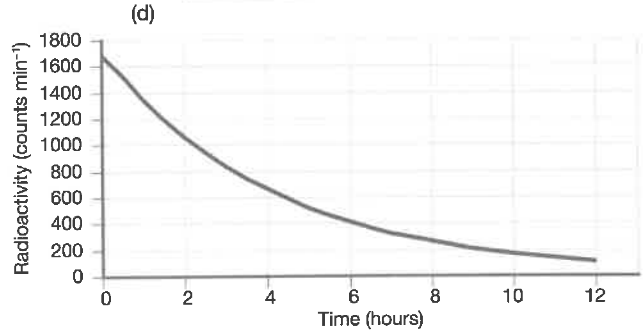
8.22.2.1 (a) 50

(b) The background radiation is always there and it contributes to the overall count. If it is not considered, then the results will be in error by this amount. It would be a 'zero' error and make the result invalid.

(c)

Time (hours)	Total radiation counts recorded (counts min^{-1})	Radiation due to X (counts min^{-1})
0	1730	1680
2	1110	1060
4	715	665
6	465	415
8	320	270
10	215	165
12	160	110

(d)



(e) 3 hours

(f) About 19 + background radiation = about 69

(g) 36 hours represents 12 half-lives which is beyond a measurable number, so count will simply indicate the background radiation = about 50.

7.14.1.8 The principle of relativity states that the laws of physics hold in all frames of reference but indicate that constant motion cannot be detected in an inertial frame of reference without reference to some point outside the frame. The principle of relativity does not hold in a non-inertial frame of reference.

7.14.1.9 D

7.14.1.10 (a) C

(b) Because a satellite in a stable orbit is falling freely under the influence of gravity and there are therefore no reaction forces acting, there is no way its movement can be detected without reference to an outside point. It is therefore an inertial frame of reference.

7.14.1.11 D

7.14.2.1 (a) All motion is relative – the principle of relativity holds in all situations.

The speed of light is constant regardless of the observer's frame of reference.

(b) The aether model must be wrong.

(c) The aether was 'invented' to account for the particle nature of light and it would therefore affect the speed of light. If the speed of light is constant, then the particle theory in Newtonian terms must also be wrong (light is composed of quantum particles which do not obey the laws of classical physics) and therefore there is no need for the concept of the aether.

7.14.2.2 Einstein showed that when a material body lost energy (either by radiation or heat) of amount E, its mass decreased by the amount $\frac{E}{c^2}$. This led to the famous mass-energy equivalence formula: $E = mc^2$.

7.14.2.3 Minkowski realised that Einstein's special theory of relativity could best be understood in a four-dimensional space, now known as the 'Minkowski space time', in which time and space are not separated entities but connected in a four-dimensional space time continuum. Einstein recognised the importance of Minkowski's space time concept and used it for his work on the foundations of general relativity.

7.14.2.4 B

7.14.2.5 (a) C

(b) (D) – Nothing can travel faster than the speed of light (3×10^8 m s^{-1})

7.14.2.6 C

7.14.2.7 (a) A

(b) If the speed of light is constant as proposed, then light must be independent of any aether. So, there is no need for an aether to exist to carry light energy. Note that the statements do not prove the non-existence of the aether.

7.14.2.8 D

7.14.2.9 D

7.15.1.1 In his first thought experiment Einstein wondered: 'Suppose I am sitting in a train travelling at the speed of light. If I hold a mirror in front of me, will I see my reflection?'

He contemplated two possibilities:

1. No. If the train is travelling at the speed of light, light from his face would not reach the mirror in order to be reflected back. By not being able to see his reflection, he would know that the train was travelling at the speed of light without having to refer to an outside point. This violates the principle of relativity.
2. Yes. This means that light would travel at its normal speed relative to the train. This does not violate the principle of relativity. However, it also means that, relative to a stationary observer outside the train, light would have to travel at twice its usual speed!

   On the basis of not violating the principle of relativity, he decided that he must see his image and proposed the consistency of the speed of light, and the non-constant nature of time.

7.15.1.2
- Length and time can no longer be regarded as separate concepts.
- In order to define an object's position we must consider four coordinates in the space time continuum – three dimensions of space and time (Minkowski's proposal).
- A new standard of length had to be defined.

7.15.2.1 The principle of simultaneity which states that events that are simultaneous in one frame of reference may not be seen as simultaneous from a different frame of reference.

7.15.2.2 (a) In this thought experiment Einstein imagined a light on the ceiling of a moving train shining onto a mirror on the floor. The light reflects from the mirror and travels back to the ceiling to a detector that records the time of its arrival. Two observers watch what happens – one inside the train, the other outside the train.

(b) Einstein's mathematics showed that the time for the light to reflect and return to the source was shorter for the observer inside the train (the observer at rest relative to the event) than for the observer outside the train (the observer in motion relative to the train).

(c) Einstein concluded that time in a moving frame of reference always passes more slowly than time in any other frame of reference.

(d) This effect is known as time dilation.

(e) $t_v = \gamma t_o = \dfrac{\Delta t}{\sqrt{1-\frac{v^2}{c^2}}}$

7.15.2.3 (a) Imagine an observer on Earth looking at the clock on a spaceship travelling away from him at constant speed. The clock on the spaceship will be seen to be running more slowly than his clock on Earth. By the same principle, the astronaut on the spaceship will observe the clock on Earth to be running slower than his clock on the ship.

(b) The term 'the event' refers to what is happening relative to the observer, and this depends on which observer is being considered. For example, for the observer on Earth, 'the event' is the spaceship moving away from Earth.

For the astronaut in the spaceship, 'the event' is the Earth moving in the opposite direction away from him.

(c) t_o is always the time measured on the clock which is stationary relative to 'the event'. For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the spaceship moving away from him, so the clock in the spaceship, which is moving along with the spaceship, is at rest relative to the spaceship. The clock on the spaceship therefore records t_o.

(d) t_v is always the time measured on the clock which is moving relative to 'the event'. For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the spaceship moving away from him, so the clock on Earth is moving relative to the spaceship. The clock on the spaceship therefore records t_v.

(e) The confusing aspect of time dilation is that it works both ways as outlined in the answers above. For both observers, the clock in front of them seems to be running faster than the clock in the other frame of reference That is, more time will pass on the clock in their frame of reference (t_v) that on the clock in the other frame of reference (t_o). In other words $t_v > t_o$. So to remember this, this author teaches that the person making the observation is always watching TV – the time on his clock is t_v!

7.15.2.4 Time can no longer be considered as a fundamental quantity.

In order to correctly define an object's position in space we need to consider four coordinates in the space-time continuum – the three dimensions of space itself, and time.

A new standard of both time and length needed to be found that was not affected by the motion of the observer.

7.15.2.5 (a) Diagram X is from the frame of reference of the observer inside the train.

Diagram Y is from the frame of reference of the observer outside the train.

(b) For X, $c = \frac{2L}{t}$

For Y, $c = \frac{2D}{t}$

(c) The speed of light is constant regardless of the frame of reference of the observer.

(d) For the observer inside the train, $c = \frac{2L}{t}$

For the observer outside the train, $c = \frac{2D}{t}$

But, because the speed of light is constant, then

$\frac{2L}{T} = \frac{2D}{t}$

However, D is a greater distance than L, so for these quotients to be equal, the time measured by the observer outside the train must be greater than the time measured by the observer inside the train.

That is, Time outside train > time inside train

Or, as Einstein put it $t_v > t_o$

7.15.3.1 (a) By definition, t_o is always the time measured on the clock which is *stationary* relative to 'the *event*'.

(b) For example, for an observer on Earth comparing times of clocks on Earth and in the spaceship, 'the event' is the *spaceship moving away from him*.

(c) Therefore the clock in the spaceship, which is moving along with the spaceship, is at rest *relative* to the spaceship.

(d) The clock on the spaceship therefore records t_o.

(e) The clock on the desk next to the Earth observer is therefore measuring t_v and his clock is in *relative motion* to 'the *event*'.

(f) Therefore, according to the observer on *Earth*, the clock on the spaceship will be running *more slowly* than his clock on Earth.

7.15.3.2 (a) The same definition holds – t_o is always the time measured on the clock which is *stationary* relative to 'the *event*'.

(b) In this example, for the observer on the spaceship comparing times of clocks on Earth and in the spaceship, 'the event' is the *Earth moving away from the spaceship*.

(c) Therefore the clock on *Earth*, which is moving with the Earth, is at *rest relative* to the Earth.

(d) The clock on *Earth* therefore records t_o.

(e) The clock on the desk next to the *astronaut*, is therefore measuring t_v and his clock is in *relative motion* to 'the event'.

(f) Therefore, according to the observer on the *spaceship*, the clock on the Earth will be *running more slowly* than his clock on the spaceship.

7.15.3.3 This phrase is designed to help students distinguish between t_o and t_v. Because t_v is always the time measured on the clock belonging to the person making the observations, then let the observer be watching TV!

7.15.3.4 (a) The event is the spaceship moving away from Earth

(b) The pilot in the spaceship

(c) t_v

7.15.3.5 (a) The event is the Earth receding away from the spaceship

(b) The observer on the Earth

(c) t_v

7.15.3.6 (a) The spaceship moving relative to him

(b) The Martian's clock

(c) The Martian's clock

(d) The spaceship clock

(e) The Martian's clock

7.15.3.7 (a) Spaceship Y moving towards him

(b) Captain X's clock

(c) Captain X's clock

(d) Captain Y's clock

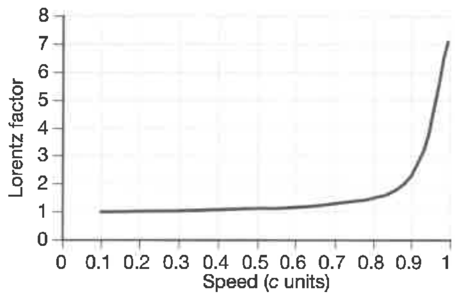
(e) Captain X's clock

7.15.4.1 A light clock is a device in which time is measured by dividing the distance light travels from a source to a mirror where it is reflected and then travels back to the source by the speed of light. In other words, $t = \frac{d}{c}$. This time, if measured by an observer in the same frame of reference as the clock it is known as proper time.

7.15.4.2

Speed of ship (c)	Lorentz factor
0.1	1.005
0.3	1.048
0.5	1.155
0.7	1.400
0.9	2.294
0.99	7.089

7.15.4.3 (a)

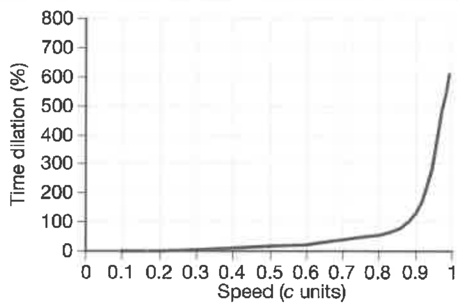


(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 *c*.

7.15.4.4

Time on spaceship (s)	Speed of ship (c)	Lorentz factor	Length of 1 second on spaceship as perceived by observer on Earth	Time dilation effect (%)
1	0.1	1.005	1.005	0.5
1	0.3	1.048	1.048	4.8
1	0.5	1.155	1.155	15.5
1	0.7	1.400	1.400	40.0
1	0.9	2.294	2.294	129.4
1	0.99	7.089	7.089	608.9

7.15.4.5 (a)



(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 *c*.

7.15.4.6 (a) Astronauts see this as = 2.18 years.
(b) Time recorded on Earth = (4.5 ÷ 0.9) = 5 years

7.15.4.7 (a) 7.79 hours
(b) 8.21 hours

7.15.4.8 Speed of the meson is 0.99 *c*.

7.15.4.9 (a) 11.55 hours
(b) 8.7 hours

7.15.4.10 0.503 s

7.15.4.11 4.9 s

7.15.4.12 5.45 s

7.15.4.13 0.94 *c*

7.15.4.14 (a) 3×10^8 m s^{-1}
(b) 3×10^8 m s^{-1}
(c) (i) 3×10^8 m s^{-1}
(ii) 3×10^8 m s^{-1}

7.15.4.15 (a) 2.8×18^8 s (8.88 years)
(b) 2.2×18^8 s (6.98 years)
(c) Proper time is time measured by the observer who is at rest relative to the event, which in this case is the astronaut. Note that both observers however would consider their time to be the correct time.
(d) The biological age of the astronaut will be less because of time dilation despite the fact that the astronaut will experience various forces and accelerations during the trip.

7.15.4.16 (a) 40 years
(b) 36.66 years
(c) 14.66 light years
(d) 0.4 *c*

7.15.5.1 The answer to this depends on your concept of 'stationary observer' as there is probably no absolute state of not moving since all parts of the Universe are moving as it expands. However, if we consider this observer to be stationary relative to the Solar System, then he would notice a small time dilation for Earth (due to its orbital motion) and a larger time dilation effect for time on the spaceship as the spaceship would also be moving faster relative to this observer.
(Note that if you take the observer as stationary relative to Earth – a less correct assumption – then you would get no time dilation on Earth and some time dilation on the spaceship.)

7.15.5.2 (a) B
(b) Both observers are in inertial frames of reference and are moving relative to each other, so both observers will detect a time dilation effect in the clocks of the other person.

7.15.5.3 D

7.15.5.4 (a) B
(b) Both observers are in inertial frames of reference and are moving relative to each other, so both observers will detect a time dilation effect in the clocks of the other person.

7.15.5.5 C

7.15.5.6 C

7.15.5.7 (a) A
(b) Both pulse rate and heartbeat would be slower due to the time dilation effect.

7.15.5.8 (a) D
(b) Because they are both moving *relative to each other* they will both notice a time dilation effect. Each person will observe that time passes more slowly in the other person's frame of reference. So, 5 seconds in their frame of reference will be observed to be less than 5 seconds in the other frame of reference.

7.15.5.9 C

7.15.5.10 B

7.15.5.11 C

7.15.5.12 A

7.15.6.1 Proper length is the length measured by an observer at rest to the object.

7.15.6.2 (a) 1.5 m
(b) $L = \gamma L_0$
(c) *L* will be shorter because the desk is moving relative to Jenny, so length contraction will occur for her.

7.15.6.3 0.53 *c*

7.15.6.4 (a) Its pilot – 100 m.
(b) An observer on the space platform – 60 m.
(c) The pilot – 150 m.
(d) An observer on the space platform – 250 m.

7.15.6.5 (a) 0.66 *c*
(b) 0.87 *c*

7.15.6.6 (a) 116 189.5 km
(b) 96.82 m

7.15.6.7 (a) 38 m (Speed is too slow for a significant relativistic effect.)
(b) 250 km
(c) 250 km

7.15.6.8 (a) 1 hour
(b) 1.67 hours
(c) 8.64×10^8 km
(d) 1.44×10^9 km
(e) 167 m
(f) 100 m

7.15.6.9 124.9 m
7.15.6.10 293.6 m
7.15.6.11 137.5 m
7.15.6.12 D
7.15.6.13 B
7.15.6.14 B
7.15.7.1 C
7.15.7.2 (a) A
(b) 120 m high by 120 m deep by 72 m long – the length contraction is only in the direction of the motion of the object.

7.15.7.3 (a) B
(b) 50 m – (The length contraction is only in the direction of the motion.)

7.15.7.4 C
7.15.7.5 C
7.15.7.6 D
7.15.7.7 D
7.15.7.8 A
7.15.7.9 C
7.15.7.10 A
7.15.7.11 B
7.15.7.12 D
7.15.7.13 B
7.15.8.1 (a) Using $\gamma = \sqrt{\left(1-\frac{v^2}{c^2}\right)} = \frac{1}{\sqrt{\left(1-\frac{0.8^2}{1^2}\right)}} = 1.67$

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 150\sqrt{\left(1-\frac{(0.8\ c)^2}{c^2}\right)}$
$= 150 \times 0.6 = 90$ m

(c) $t = \frac{90}{(0.8 \times 3 \times 10^8)} = 3.75 \times 10^{-7}$ s

(d) $t = \frac{150}{(0.8 \times 3 \times 10^8)} = 6.25 \times 10^{-7}$ s

(e) 9.109×10^{-31} kg

(f) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = \frac{(9.109 \times 10^{-31})}{\sqrt{\left(1-\frac{(0.8\ c)^2}{c^2}\right)}}$
$= 1.521 \times 10^{-30}$ kg

(g) Graph will be the usual exponential graph.

7.15.8.2 (a) Astronaut will notice no changes. He is at rest relative to his frame of reference.
(b) Astronaut's body will appear to be thinner in the direction of movement, his mass will be relativistically increased, and his pulse rate will be slower due to the perceived time dilation effect as observed by the Earth observer.

7.15.8.3 (a) $v = \frac{15.8}{16} = 0.9875\ c$

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 16\sqrt{\left(1-\frac{(0.9875\ c)^2}{c^2}\right)} = 2.52$ years

(c) Being in the spaceship, the length of journey itself is not in the astronaut's frame of reference so it will be contracted to 2.49 light years. Travelling at 0.9875 *c*, the ship will cover this distance in 2.52 years.

7.15.8.4 The astronaut will consider that time is passing normally for him. An Earth observer would perceive the astronaut's time as passing more slowly

7.15.8.5 No, it is not correct. The patient will be in the same frame of reference as the spaceship and so will experience time passing as normal. The disease will run its course as if he was still on Earth with time passing normally (to him).

7.15.8.6 (a) $t = \frac{s}{t} = \frac{4.2}{0.6} = 7$ years

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 7\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 5.6$ years

(c) 4.2 light years

(d) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 4.2\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 3.36$ light years

(e) 5.6 years

(f) Being in the spaceship, the length of journey itself is not in the astronauts' frame of reference so it will be contracted to 3.36 light years. Travelling at 0.6 *c*, the ship will cover this distance in 5.6 years.
Observers on Earth, measuring 7 years as passing in the spaceship's frame of reference will record the astronauts journey time as 5.6 years.

7.15.8.7 (a) 200 m

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 200\sqrt{\left(1-\frac{(0.4\ c)^2}{c^2}\right)} = 183.3$ m

(c) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 2\sqrt{\left(1-\frac{(0.4\ c)^2}{c^2}\right)} = 1.833$ km

(d) 2.0 km

7.15.8.8 (a) $t = \frac{10.5}{0.75} = 14$ years

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 14\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)} = 9.26$ years

(c) $t = 2 \times 14 = 28$ years

(d) $t = 2 \times 9.26 = 18.52$ years

7.15.8.9 (a) $t = \frac{s}{v} = \frac{100}{(0.75 \times 3 \times 10^8)} = 4.44 \times 10^{-7}$ s

(b) $t_0 = t_v\sqrt{\left(1-\frac{v^2}{c^2}\right)} = (4.44 \times 10^{-7})\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)}$
$= 2.94 \times 10^{-7}$ s

(c) 100 m

(d) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 100\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)} = 66.14$ m

(e) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = (1.673 \times 10^{-27})\sqrt{\left(1-\frac{(0.75\ c)^2}{c^2}\right)}$
$= 2.529 \times 10^{-27}$ kg

(f) 1.673×10^{-27} kg

7.15.8.10 (a) 500 m

(b) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 500\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 400$ m

(c) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)} = 1600\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 1280$ m

(d) 1600 m

(e) 3000 kg

(f) $m_v = \frac{m_0}{\sqrt{\left(1-\frac{v^2}{c^2}\right)}} = 3000\sqrt{\left(1-\frac{(0.6\ c)^2}{c^2}\right)} = 3750$ kg

(g) $L_v = L_0\sqrt{\left(1-\frac{v^2}{c^2}\right)}$; $500 = 1600\sqrt{\left(1-\frac{v^2}{c^2}\right)}$;

$1-\frac{v^2}{c^2} = 0.098$; $\frac{v^2}{c^2} = 0.9023$; $v = 0.95\ c$

7.15.8.11 (a) $v = \frac{(v_A + v_B)}{\left(1+\frac{v_A v_B}{c^2}\right)} = \frac{(0.6\ c + 0.8\ c)}{\left(1+\left(\frac{0.6\ c \times 0.8\ c}{c^2}\right)\right)} = 0.95\ c$

(b) c *Note:* The velocity of EM radiation (the signal) is always c.

(c) c

(d) c

(e) c

(f) c

(g) c

7.16.1.1 In 1972 four ultra accurate atomic clocks were placed on fast planes (flying at one millionth the speed of light). After two days of continuous flight (two around the world in different directions) the time shown by the airborne clocks differed (by nanoseconds!) from that shown by a synchronised clock left on Earth. However, questions were asked about the accuracy of the experiment and the Nobel Committee has chosen not to recognise it as experimental proof.

7.16.1.2 Muons are elementary particles created by cosmic rays in the Earth's atmosphere at an altitude of about 9 km.

At the speed they travel, 99.7 per cent of the speed of light, the muons should reach sea level in 16 to 31 microseconds (depending on the altitude at which they form), far longer than the time it takes them to decay and 'disappear'. Therefore, theoretically, they should never be detected at sea level. However, they are detected at sea level and so, in their frame of reference must take only about 2.2 μs to travel from the upper atmosphere to the surface. For them, the distance of 9 km contracted to 1.26 km.

7.16.1.3 The relativistic mass increase of particles accelerated to near light speeds in particle accelerators has been shown frequently. If the speed of the particles only is used to calculate conservation of energy data in high energy collisions, the law would seem to be disobeyed. However, when relativistic mass increases are considered, energy conservation is shown to occur.

7.16.1.4 The Michelson-Morley experiment was designed to detect the motion of the aether relative to the Earth. Their hypothesis was that because the aether was the medium that carried light, then the speed of light relative to Earth would vary if the speed of the aether relative to Earth varied, so the speed of light relative to Earth from different directions would be different. Their null result can be taken as evidence for the consistency of the speed of light.

7.16.2.1 Half-life refers to the time it takes a quantity, such as the mass of a radioactive particle or a number of muons to reduce to half its initial mass or number.

7.16.2.2

Time (μs)	Number of half-lives	Number of muons
0	0	1 000 000
2.2	1	500 000
4.4	2	250 000
6.6	3	125 000
8.8	4	62 500
11.0	5	31 250
13.2	6	15 625
15.4	7	7612
17.6	8	3806
19.8	9	1903
22.0	10	951
24.2	11	475
26.4	12	237
28.6	13	118

7.16.2.3 (a) 656 m

(b) 46.95 μs

(c) 21.34 half-lives

(d) 0

7.16.2.4 (a) 20.1 μs

(b) About 6030 m

(c) 2.32

(d) About 200 000

7.16.2.5 (a) About 1530 m

(b) 5.1 μs

(c) 2.32

(d) About 200 000

7.16.2.6 The calculations based on the equations of special relativity which predict the proportion of muons reaching the surface and the observations which show the predictions to be correct provide one of the strongest pieces of evidence to support the theory.

7.17.1.1 Rest mass is the mass of an object when it is at rest.

7.17.1.2 Because the mass of an object increases as its speed increases.

7.17.1.3 The mass of an object is affected if it is moving. At all speeds, mass increases according to Einstein's relativistic mass equation. So mass cannot be regarded as a fundamental quantity – it changes according to the speed of the object.

7.17.1.4 9.214×10^{-31} kg

7.17.1.5 2.788×10^{-27} kg

7.17.1.6 (a) 0.745 c

(b) (1×10^{-7})%

7.17.1.7 (a) 9.16×10^{-31} kg

(b) 2.92×10^{-30} kg

(c) 0.8 c

7.17.1.8 (a) From $W = qV = \frac{1}{2}mv^2$

$1.6 \times 10^{-19} \times 5 \times 10^5 = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

From which $v = 1.326 \times 10^8$ m s^{-1} = 4.2×10^8 m s^{-1}

(b) This velocity is impossible because it exceeds the speed of light.

7.17.1.9 (a) Negligible (don't even bother working it out).
(b) Negligible (ditto).
(c) 34.2%

7.17.1.10 0.999885 c (Do not round to 1.0 c, as this would make the mass of the electron infinite.)

7.17.1.11 (a) 2.3×10^{-14} J
(b) 3.49×10^{-14} J

7.17.1.12 (a) Newtonian physics will give (i.e. ignoring relativistic increases in mass that occur) gain in kinetic energy = 6.56×10^{-15} J
Repeating the calculation using relativistic effect at 0.4 c we get

Work done = $\frac{1}{2} \times 9.94 \times 10^{-31} \times (0.4 \times 3 \times 10^8)^2$

$= 7.2 \times 10^{-15}$ J which is a more correct answer.

(b) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 1.52 \times 10^{-30} \times (0.8 \times 3 \times 10^8)^2 - \frac{1}{2} \times 9.94 \times 10^{-31} \times (0.4 \times 3 \times 10^8)^2$

$= 4.4 \times 10^{-14} - 7.2 \times 10^{-15} = 3.7 \times 10^{-14}$ J

(c) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 6.46 \times 10^{-30} \times (0.99 \times 3 \times 10^8)^2 - \frac{1}{2} \times 1.52 \times 10^{-30} \times (0.8 \times 3 \times 10^8)^2$

$= 2.85 \times 10^{-13} - 4.4 \times 10^{-14} = 2.4 \times 10^{-13}$ J

(d) Work done will equal the change in kinetic energy, both calculated using relativistic masses

$= \frac{1}{2} \times 2.04 \times 10^{-29} \times (0.999 \times 3 \times 10^8)^2 - \frac{1}{2} \times 6.46 \times 10^{-30} \times (0.99 \times 3 \times 10^8)^2$

$= 9.16 \times 10^{-13} - 2.85 \times 10^{-13} = 6.3 \times 10^{-13}$ J

(e) (Comparing answer (b) to answer (a) – for the same increase in speed, i.e. 0.4 c, 3.6 times as much work must be done. Comparing answer (c) to answer (b) – to increase the speed by 25%, 9.6 times as much work must be done. Comparing answer (d) to answer (c) – to increase the speed by 0.1%, 2.5 times as much work must be done (note that if we multiply this by 250 = 25% ÷ 0.1%. we get 2.5 × 250 = 625 so although it is only 2.5 times as much work for a 0.1% increase, it represents an equivalent amount 625 times larger than the previous amount for the 25% increase.)
These figures therefore show an exponential increase in the amount of energy needed to increase the speed of an object by very small amounts as it approaches the speed of light, suggesting that an infinite amount of energy may be needed to reach the speed of light, further suggesting that we cannot reach it, let alone exceed it.

7.17.1.13 (a) 1.0×10^5 eV
(b) $W = qV = 1.6 \times 10^{-14}$ J
(c) Work done = kinetic energy gained = 1.6×10^{-14} J
So velocity = 1.874×10^8 m s^{-1} (= 0.625 c)
(d) 0.625 c
(e) 9.11×10^{-31} kg
(f) 1.17×10^{-30} kg

7.17.1.14 (a) Relativistic mass of X = 2.09125×10^{-27} kg
Relativistic mass of Y = 3.83812×10^{-27} kg
Difference = 1.74689×10^{-27} kg
(b) Newtonian kinetic energy X = 2.710×10^{-11} J
Newtonian kinetic energy Y = 6.098×10^{-11} J
Difference = 3.388×10^{-11} J
(c) Relativistic kinetic energy X = 3.3878×10^{-11} J
Relativistic kinetic energy Y = 1.399×10^{-10} J
Difference = 1.0602×10^{-10} J
(d) X since it is the slower speed.
(e) Y because relativistic effects are exponential as speed approaches the speed of light, and Y will be much closer to that speed than X.

7.17.2.1 (a) C
(b) The mass of particles in accelerators increases as their speed increases. JJ Thomson also found proof of this in his cathode ray oscilloscope experiments in the 1880s.

7.17.2.2 (a) D
(b) Never. If an object exists it must have mass. (Let's not confuse this simple concept by talking about neutrinos!)

7.17.2.3 D
7.17.2.4 B
7.17.2.5 C
7.17.2.6 B
7.17.2.7 B
7.17.2.8 B
7.17.2.9 C
7.17.2.10 A
7.17.2.11 (a) B
(b) Relativistic mass effects are greater at higher speeds, so the increase in mass of the spaceship will be larger from 0.8 c to 0.9 c than from 0.6 to 0.7 c (it will be larger at 0.8 c than at either 0.6 c and 0.7 c anyway), so the constant thrust will have less effect at the higher speeds. The acceleration of Y will therefore be less than the acceleration of X.

7.17.3.1 (a)

Speed (c)	Classical momentum ($\times 10^{-22}$)	Relativistic momentum ($\times 10^{-22}$)	Relativistic momentum compared to classical momentum
0.10	0.273	0.276	1.005
0.25	0.683	0.706	1.034
0.50	1.36	1.57	1.115
0.75	2.05	3.10	1.51
0.99	2.71	19.2	7.08
0.999	2.730	61.1	22.38
0.9999	2.733	193.2	70.72
0.99999	2.733	611.1	223.60
0.999999	2.733	1932.5	707.1

(b) Almost the same for the first 4 – low speed but rising exponentially for the speeds near c.
(c) The mass is increasing at the expense of speed so c will never be attained.

7.17.3.2 Gamma factor at 0.235 c = 1.0288
Gamma factor at 0.47 c = 1.1329
Therefore relativistic momentum increases by $\frac{1.1329}{1.0288}$ = 1.1 times larger

7.17.3.3 (a) They will have the same momentum at low speeds, but at speeds which are a significant proportion of the speed of light, particle B will have the higher momentum. At the higher speeds the gamma factor is larger, so the relativistic mass is larger as well as the speed being larger, so the relativistic momentum will be larger at higher speeds.
(b) Relativistic momentum of A = $\gamma m_o.v$ = 1.115 × 2 × 0.5 = 1.115 units
Relativistic momentum of B = $\gamma m_o.v$ = 1.034 × 4 × 0.25 = 1.034 units
(c) Relativistic momentum of A = $\gamma m_o.v$ = 1.667 × 40 × 0.8 = 53.34 units
Relativistic momentum of B = $\gamma m_o.v$ = 1.091 × 80 × 0.4 = 34.91 units

7.17.3.4 0.866 c

7.17.3.5 (a) 4.73×10^{-22} kg m s^{-1}
(b) 2.367×10^{-22} kg m s^{-1}
(c) At a speed of 0.866 c, the gamma factor is 2.0 which means the relativistic momentum is twice the classical momentum.

7.18.1.1 Einstein's explanation of this is that when an object is moving (at any speed), the energy used to accelerate the mass also changes its mass. At high speeds, while the energy still changes the mass of the object, not all of it results in an increase in speed. He put forward a new concept for the total energy of an object: $E_{total} = KE + m_oc^2$.

7.18.1.2 1.508×10^{-10} J

7.18.1.3 C

7.18.1.4 (a) B
(b) Total energy = kinetic energy due to the movement + rest energy = $\frac{1}{2}mv^2 + mc^2$

7.18.1.5 (a) B
(b) The rest energy of an electron cannot be zero as it has mass.

7.18.1.6 (a) A
(b) This mass is smaller than that of an electron, so only possible if there is some subatomic particle smaller than the electron (and there are plenty of those!) – however, your answer must give this proviso to be correct.

7.18.1.7 C

7.18.1.8 (a) C
(b) The same amount. One kilogram of any element will produce the same amount of energy.

7.18.1.9 (a) A
(b) The gradient would be constant and equal to c^2.

7.18.1.10 (a) A
(b) As the speed of an object increases, its mass increases, and so does the force needed to accelerate it. At speeds approaching the speed of light, the mass increases towards infinity, so the force needed to accelerate it to a higher speed also increases towards infinity. We cannot have an infinite force, therefore we cannot accelerate the mass beyond the speed of light.

7.18.1.11 (a) D
(b) The rest mass of an object can never be zero – mass can never be zero.

7.18.1.12 (a) B
(b) No, because the rest mass is the mass when it is at rest and it can never be moving slower than zero.

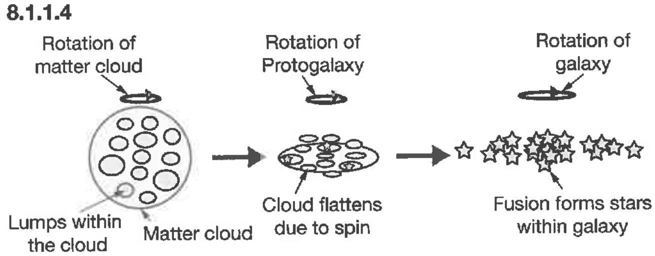
Module 8 From the Universe To the Atom

8.1.1.1 (a) The Big Bang produced an enormous amount of energy which expanded outwards.
(b) As the Universe cooled, the energy condensed to simple particles first, then to more complex particles.
(c) The first particles formed were the fundamental particles, the leptons, neutrinos and quarks.
(d) The formation of mass particles allowed the gravitational force to take effect on them.
(e) Gravity collected the newly forming particles together to form 'lumps' within the developing Universe.
(f) As the temperature fell, quarks combined to form matter hadrons and antimatter hadrons.
(g) The initial hadrons were mainly protons and neutrons, as isolated particles.
(h) This explains the huge amounts of hydrogen in the Universe.
(i) The formation of these hadrons required the strong nuclear force to come into play.
(j) The charged leptons resulted in the electromagnetic force.
(k) The next phase is thought to have been the annihilation of hadrons and antihadrons as they combined.
(l) This annihilation released leptons and energy in the form of gamma rays.
(m) However, due to an excess of matter over antimatter, some matter hadrons remained.
(n) These hadrons gravitated towards each other forming dense collections of molecules of hydrogen.
(o) The energy produced by the annihilation was enough to allow fusion of some hydrogen into heavier nuclei.
(p) The main nuclei formed initially by this fusion were deuterium, helium and lithium.
(q) Over the next few hundred thousand years enough matter accumulated to form stars and galaxies.
(r) The Universe as we know it started to form.

8.1.1.2 The Big Bang event.

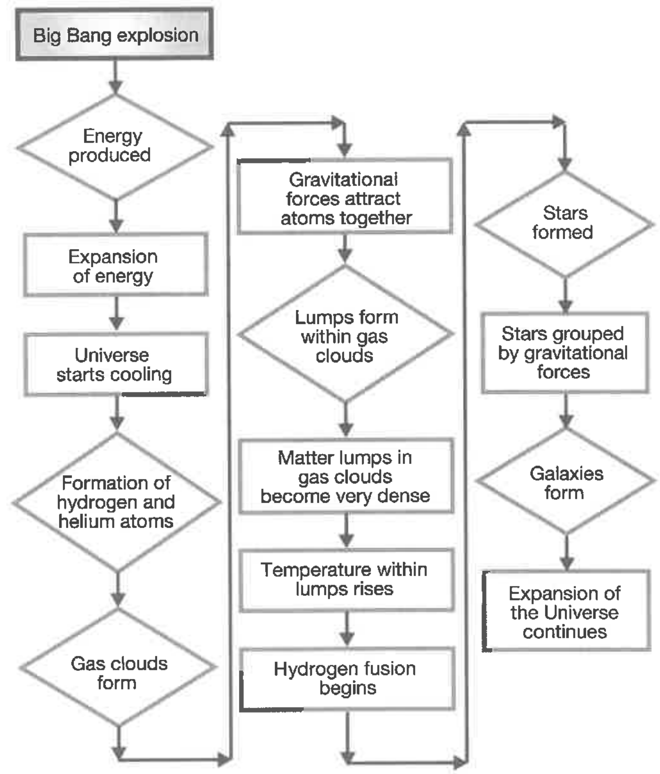
8.1.1.3 (a) The term lumpy' refers to the composition of the Universe as being pockets of matter (in some cases antimatter) isolated in space with huge distances between each pocket of matter.
(b) The Big Bang produced both matter and antimatter, with matter in excess. Wherever matter and antimatter coexisted, they annihilated each other resulting in the empty spaces. The 'lumps' are the left over matter (or antimatter) which was not near any antimatter (or matter).
(c) Gravitational attraction of the matter within each lump formed denser clumps of matter.
(d) The galaxies and the stars that compose them.

8.1.1.4



8.1.1.5 (a) Like all accepted theories in science, the Big Bang theory explains more observations than rival theories and makes more accurate predictions of observations than Astronomers have been making in modern times.
(b) Their idea was that the energy was generated due to the gravitational forces compressing the matter into the centre of the stars.
(c) Almost all life on Earth is dependent either directly or indirectly on the photosynthesis that occurs in plants, and the energy that runs photosynthesis comes from the Sun.

8.1.1.6



8.1.2.1 (a) It shows us that the Big Bang event produced the energy that produced matter which became more complex as time from the Big Bang event increased. We could say that the formation of matter was directly related to the time passing since the Big Bang event.
(b) The diagram assumes that time is measured relating to the Big Bang event, perhaps assuming that time did not exist before the event.

8.1.2.2 This is more difficult because the diagram assumes the existence of a 'unified force' which is thought to be a single force encompassing the four fundamental forces. As matter stated to form and become more complicated, the separate forces started to become independent of the others – they acted in their own right – so perhaps we could say that the appearance of these separate forces was directly related to the formation of the particles of matter.

8.1.2.3 Time and the size of the Universe are directly related. As time passes, the Universe gets larger.

8.1.2.4 Indirectly related. As time passes the temperature of the Universe decreases.

8.1.2.5 (a) 10^{-43} seconds

(b) The fermions – the fundamental particles, quarks and electrons and neutrinos (and their antimatter equivalents).

8.1.2.6 (a) Around 10 seconds after the Big Bang.

(b) Leptons and gamma radiation.

(c) The energy produced added to the energy produced by the Big Bang and enabled the expansion of the Universe to continue.

8.1.2.7 The temperature of the Universe had to cool sufficiently to allow the developing matter to attract (gravitational forces) and form atoms pressed close enough together for the fusion to commence.

8.1.3.1 (a) The red shift in light from distant galaxies shows that the Universe is expanding no matter in which direction we look. Calculations show that galaxies further away from us are moving faster. This data supports the idea of the Big Bang explosion in that this is exactly the way pieces of a hand grenade or an exploding bomb move after they explode.

(b) The Universe is composed of about 25% helium and 75% hydrogen. Calculations show that if the Universe began with a big bang, then these elements would have formed in these proportions. This supports the Big Bang idea.

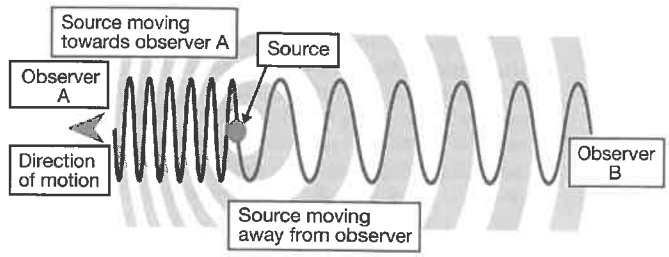
(c) Hotter, larger stars produce heavier elements in the fusion reactions that occur in their cores, and that all stars (except dwarfs) fuse hydrogen to form helium. If the 25% helium in the Universe had been formed in this way, then most stars would be much hotter than they are because of the amount of nuclear fusion of hydrogen required to produce it. In addition, older stars would have less helium than younger stars (due to its conversion to heavier elements). However, they don't. Again, the calculations which lead to these results also favour a Big Bang event

(d) If the Universe started with a big bang, then it is getting older every year. We should be able to see signs of this. Light from galaxies far away from us has taken billions of years to reach us. This light should provide evidence to show these galaxies are different from ours (being much younger) and from other, closer galaxies. This evidence is found. At large distances from us, many galaxies are radio galaxies – they emit radiation in the radio frequencies, and contain many more blue stars. Blue stars are very hot, and have a much shorter life span than stars like the Sun. These two observations give evidence of younger galaxies, supporting the ageing concept.

(e) An exciting development in physics is the link between high speed particle physics and cosmology, the study of how the Universe began. As scientists built bigger and better particle accelerators and collided particles with more and more energy they realised that the particles they were producing could have been those which existed when these types of energies existed in the Universe. They started linking their ideas about the structure of matter to the conditions which they thought existed just after the 'Big Bang'. While astronomers were hypothesising from time zero forwards, particle physicists started working backwards from now. They both arrived at the same points.

(f) George Gamow, a former student of Friedmann, predicted in 1948 that if the Universe started with a highly energetic explosion, then the remnants of the energy associated with that explosion should be able to be detected as a 'background radiation' of wavelength of about 1 mm throughout all of space. He estimated that the expansion of the Universe would have resulted in its cooling down to about 3 kelvins. This has been found to be correct.

8.1.3.2



8.1.3.3 The Big Bang should be considered as an 'event' rather than an actual explosion. An explosion implies the existence of matter which is hurled into space. The Big Bang theory says that nothing existed before the 'event'. Space did not exist. What happened was the space was formed and started expanding outwards, carrying with it, the matter and energy associated with the 'event'. How the matter and energy was produced is not accounted for. What happened in the 10^{-43} seconds before the appearance of the fundamental particles is not known (yet). Remember, that while space continues to expand, the galaxies within space do not. They maintain their relative sizes and shapes.

8.2.1.1 Advances in technology, specifically developments in telescopes, including lenses and reflecting mirrors and spectrographs.

8.2.1.2 (a) Einstein's mathematics on the laws of gravity and special relativity actually predicted the expansion of the Universe. This was the first time this had been considered.

(b) Instead of trusting his mathematics and searching for more evidence, Einstein seems to have let his personal belief that the Universe was stationary influence his mathematics to the point that he introduced a constant into his work so that the mathematics supported his belief.

8.2.1.3 (a) The optical Doppler effect is the red or blue shift in the spectrum of light from distant galaxies when their emission spectrum is compared to a stationary emitter, like our Sun.

(b) Vestro Slipher, was an astronomer working at the Lowell Observatory in Arizona. He examined the spectrum of light produced by spiral nebulae (he did not know these were different galaxies).

(c) The red shift is produced by galaxies that are moving away from us. The blue shift is caused by galaxies moving towards us.

(d) Any frequency of electromagnetic radiation will be subject to frequency shifts if the emitter is moving relative to an observer. Sound also undergoes an audio Doppler effect.

(e) The frequency of sound emitted by the sirens of ambulances, police, fire trucks increases as they come towards us, decreasing as they pass and go away from us.

(f) Galaxy X is stationary relative to Earth. Its spectrum is the normal reference spectrum.
Galaxy Y is showing a red shift due to its motion away from Earth.
Galaxy Z is showing a blue shift due to its motion towards Earth.

8.2.1.4 In 1922, Friedmann, a Russian physicist read Einstein's work and how he had solved the problem of an expanding Universe by introducing the cosmological constant. Friedmann considered this had been an error, and set about solving Einstein's equations without the constant. He found that they predicted either an expanding or contracting Universe. With no other evidence to back him up, he favoured an expanding Universe in which both space and time are curved.

8.2.1.5 Hubble's discoveries were to revolutionise ideas on the structure of the Universe. He discovered that not all stars belonged to the Milky Way Galaxy and discovered over 20 new galaxies awakening people to the fact that the Universe was very much larger than previously thought. He applied the idea of the red shift to his new galaxies and discovered that they were all moving away from Earth, no matter in which direction he looked. So while Friedmann proposed the expansion of the Universe, Hubble proved it. Hubble went further to show that the further away from us galaxies are, the faster they are moving away, and that this is a mathematically direct relationship. This data enabled more accurate calculations of the age of the Universe.

8.2.1.6 (a) Edwin Hubble's

(b) From the equation, average speed = $\frac{\text{distance}}{\text{time}}$

Therefore $D = vt$

From the graph,

Gradient = Hubble's constant H_0

= velocity ÷ distance to galaxy

$= \frac{v}{D}$

From which $D = \frac{v}{H_0}$

Equating the two equations for distance:

$vt = \frac{v}{H_0}$

Dividing both sides by v, we get t, so that t, the age of the Universe, is given by:

$t = \frac{1}{H_0} \approx 15.6$ billion years

8.2.1.7 The Big Bang does not consider the 'creation' of this initial energy, only its evolution after creation.

8.3.1.1 Einstein's explanation of this is that when an object is moving (at any speed), the energy used to accelerate the mass also changes its mass. At high speeds, while the energy still changes the mass of the object, not all of it results in an increase in speed. He put forward a new concept for the total energy of an object:

$E_{total} = KE + m_0c^2$

8.3.1.2 1.508×10^{-10} J

8.3.1.3 (a) A

(b) The gradient would be constant and equal to c^2.

8.3.1.4 (a) Rest mass refers to the mass of an object when it is at rest.

(b) Because Einstein's work and observations of particles in accelerators have shown that the mass of an object increases as its speed increases.

(c) The rest energy of a mass is its energy equivalence when it is stationary.

8.3.1.5 C

8.3.1.6 (a) B

(b) Total energy = kinetic energy due to the movement + rest energy = $\frac{1}{2}mv^2 + mc^2$

8.3.1.7 (a) B

(b) The rest energy of an electron will be zero when it is at absolute rest.

8.3.1.8 (a) A

(b) This mass is smaller than that of an electron, so only possible if there is some subatomic particle smaller than the electron (and there are – plenty of those!) – however, your answer must give this proviso to be correct.

8.3.1.9 C

8.3.1.10 (a) C

(b) The same amount. One kg of any element will produce the same amount of energy.

8.3.1.11 (a) D

(b) No. Mass is the amount of matter in an object – this cannot be zero.

8.3.1.12 (a) B

(b) No. Rest mass is the mass of an object when it is stationary – it cannot move slower than stationary!

8.3.1.13 In a nuclear reaction, the mass of the products is usually less than the mass of the reactants. The difference, called the mass defect, is the mass converted to energy during the reaction. The amount of energy released can be calculated using the Einstein equation.

8.3.2.1 (a) Mass of reactants = $4 \times 1.67325 \times 10^{-27}$ kg

$= 6.693 \times 10^{-27}$ kg

(b) Mass of products = 6.645×10^{-27} kg

(c) Mass defect = $6.693 \times 10^{-27} - 6.645 \times 10^{-27}$

$= 0.048 \times 10^{-27}$ kg

(d) $E = mc^2 = 0.048 \times 10^{-27} \times 9 \times 10^{16}$

$= 4.32 \times 10^{-12}$ J

8.3.2.2 (a) Number of fusions = $\frac{4 \times 10^{26}}{4.32 \times 10^{-12}}$

$= 9.26 \times 10^{37}$ per second

(b) Note that there are 4 hydrogen atoms used in every fusion, therefore mass of hydrogen fused

$= 4 \times 9.26 \times 10^{37} \times$ mass of hydrogen atom

$= 1.67325 \times 10^{-27}$ kg

$= 6.198 \times 10^{11}$ kg

= about 620 million tonnes

(c) Mass of helium-4 produced

$= 6.645 \times 10^{-27} \times 9.26 \times 10^{37}$ kg

$= 6153 \times 10^{12}$ kg

= about 615 million tonnes

(d) The loss in mass of the Sun each second

= about 5 million tonnes

(e) The mass lost by the Sun each year

$= 5 \times 365.25 \times 24 \times 3600$

$= 1.58 \times 10^{8}$ million tonnes

(f) Percentage mass lost each year

$= \frac{1.58 \times 10^{17}}{2 \times 10^{30}} \times 100 = 7.9 \times 10^{-12}$ %

(g) Sun will last, at this rate

$= 2 \times 10^{30}$ kg ÷ 5 million tonnes

$= 2 \times 10^{30} \div 1.58 \times 10^{17}$

$= 1.27 \times 10^{13}$ years

$= 1.27 \times 10^{4}$ billion years

(h) Long before this time, about 5 billion years from now, the Sun's concentration of hydrogen in its core will be insufficient to maintain hydrogen fusion. At this stage, gravitational collapse will not be counteracted by the thermal expansion due to the fusion reactions, so the Sun will shrink in on itself and then, when the pressure and temperature rises sufficiently, helium fusion will commence. The Sun will then expand extremely rapidly producing a red giant.

(i) Mass 4.5 billion years ago

$= 2.0 \times 10^{30} + (4.5 \times 10^{9} \times 1.58 \times 10^{17})$

$= 2.00071 \times 10^{30}$ kg

(j) Percentage of mass lost in 4.5 billon years

= 0.036%

8.4.1.1 When atoms are excited they emit electromagnetic radiation of characteristic wavelengths. This radiation can be split into its component wavelengths which can then be detected using photographic or similar plates. The pattern formed on the photographic plate is called a spectrum.

8.4.1.2 (a) Continuous
Emission
Absorption

(b) Continuous – All wavelengths (or frequencies) are present forming (in the case of the visible spectrum) a continuous, unbroken band of colour ranging according to ROYGBIV

Emission – Mostly a black band with varying numbers of isolated coloured lines representing the spectrum of the particular element(s) present.

Absorption – A continuous band of colour with selected omissions of frequencies (depending on the element(s) involved) which will appear as isolated black lines in the band.

8.4.1.3 The coloured lines in the emission spectrum will be the same frequencies as the black lines in the absorption spectrum.

8.4.1.4 (a) The spectrum formed from light from the Sun.

(b) To produce an absorption spectrum a quantity of the material (e.g. hydrogen gas) needs to be placed in the beam of (say) sunlight, and the resulting light passed into the spectrometer. The hydrogen gas will absorb the frequencies determined by its electron structure and an absorption spectrum without these frequencies (i.e. black lines produced) will be formed. (Note that an emission spectrum cannot be formed from a continuous spectrum. It is formed by passing the light formed by burning the substance, or emitted from the very hot substance, through a spectrometer.)

8.4.1.5 (a) Continuous: All spectral lines appear in the spectrum; our eyes do not have the resolution to see them as separate lines – the spectrum appears continuous. Continuous spectra are emission spectra which involve emitted radiation from many elements such that all wavelengths are represented.

(b) Emission: Electromagnetic radiation is emitted as excited electrons fall back to lower energy levels causing photon emission to produce the emission spectrum lines – the rest of the spectrum is black. The few lines that do appear represent the energy values of the particular electron transfers for that element.

(c) Absorption: White light (all wavelengths) passes through a gas and photons of the energy representing energy transitions of the atoms of that gas, are absorbed – these energy values in the spectrum appear as black lines because they have been absorbed or removed from the beam of white light.

8.4.1.6 (a) Gustav Kirchhoff in 1859.

(b) The scientific research that followed in order to explain spectra was the beginning of quantum physics.

8.4.1.7 A = continuous spectrum
B = emission spectrum
C = absorption spectrum

8.4.1.8 (a) Short wavelength end is the left hand end (the blue end).

(b) High frequency end is also the blue end.

(c) Blue/violet end.

8.4.1.9 (a) A black body is a theoretical object which absorbs all radiation falling on it, and later re-emits that radiation.

(b) The continuous spectrum from a black body would be like the spectrum of the Sun.

8.5.1.1 Planck's work on the radiations from hot bodies suggested that the wavelength (or frequency) of the peak radiation indicated the temperature of the radiating body. He found that all hot objects, regardless of composition, had the same peak radiation wavelength for the same temperatures. Astronomers applied this idea to the radiation curves from stars and developed the mathematics (e.g. Wien's law) to determine surface temperature and intensity of emitted radiation.

8.5.1.2 (a) X then Y the Z

(b) Z then Y then X

(c) Z then Y then X

(d) (i) X = towards red end of spectrum, perhaps red or orange

(ii) Y = towards middle of spectrum, perhaps yellow

(iii) Z = towards blue end of spectrum, perhaps blue or blue/white

8.5.1.3 (a) Peak radiation wavelength = 500 nm
Therefore from $\lambda_{max}T = b$
$500 \times 10^{-9} \times T = 2.898 \times 10^{-3}$
Therefore $T = 5796$ K

(b) Most probable colour is yellow as this is about the same surface temperature as our Sun.

8.5.1.4 (a) It is an intensity/frequency graph rather than an intensity/wavelength graph.

(b) U – it has the highest peak frequency.

(c) P – it has the lowest peak frequency.

(d) S – it has radiation frequency about 6×10^{14} Hz which is wavelength about 600 nm which is the same as our Sun.

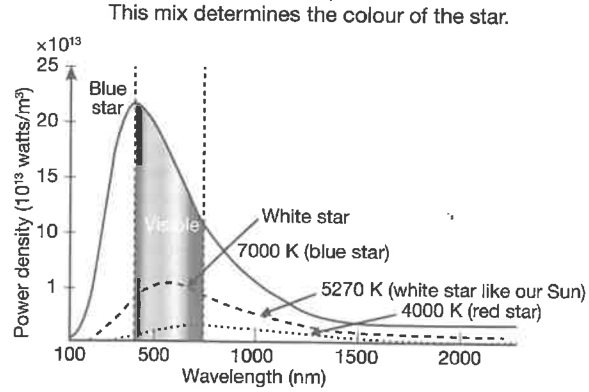
(e) No – she is incorrect. Star T has a higher peak radiation frequency than S and will therefore be hotter than S.

8.5.2.1 (a) The black body radiation curve for different temperatures peaks at a wavelength inversely proportional to the temperature, or
As the temperature of a black body rises, the Planck curve of the emitted radiation shifts to a higher frequency, the peak intensity indicating the surface temperature of the body.

(b) $T = \dfrac{\text{constant}}{\lambda_{peak}}$
(constant = 2.8977729×10^{-3} m K)

(c) The Kelvin or absolute scale.

8.5.2.2 The higher the frequency range of the emitted radiation, the less red and more blue radiation from the visible spectrum is present in the Planck curve. This mix determines the colour of the star.



8.5.2.3 From $T = \frac{\text{constant}}{\lambda_{peak}}$

$= \frac{2.8977729 \times 10^{-3}}{500 \times 10^{-9}} = 5795.5 \text{ K} = 5522.5.5°\text{C}$

8.5.2.4 An analysis of the black body radiation curve from a star will determine its peak radiation frequency. This can be substituted into Wien's equation to determine the surface temperature of the star.

8.5.2.5 From $T = \frac{2.8977729 \times 10^{-3}}{\lambda_{peak}}$

$\lambda_{peak} = \frac{2.8977729 \times 10^{-3}}{2.7} = 1.07 \text{ mm}$

8.5.2.6 From $T = \frac{\text{constant}}{\lambda_{peak}}$

$= \frac{2.8977729 \times 10^{-3}}{675 \times 10^{-9}} = 4293 \text{ K} = \text{about } 4300 \text{ K}$

8.5.2.7 (a) X will be hotter than Y. It has peak radiation wavelength shorter than Y, therefore peak frequency higher than Y, therefore temperature higher than Y.

(b) Temperature X = $\frac{2.8977729 \times 10^{-3}}{6 \times 10^{-6}} = 483 \text{ K}$

Temperature Y = $\frac{2.8977729 \times 10^{-3}}{6 \times 10^{-6}} = 414 \text{ K}$

8.5.2.8 From $T = \frac{2.8977729 \times 10^{-3}}{4.5 \times 10^{-3}} = 0.64 \text{ K} = -272.4 \text{ C}$

8.5.2.9 From $T = \frac{2.8977729 \times 10^{-3}}{\lambda_{peak}}$

$\lambda_{peak} = \frac{2.8977729 \times 10^{-3}}{4500} = 643.9 \text{ nm}$

8.5.2.10 (a) The line has been drawn so that it connects the peak wavelengths of the radiation curves, the point on the curves that indicates their surface temperatures. Its gradient is negative, indicating that there is an inverse relationship between the peak wavelength and the maximum intensity of the radiation intensity at the peak wavelength. Wien's displacement law states that the black body radiation curve for different temperature peaks at a wavelength inversely proportional to the temperature of the star.

(b) If we assume that the two vertical dashed lines represent the visible spectrum of light, then the Sun would be the star whose peak frequency was closest to the centre of these two lines. That is, star Q.

(c) Star S

(d) Star P

(e) None of the radiations from star U are in the visible spectrum, so it is unable to be seen.

8.6.1.1 An H-R diagram is a plot of the luminosity of stars against their temperature, which also represents their colour ranges and spectral classes.

8.6.1.2 That the stars were arranged in obvious patterns and groups on the diagram.

8.6.1.3 Both colour and spectral class are determined by the temperature of the star.

8.6.1.4 Main sequence stars can have luminosities across the whole range. Red giants tend to have luminosities ranging from 100 times that of the Sun to 1000 times that of the Sun. Their luminosity is greater than their temperature would indicate, but their surface area is huge. White dwarfs have luminosities ranging about equal, to 10 000 times less than that of the Sun. Given their temperatures, these luminosities compare to equal temperature main sequence stars. This is due to their very small size.

8.6.1.5 White dwarfs range (approximately) between 6000 K and 40 000 K, red giants from 2500 K to 6000 K, and supergiants from 2500 K to 25 000 K.

8.6.1.6 For main sequence stars, the more luminous they are, the more massive they are. White dwarfs are the least massive of the stars.

8.6.1.7 (a) Main sequence stars

(b) Blue giants

(c) Red supergiants

(d) Red giants

(e) White dwarfs

(f) Red dwarfs

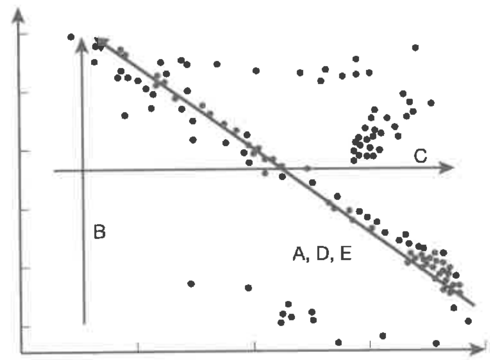
(g) (i) At E (ii) At A

(iii) At H (iv) At C

(v) At A (vi) At E

(h) At G

8.6.1.8



8.6.2.1 A main sequence star.

8.6.2.2 Red giant stars are more luminous than our Sun – they give out much more total energy – but, they are also much cooler than the Sun. Therefore they must be significantly larger.

8.6.2.3

Star type	Energy producing process(es)
Main sequence	Hydrogen fusion
Red giant	Helium fusion
Red supergiant	Helium fusion
Blue supergiant	Helium fusion
Red dwarf	Hydrogen fusion (they are main sequence stars)
White dwarf	No energy source, only radiating energy due to temperature

8.6.2.4 A temperature of around 10^7 K at the core of a star is required to initiate hydrogen fusion. Below this, stars will simply be radiating energy indicative of their surface temperature. They will have no internal fusion energy source.

8.6.2.5 (a) Main sequence stars are all characterised by producing energy by core hydrogen fusion.

(b) Red giants and larger, hotter stars will have a core which provides energy through helium fusion.

(c) All main sequence stars, regardless of size, produce energy by hydrogen fusion.

(d) If the mass of a non main sequence star is greater than 5 solar masses, then carbon fusion and fusion of heavier elements will occur at the core with helium and hydrogen fusion continuing in the outer core layers.

8.6.2.6 The size of a star is determined by the equilibrium that exists between the thermal expansion caused by heat energy generated at its core, known as radiation pressure (expanding its size), and gravitational forces which contract its mass towards the centre. When these two factors balance each other, the size of the star is constant.

8.6.2.7 Hotter main sequence stars are hotter because they are fusing more core hydrogen more rapidly than cooler stars. They will therefore deplete their core hydrogen more quickly and change to helium fusion, which takes them off the main sequence in terms of classification.

8.6.2.8 Because of their small size, not as much helium collects in a central core, because much of it is carried by convection currents towards the surface and space. Because of this they will burn a larger proportion of their hydrogen before the helium concentration in their core increases to the point that hydrogen fusion ceases and helium fusion starts and therefore before leaving the main sequence.

8.6.2.9 When hydrogen fusion stops in a main sequence star, there is less radiative pressure to counteract gravity, so it shrinks inwards, compressing the high concentration helium in its core. This causes the core temperature to rise, and when it reaches around 10^8 K, a sudden, massive fusion of core helium occurs releasing in an instant more energy than that produced normally by the Milky Way Galaxy. This huge release of energy is known as the 'helium flash'. After commencing helium fusion in this way, the star then expands rapidly, cools, and helium fusion continues at a 'normal' rate.

8.6.3.1 The gas cloud must be sufficiently dense and be sufficiently massive so that high gravitational forces are exerted in its core, producing the pressure and temperature required to initiate fusion.

8.6.3.2 A nebula.

8.6.3.3 As the particles in a nebula move closer together under gravitational attraction (referred to also as accretion of particles) their temperature increases and the number of ionised particles therefore increases. The system will acquire its own luminosity and a protostar is formed. Further accretion occurs and the pressure and temperature at the centre of the protostar becomes large enough to strip all atoms of their electrons and a central plasma is formed. When the temperature rises sufficiently, hydrogen fusion commences. A main sequence star is born.

8.6.3.4 Its mass.

8.6.3.5 Protostars with less than 0.08 solar masses do not have enough mass to develop the pressures and temperatures needed to initiate hydrogen fusion. They will simply contract to a brown dwarf. Protostars with masses greater than 100 solar masses develop so much internal temperature and pressure that they blow apart and eject enormous amounts of matter thereby disrupting the formation of a star.

8.6.3.6 Its mass. Stars with masses between 4 and 8 solar masses will form red supergiants. Less than 4 solar masses results in red giants.

8.6.3.7 In a red giant helium is fused. If the mass is less than 0.5 solar masses, then the helium core does not fuse and is surrounded by a shell of hydrogen fusion. If the mass is between 0.5 and 5 solar masses, the red giant will contract until the temperature and pressure rises enough to start fusing helium. Above 5 solar masses it is thought that the star fuses different elements in 'shells' (neon, oxygen, carbon, silicon) with the core forming iron.

8.6.3.8 The star, probably a red supergiant, fuses elements higher than helium in shell burning and explodes as a supernova. The core matter collapses to form a neutron star.

8.6.3.9 Neutron stars have a strong magnetic field and stars rotate rapidly. Charged particles accelerated in the large magnetic field produce directed beams of radiation which sweep across Earth and can be detected.

8.6.3.10 The core density of a star is limited by a quantum effect known as electron degeneracy. Essentially, contraction of a star cannot continue past the point where electrons are packed as closely together as they can be. This sets an upper limit on the mass of a star that can simply degenerate into a white dwarf. This limit is the Chandrasekhar limit.

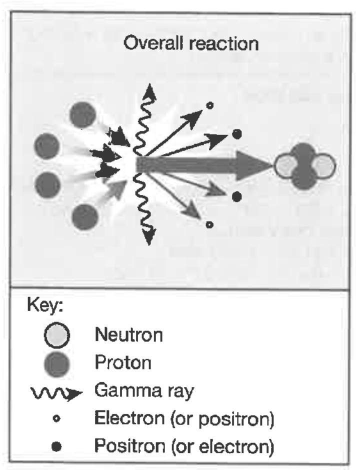
8.6.3.11 Stars with masses less than 8 solar masses usually end up as white dwarfs, because they eject most of their mass into space as they nova in the final stage of their life as a red giant. The core mass left is usually under the Chandrasekhar limit.

8.6.3.12
(a) (i) Red giant.
(ii) White dwarf.
(b) Hydrogen concentration in its core will have reduced significantly as it has fused to form helium. Core fusion of helium will commence, producing more energy which causes it to expand.
(c) The luminosity will increase as its surface area increases.
(d) F is the region on the H-R diagram where white dwarfs are found and the Chandrasekhar limit suggests that stars with masses less than 1.4 solar masses will become white dwarfs.

8.6.3.13
(a) Star Q will most likely become a white dwarf, while P will become a neutron star or a black hole.
(b) Its position on the H-R diagram would suggest P has a much greater mass than this. However, if in the process of becoming a red supergiant and maybe a supernova, if it loses enough mass it could end as a white dwarf.

8.7.1.1
A ^1_1H
B ^3_2He
C ^1_1H
D ^7_4Be
E ^4_2He
F ^1_1H
G ^8_4Be
H ^8_4Be
I 2^4_2He

8.7.1.2
(a) $^0_{-1}e + ^0_1\bar{e} \rightarrow \gamma$
(b) Antielectron

8.7.1.3
(a)


(b) $4^1_1H \rightarrow ^4_2He + 2^0_1\bar{e} + 2v_e + 2\gamma$
(c) The energy given out.

8.7.1.4 Main sequence stars are the stars that fuse hydrogen as their main source of energy – that is the reason for their classification. Stars larger in size than the Sun have core temperatures which are too high for the PP reactions and they fuse hydrogen via the CNO cycle.

8.7.1.5 C

8.7.1.6 D

8.7.1.7 A

8.7.1.8

Step 1: $^1_1H + ^1_1H \rightarrow ^2_1H + ^0_1\bar{e} + v$

Step 2: (W) $^2_1H + ^1_1H \rightarrow ^3_2He + \gamma$

Step 3: (X) $^3_2He + ^4_2He \rightarrow ^7_4Be + \gamma$

Step 4: (Y) $^7_4Be + ^0_{-1}e \rightarrow ^7_3Li + v$

Step 5: (Z) $^7_3Li + ^1_1H \rightarrow ^4_2He + ^4_2He$

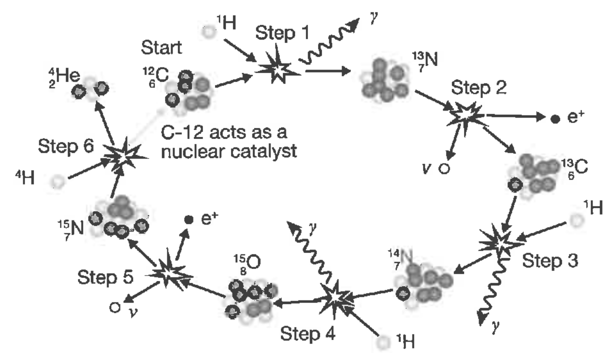
Particle	Mass (μ)
^1_1H	1.007825
^2_1H	2.014102
^3_2H	3.016029
^4_2H	4.002603
^7_4Be	7.016929
^7_3Li	7.016003
$^0_{-1}e$	0.0005486
$^0_{+1}e$	0.0005486

8.7.1.9 (a) Reaction 1: 0.0009994 *u*
Reaction 2: 0.005898 *u*
Reaction 3: 0.001703 *u*
Reaction 4: 0.0014746 *u*
Reaction 5: 0.018622 *u*

(b) Total mass defect for the 5 reactions is 0.0257478 *u*

(c) Total mass defect is equivalent to 23.98 MeV (= mass defect × 931.494)

8.7.2.1 (a), and (b) and (c)



8.7.2.2

Step 1: Nuclear equation $^{12}_6C + ^1_1H \rightarrow ^{13}_7N + \gamma$ **Mass defect** = 13.005738 – (12.000000 + 1.007825) = 0.002087 *u* = 0.002087 × 1.660 × 10^{-27} = 3.4644 × 10^{-30} kg **Energy released (MeV and J)** = 0.002087 × 931.494 = 1.944 MeV = 1.944 × 10^6 × 1.6 × 10^{-19} = 3.11 × 10^{-13} J **Check** $E = mc^2$ = 3.4644 × 10^{-30} × 9 × 10^{16} = 3.11 × 10^{-13} J (Difference = rounding off errors)	**Step 2: Nuclear equation** $^{13}_7N + ^{13}_6C \rightarrow ^0_1\bar{e} + \nu_e$ **Mass defect** = (13.003355 + 0.0005486) – 13.005738 = 0.001834 *u* = 0.001834 × 1.660 × 10^{-27} = 3.0451 × 10^{-30} kg Energy released (MeV and J) = 0.001834 × 931.494 = 1.71 MeV = 1.71 × 10^6 × 1.6 × 10^{-19} = 2.73 × 10^{-13} J **Check** $E = mc^2$ = 3.0451 × 10^{-30} × 9 × 10^{16} = 2.74 × 10^{-13} J (Difference = rounding off errors)
Step 3: Nuclear equation $^{13}_6C + ^1_1H \rightarrow ^{14}_7N + \gamma$ **Mass defect** = 14.003074 – (13.003355 + 1.007825) = 0.008106 *u* = 0.008106 × 1.660 × 10^{-27} = 1.35456 × 10^{-29} kg **Energy released (MeV and J)** = 0.008106 × 931.494 = 7.55 MeV = 7.55 × 106 × 1.6 × 10^{-19} = 1.21 × 10^{-12} J **Check** $E = mc^2$ = 1.35456 × 10^{-29} × 9 × 10^{16} = 1.22 × 10^{-12} J (Difference = rounding off errors)	**Step 4: Nuclear equation** $^{14}_7N + ^1_1H \rightarrow ^{15}_8O + \gamma$ **Mass defect** = 15.003056 – (14.003074 + 1.007825) = 0.007843 *u* = 0.007843 × 1.660 × 10^{-27} = 1.30194 × 10^{-29} kg **Energy released (MeV and J)** = 0.007843 × 931.494 = 7.31 MeV = 7.306 × 10^6 × 1.6 × 10^{-19} = 1.17 × 10^{-12} J **Check** $E = mc^2$ = 1.30194 × 10^{-29} × 9 × 10^{16} = 1.17 × 10^{-12} J (Difference = rounding off errors)
Step 5: Nuclear equation $^{15}_8O + ^{15}_7N \rightarrow ^0_1\bar{e} + \nu_e$ **Mass defect** = (15.000109 + 0.0005486) – 15.003056 = 0.0023984 *u* = 0.0023984 × 1.660 × 10^{-27} = 3.98134 × 10^{-30} kg **Energy released (MeV and J)** = 0.0023984 × 931.494 = 2.23 MeV = 2.23 × 10^6 × 1.6 × 10^{-19} = 3.57 × 10^{-13} J **Check** $E = mc^2$ = 3.98134 × 10^{-30} × 9 × 10^{16} = 3.58 × 10^{-13} J (Difference = rounding off errors)	**Step 6: Nuclear equation** $^{15}_7N + ^1_1H \rightarrow ^{12}_6C + ^4_2He$ **Mass defect** = 12.000000 + 4.002603 – (15.000109 + 1.007825) = 0.005311 *u* = 0.005311 × 1.660 × 10^{-27} = 8.84946 × 10^{-30} kg **Energy released (MeV and J)** = 0.005311 × 931.494 = 4.95 MeV = 5.88 × 10^6 × 1.6 × 10^{-19} = 9.41 × 10^{-13} J **Check** $E = mc^2$ = 8.84946 × 10^{-30} × 9 × 10^{16} = 7.96 × 10^{-13} J (Difference = rounding off errors)

8.8.1.1 (a) D
(b) It enabled them to observe the cathode rays for a much longer period of time.

8.8.1.2 (a) B
(b) Cathode rays, beta particles.

8.8.1.3 (a) A
(b) Waves cannot be charged, so if cathode rays are charged, then they must be exhibiting particle nature.

8.8.1.4 (a) B
(b) Cathode rays were deflected by magnetic fields and this indicated they must be charged, and therefore must be particles as waves cannot be charged. However, their apparent non-deflection by electric fields indicated to these scientists that cathode rays were not charged, and therefore could be waves.

8.8.1.5 (a) D
(b) It showed that they were charged and therefore could not be waves – they must be particles.

8.8.1.6 (a) D
(b) He succeeded in deflecting them by an electric field (better equipment than previous scientists) and so proved that they were charged and therefore had to be particles as electromagnetic waves cannot carry a charge.

8.8.1.7 (a) C
(b) Thomson in his experiment to determine the ratio of charge to mass of cathode rays. He was able to produce a much stronger electric field and a better vacuum and showed that they were deflected by electric fields.

8.8.1.8 A

8.8.1.9 C (Energy can be transferred by cathode rays.)

8.8.1.10 (a) A
(b) If they were charged particles then they should have been deflected by both magnetic and electric fields. Apparent non-deflection by electric fields left open the idea that perhaps they were waves and that the experiment with magnetic fields was wrong.

8.8.1.11 B

8.8.1.12 (a) D
(b) They are blocked or absorbed by solid objects.

8.8.1.13 (a) D
(b) They are negatively charged.

8.8.1.14 B

8.8.1.15 D

8.8.1.16 C

8.8.1.17 C

8.8.1.18 (a) A
(b) They are not electromagnetic, they do not produce high voltage electric fields, they do have mass and therefore they are affected by gravitational fields, they can be refracted but these tubes do not show this, they are electrons, but these tubes do not show this.

8.8.1.19 (a) B
(b) B and C – modern tubes have stronger electric fields and better vacuums and so deflection by electric fields can be detected.

8.8.2.1 A cathode ray tube consists of an evacuated glass tube with an electrode at each end (usually). The cathode is often photoemitting.

8.8.2.2 (a) The vacuum tube.
(b) It allowed the cathode rays to travel further and therefore be observed for a longer period of time.

8.8.2.3 According to the scientists of the 1800s, the Maltese cross tube, the deflection by magnetic fields and the paddle wheel tube all indicated cathode rays were particles.

8.8.2.4 The tube with the electric plates (which did not cause a deflection in cathode ray beams) confused scientists of the 1800s, and caused them to suspect cathode rays could be waves.

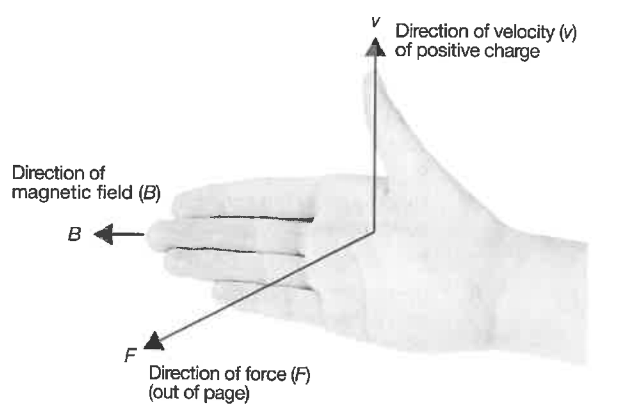
8.8.2.5 If magnetic fields deflected them, this indicated they were charged and therefore particles (waves cannot be charged). However, when their (not strong enough) electric fields did not deflect (deflection was too small to be seen), this started them thinking that maybe the rays were uncharged and perhaps waves.

8.8.2.6

Discharge tube	Observations	Conclusions drawn from each observation
Maltese cross	1. Cast a sharp shadow of the cross on the end of the tube. 2. Rays were blocked by the cross.	Rays travelled in straight lines. Rays were absorbed by the metal in the cross.
Fluorescent display	1. Fluorescent line was straight. 2. Line glowed on the screen. 3. Beam was deflected by a magnetic field.	Rays travelled in straight line. They caused fluorescence. They were charged, and therefore must be particles.
Paddle wheel	1. Caused the paddle wheel to move.	Have momentum, therefore must have mass, therefore must be particles.
Electric plates	1. Ray not deflected. 2. Rays travel in straight line.	Rays not charged, perhaps waves. Travel in straight lines.

8.8.2.7 (a) The bottom plate is positive.
(b) Magnetic field would need to be vertically out of the page.
(c) The cathode is electrode A.

8.9.1.1 By using the right hand rule – your diagram should label the extended fingers as the direction of magnetic field, your thumb as the direction of motion of positive charge and the direction in which the palm of your hand points as the direction of the force on the charged particles.



8.9.1.2 Uniform circular motion.

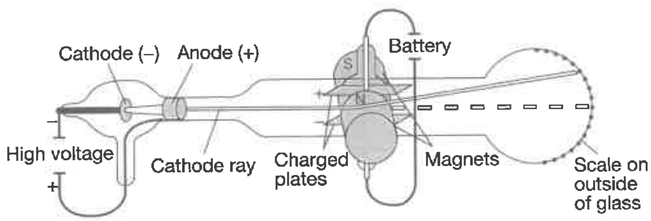
8.9.1.3 Because a charged particle moving in a magnetic field undergoes uniform circular motion, the force acting on it must also be a centripetal force – hence the magnetic force equation can be equated to the equation for centripetal force.

8.9.1.4 Thomson found the ratio to be about 1800 times greater than that of a hydrogen ion. From this, because neither charge nor mass could be found, he could conclude that:

- The charge on cathode rays was 1800 times larger than the charge on a hydrogen ion; or
- The mass of cathode ray particles was 1800 times less than that of a hydrogen ion.

From these results, Thomson assumed that the charge on them was similar in size to that on a hydrogen ion and calculated their mass to be 9.11×10^{-31} kg. He also assumed they were the particles predicted by George Stoney in 1894 to be part of an atom and responsible for electricity.

8.9.1.5 Thomson used the apparatus shown, deflecting the cathode rays either up or down by the parallel plates D and E, then cancelling this deflection using the magnetic field produced by the coils.



The electric force on the particles could be represented by:

$F_E = qE = \frac{qV}{d}$

And the magnetic field by:

$F_B = bqv = \frac{mv^2}{r}$

The velocity of the charges could be found knowing that, when they passed through the electric and magnetic fields undeflected, so:

$F_E = qE = F_B = Bqv$ and $v = \frac{E}{B}$

Also, the work done by the electric field in deflecting the cathode rays is given by:

$W = qV = = \frac{1}{2}mv^2 = \frac{\frac{1}{2}mE^2}{B^2}$

Rearranging these we get:

$\frac{q}{m} = \frac{E^2}{2VB^2}$

Since E, B and V are all measurable quantities, Thomson was able to calculate the ratio of the charge to mass of cathode rays.

8.9.1.6 (a) 8×10^4 V m^{-1}
(b) 4.0 T
(c) 1.31×10^{-15} kg

8.9.1.7 (a) B
(b) He calculated the speed of the cathode rays by equating the two forces acting on them. $F = qE = Bqv \sin\theta$, and hence $v = \frac{E}{B}$.

8.9.1.8 A (*Note:* Both q and m are constants so any choice with either of these in it (all the incorrect ones) must be wrong. In the experiment, Thomson had various strength magnetic fields which caused a deflection of the cathode rays (that is, the radius of curvature depended on the magnetic field strength). He then adjusted the electric field to cancel the deflection caused by the magnetic field (i.e. the strength of the electric field depended on the magnetic field strength)).

8.9.1.9 C
8.9.1.10 D
8.9.1.11 B
8.9.1.12 C (The forces on the electron due to the magnetic field and the electric field must be equal in magnitude and opposite in direction for the electron to pass straight through. Therefore from $Bqv = \frac{qV}{d}$, V calculates at 200 V and must be directed down the page (electron moves against an electric field) since the magnetic field will deflect the electron downwards (RHPR).)

8.9.1.13 A
8.9.1.14 B
8.9.1.15 A
8.9.1.16 B From $Bqv = qE$, $B = \frac{E}{v} = \frac{400}{100} = 1.33$
From $Bqv = \frac{mv^2}{r}$ (having measured r), $\frac{q}{m} = \frac{E}{rB^2}$

8.10.1.1 (a) The purpose of the oil drop experiment was to determine the charge on an electron.
(b) A closed chamber with transparent sides was fitted with two parallel metal plates to provide an upward force on the charged oil drops due to the electric field between them. An atomiser sprayed a fine mist of oil droplets into the top portion of the chamber which were charged by hitting them with ionising radiation. Gravity pulls the drops downwards and some passed through a small hole in the top metal plate. The electric field was varied until the upward and gravitational forces were in balance. The charge on the drop was calculated.
(c) The electric force on each oil drop is given by $F = \frac{qV}{d}$.
The gravitational force on each drop is $F = mg$.
If the voltage is adjusted so that the downward motion of the drops due to gravity is balanced by an upward electric field force, then we have:
$F_E = F_G = mg = \frac{qV}{d}$
Therefore $q = \frac{mgd}{V}$

8.10.1.2 He documented all his results and proposed that the lowest common denominator of them indicated the minimum possible charge, and therefore the charge on the electron.

8.11.1.1 The scattering of alpha particles by a thin gold foil.

8.11.1.2 The alpha particles were produced by the decay of a sample of radioactive radium and were directed through a vacuum and on to a thin gold foil which caused the scattering. The positions of the scattered particles were seen as small flashes of light, which were detected using a microscope that could be rotated around the foil. The alpha particle scattering was usually only one or two degrees.

8.11.1.3 (a) Geiger and Marsden obtained scattering at very large angles and it appeared that some alpha particles bounced straight back from the sheet of gold foil.
(b)