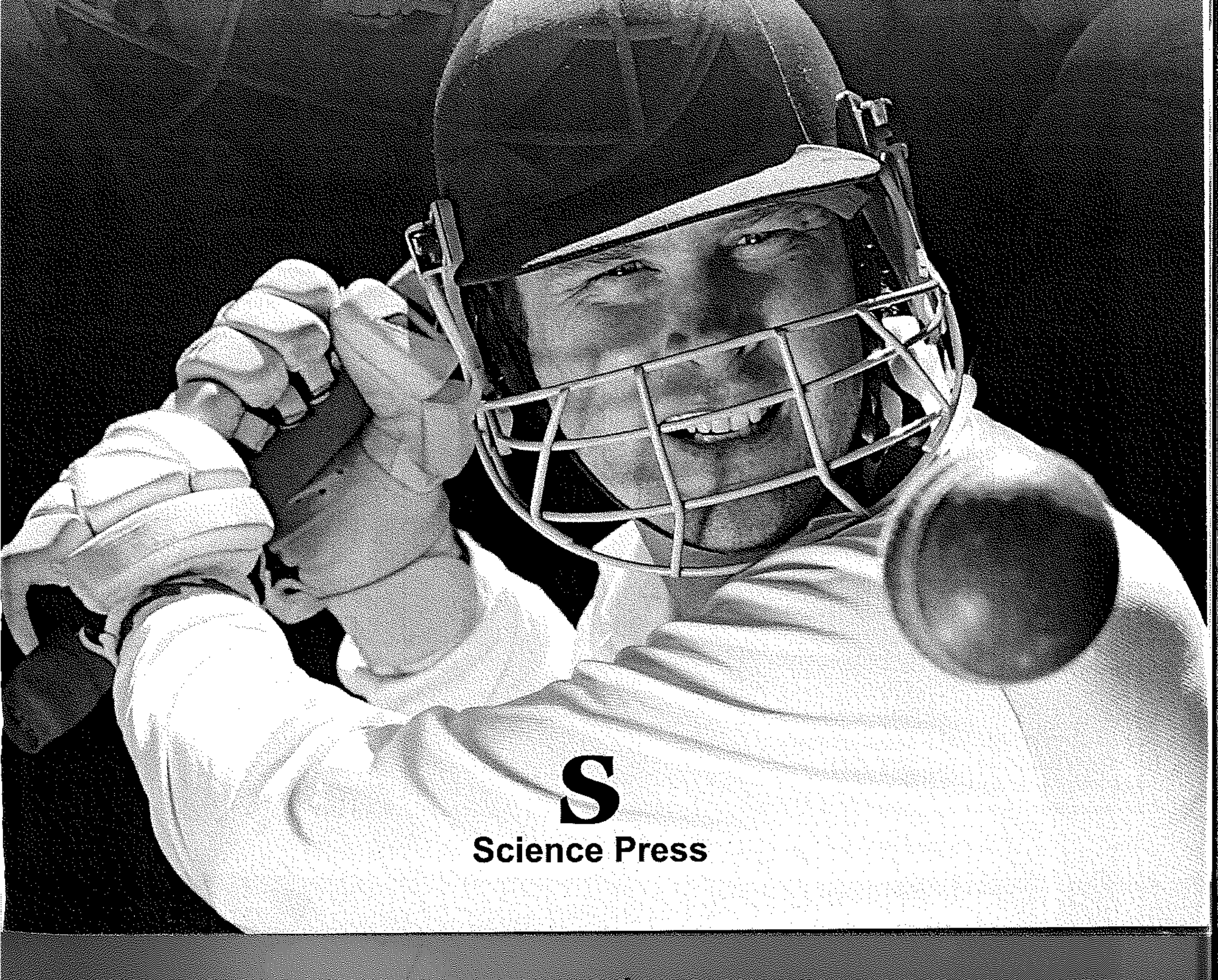
Q+A Questions and Answers

NATIONAL PHYSICS

Unit 4 Revolutions in Modern Physics

Brian Shadwick



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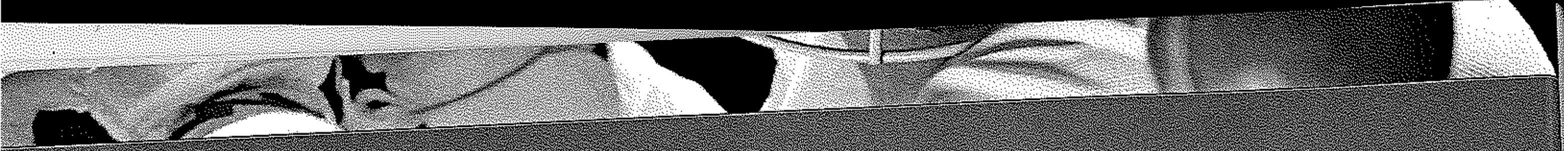
Contents



Words to Watch

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.

Questions and Answers

Special Relativity

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SET 1 Frames of Reference

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.

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.

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.

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.

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 the tie seemed to lean towards the windows of the train.
   (iii) The the tie seemed to lean towards the centre aisle.
   (iv) The 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.

6. You regain consciousness some time after an asteroid hits 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.

7. 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.

SET 2 Galilean Transformations

1. (a) What is a Galilean transformation?

(b) When do we use Galilean transformations?

(c) When can't we use Galilean transformations?

(d) What do we use when we cannot use Galilean transformations?

2. Object X is moving north at 45 m s^{-1}. Object Y is moving south at 60 m s^{-1}. Object Z is moving north at 25 m s^{-1}. Calculate the velocity of:

(a) X relative to Y.

(b) X relative to Z.

(c) Y relative to X.

(d) Y relative to Z.

(e) Z relative to X.

(f) Z relative to Y.

3. Object X is moving north at 45 m s^{-1}. Object Y is moving east at 60 m s^{-1}. Object Z is moving south at 25 m s^{-1}. Calculate the velocity of:

(a) X relative to Y.

(b) X relative to Z.

(c) Y relative to X.

(d) Y relative to Z.

(e) Z relative to X.

(f) Z relative to Y

4. From your answers to Questions 2 and 3 above, identify the relationship between the velocity of object A relative to object B and the velocity of object B relative to object A.

5. Michael, who can swim at 1.6 m s^{-1} in still water, dives into a river at X and swims towards Y directly opposite in a northerly direction. The river flows at 0.8 m s^{-1} east.

Calculate the velocity of:

(a) The water relative to the bank.

(b) Michael relative to the water.

(c) Michael relative to the bank.

(d) Imagine that Michael has to end up at Y rather than being carried downstream by the river. In what direction would he need to swim in order to accomplish this?

(e) What would be Michael's speed relative to X in situation (d)?

6. A rowing team can row a boat at 2.5 m s^{-1} in still water. They row on a river flowing at 0.5 m s^{-1}.

(a) Calculate the velocity of the boat relative to the banks of the river if the team rows:

(i) With the flow.

(ii) Against the flow.

(b) Calculate the velocity of the boat relative to the water if the team rows:

(i) With the flow.

(ii) Against the flow.

7. A plane is flying north at 300 km h^{-1} when it hits an 80 km h^{-1} wind from the south-east. Calculate:

(a) The velocity of the wind relative to the ground.

(b) The velocity of the wind relative to the plane.

(c) The velocity of the plane relative to the ground after it encounters the wind.

(d) The new course the plane must fly to head north.

(e) The speed of the plane when it is heading north again.

8. A boat, capable of travelling at 3.5 m s^{-1} in still water sets out to travel from X to Y a distance of 800 m due north. A current flows from the west at 0.7 m s^{-1}. Calculate:

(a) The direction the boat takes to move directly from X to Y.

(b) Its speed relative to the water.

(c) Its speed relative to the ground.

(d) How long it will take to make the journey.

SET 3 Constancy of the Speed of Light

1. (a) Describe what is meant by a frame of reference.
   (b) Give an example of a frame of reference that is common for you.

2. Using the example of the ideas of ancient astronomers, discuss why it is important for us to consider our frame of reference when we make measurements.

3. (a) Distinguish between inertial and non-inertial frames of reference, and give an example of each.
   (b) How would we know if we were in an inertial or a non-inertial frame of reference?
   (c) You have been kidnapped and wake to find yourself in a totally closed cabin in a spaceship. How can you work out if the spaceship is moving or stationary? Explain the physics behind your answer.

4. (a) What is inertia?
   (b) Teachers often talk about inertial forces. Inertial forces are 'fictitious' forces. That is, they do not actually exist. Explain this statement.
   (c) In which frames of reference do we notice these inertial forces acting, and in which frames do inertial forces not act? Explain why.
   (d) Outline the connection between the feeling astronauts in orbit have of being 'weightless' and frames of reference. Explain why.

5. You regain consciousness some time after a meteor hits your spaceship. You are unaware of any movement of the craft. You wonder if you are still on course and moving towards Andromeda galaxy. Suddenly another ship shoots past you, seemingly parallel to your path and moving straight ahead. Give five interpretations of the movements of your spaceship and/or the other spaceship which would explain this observation.

6. An astronaut tied her mascot to a string and hung it from the ceiling. One day she noticed that, instead of hanging straight down, it hung at an angle.
   (a) Account for this.
   (b) Identify the frame of reference the mascot is in when it hangs straight down. Justify your answer.
   (c) Identify the frame of reference when the mascot hangs at an angle. Justify your answer.

7. (a) Describe the thought experiment Einstein carried out which led to his proposal that the speed of light was constant.
   (b) What were the two possible outcomes for this thought experiment?
   (c) What conclusion did Einstein make for this experiment?
   (d) What was Einstein's reasoning for this conclusion?

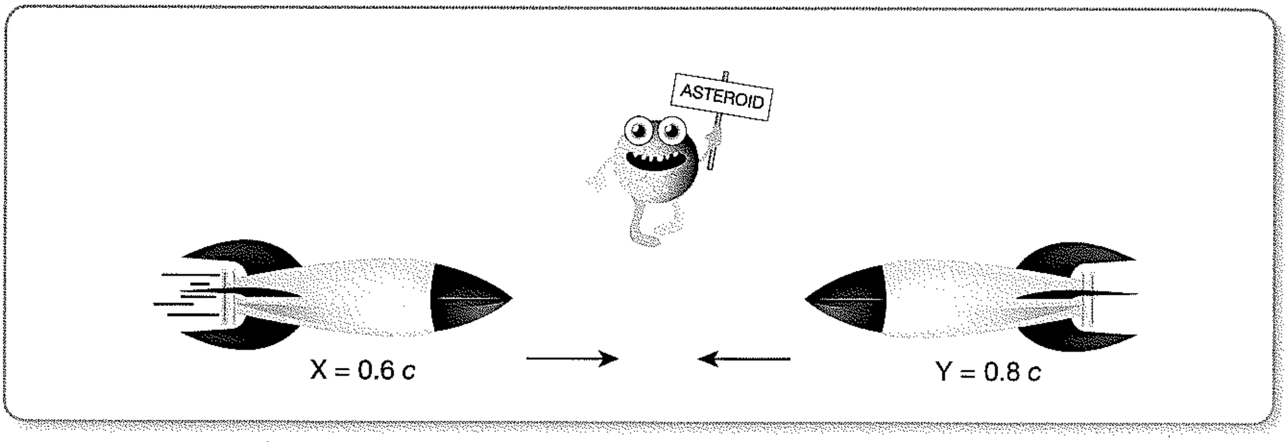
8. (a) What are the advantages of thought experiments?
   (b) What are the limitations of thought experiments?
   (c) Why was Einstein's work on special relativity derived from thought experiments rather than from real experiments?
   (d) Discuss whether or not thought experiments have a place in the methodology of scientific discovery.

9. (a) Recall the two postulates of Einstein's theory of special relativity.
   (b) In what way did these postulates change the scientific thinking in the early 1900s?

10. (a) According to Newton's physics, what is the maximum speed for any object, including light?

(b) According to Einstein's physics, what is the maximum speed for any object, including light?

11. Two spaceships are travelling through space towards each other. X is travelling at 0.6 c while Y is travelling at 0.8 c as shown in the diagram. Asteroid man watches them from far away.



X sends a radio message to Y.

(a) At what speed does the radio message travel to Y according to the observer on the asteroid?

(b) At what speed does the radio message reach Y?

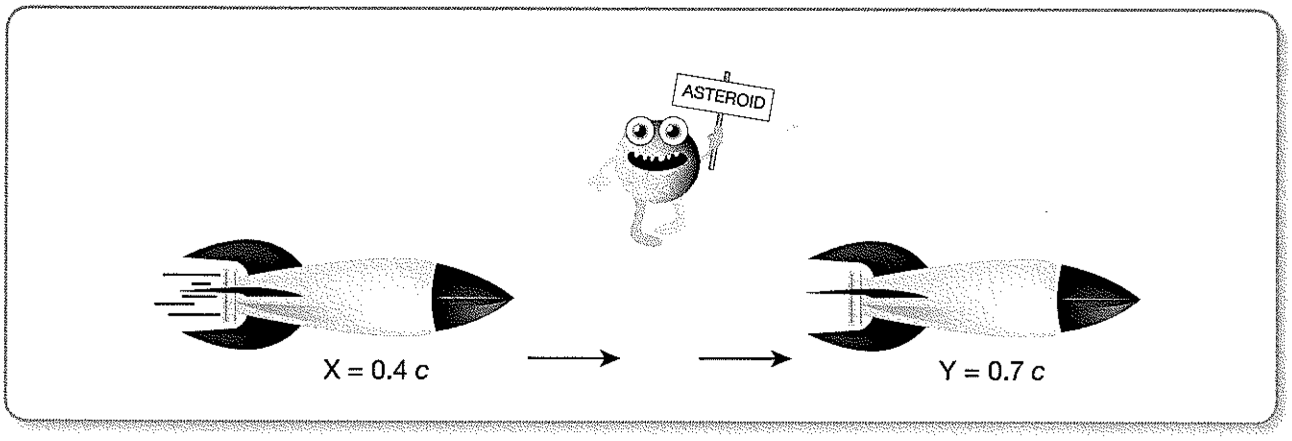
(c) At what speed does the radio message travel away from X?

(d) At what speed does the radio message travel to Y according to the pilot of X?

(e) At what speed does the radio message travel to Y according to the pilot of Y?

(f) Asteroid man also picks up the radio signal. At what speed does the signal reach him?

12. Two spaceships are travelling through space. X is travelling at 0.4 c while Y is travelling at 0.7 c in the same direction as shown in the diagram. Asteroid man watches them from far away.



Y sends a radio message to X.

(a) At what speed does the radio message travel to X according to the observer on the asteroid?

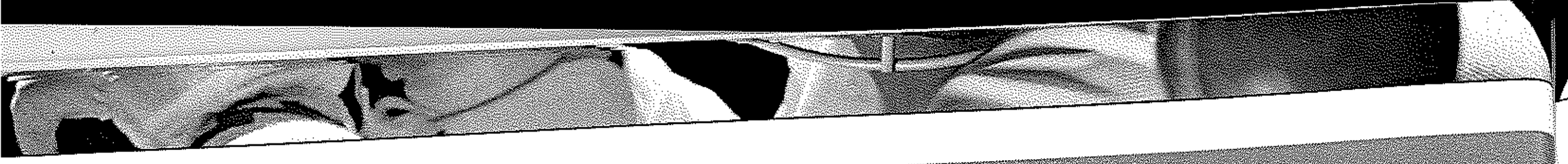
(b) At what speed does the radio message reach X?

(c) At what speed does the radio message travel away from Y?

(d) At what speed does the radio message travel to X according to the pilot of X?

(e) At what speed does the radio message travel to X according to the pilot of Y?

(f) Asteroid man also picks up the radio signal. At what speed does the signal reach him?

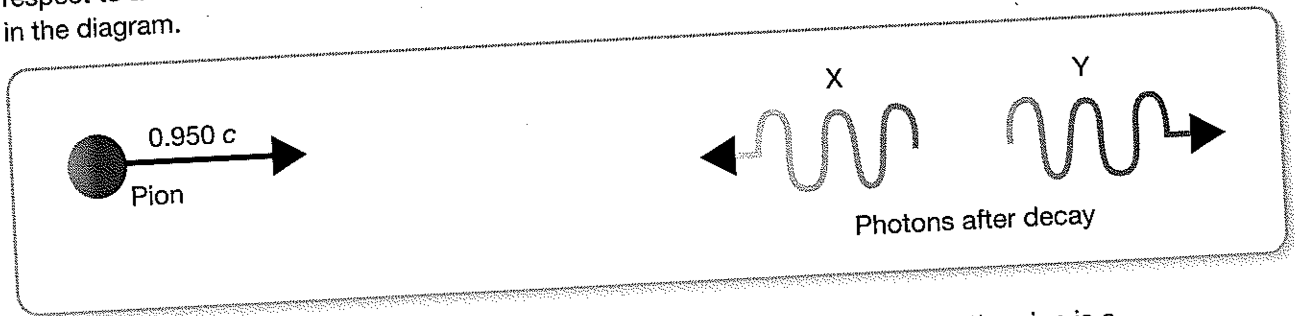


SET 4 Galilean and Relativistic Transformations

1. The way we analyse motion using Newtonian concepts is referred to as making a Galilean transformation. Describe what mathematics we use to make Galilean transformations.

2. In what situations do Galilean transformations not hold? Explain your answer.

3. A pion is an unstable particle that decays into two photons. A particular pion, travelling at 0.950 c with respect to an observer at rest, decays into two photons, X and Y travelling in opposite directions as shown in the diagram.



The speed of both photons as measured by the observer at rest with respect to the pion is c.

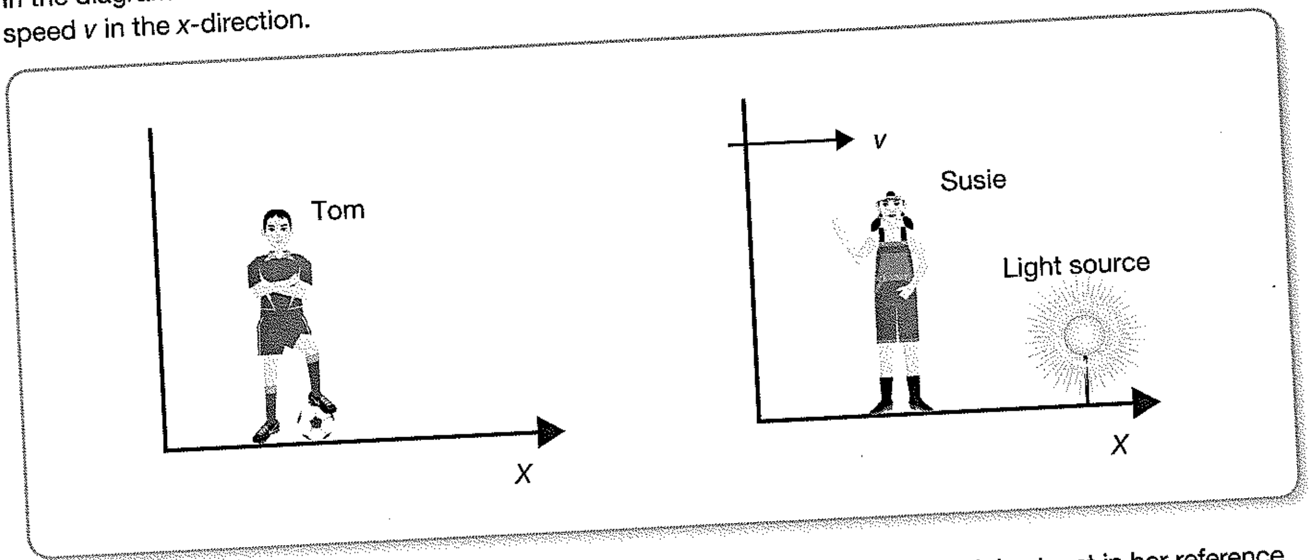
(a) Calculate the velocity of photon X with respect to the observer using Galilean kinematics.

(b) Calculate the velocity of photon Y with respect to the observer using Galilean kinematics.

(c) What will be the velocity of photon X with respect to the observer according to Einstein's postulates?

(d) What will be the velocity of photon Y with respect to the observer according to Einstein's postulates?

4. In the diagram below, Tom's reference frame is at rest and Susie's is moving away from him with constant speed v in the x-direction.



Susie carries out an experiment to measure the speed of light from a source which is at rest in her reference frame. The value of the speed that she obtains is c.

(a) Apply a Galilean transformation to find the value that Tom would obtain for the speed of light from Susie's source.

(b) State the value that Tom would be expected to obtain for the speed of light from Susie's source based on Einstein's postulates.

5. Einstein's postulates also include the concept that nothing can travel faster than the speed of light. This includes the relative velocity of high speed objects travelling towards each other.

When objects travelling at relativistic speeds approach each other, a simple Galilean transformation does not work either. Relativistic mathematics provides us with the following formula.

For objects approaching each other:

$$\text{Relative velocity} = \frac{(v_1 + v_2)}{\left(1+\frac{v_1 v_2}{c^2}\right)}$$

(a) Two spaceships approach each other, both travelling at 0.75 c. According to Galilean transformations, what is the speed of each spaceship relative to the other?

(b) What are their relative speeds according to relativistic mathematics?

(c) If they approach each other, both travelling at the speed of light, what will be their relative speeds according to Galilean transformations?

(d) What are their relative speeds according to relativistic mathematics?

6. Two spaceships approach each other at 0.8 c. What is their speed relative to each other:

(a) According to Galilean transformation? (b) According to relativistic mathematics?

7. When the two objects (including radio messages) are travelling at relativistic speeds in the same direction, the simple Galilean transformation does not work either. The relativistic mathematics formula in this situation is as follows.

For objects travelling in the same direction:

$$\text{Relative velocity} = \frac{(v_1 - v_2)}{\left(1-\frac{v_1 v_2}{c^2}\right)}$$

A spaceship travelling at 0.6 c transmits a message to another spaceship which is moving towards it at 0.4 c.

(a) Determine the speed of the message relative to the spaceship.

(b) Calculate the speed at which the second ship receives the message.

(c) What do your answers help prove about the speed of electromagnetic radiation?

8. Ship X is travelling through space at 0.4 c. Ship Y is travelling in the same direction as X at 0.7 c.

(a) Determine the speed of Y relative to X. (b) Determine the speed of X relative to Y.

9. Two protons in the Hadron Collider approach each other at 0.95 c. What will be the combined speed at which they collide with each other according to:

(a) Newton? (b) Einstein?

10. Spaceship X, travelling at 0.8 c, sends a radio message to spaceship Y, travelling in the same direction at 0.5 c, and to spaceship Z, travelling in the opposite direction at 0.2 c.

(a) Calculate the speed of spaceship X relative to spaceship Y.

(b) Calculate the speed of spaceship Y relative to spaceship X.

(c) Calculate the speed of spaceship X relative to spaceship Z.

(d) Calculate the speed of spaceship Z relative to spaceship X.

(e) Calculate the speed of spaceship Y relative to spaceship Z.

(f) Calculate the speed of spaceship Z relative to spaceship Y.

(g) Calculate the speed of the radio message relative to spaceship X.

(h) Calculate the speed of the radio message relative to spaceship Y.

(i) Calculate the speed of the radio message relative to spaceship Z.

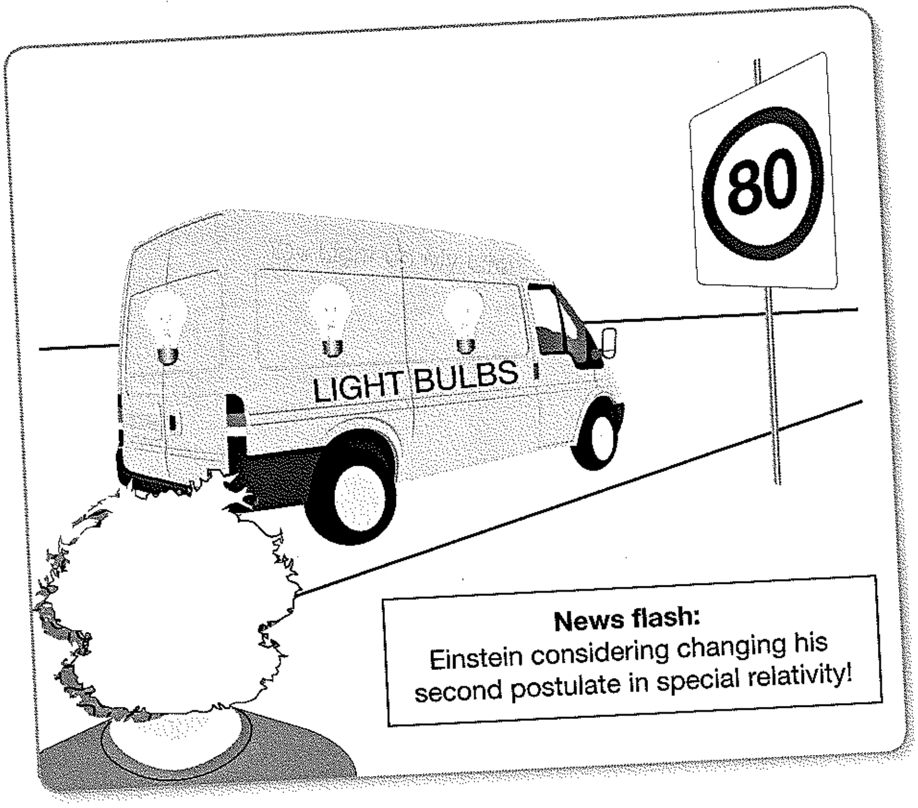
SET 5 Consequences of Einstein's Postulates

1. State the two postulates that Einstein made as a result of his developing his theory of special relativity.

2. (a) What are 'standard' units of measure?
(b) Why do we need standards of measure?
(c) What does the phrase 'SI units' refer to?
(d) Why do we use these?
(e) The standards for the SI units have changed over the years. Suggest why these changes were made.
(f) The last changes to SI units were made following Einstein's postulate on the constancy of the speed of light. Why were these changes made?
(g) In what way were the standards changed?

3. (a) What is a frame of reference?
(b) What is meant by a 'rest frame'?
(c) Give an example of a rest frame.
(d) What was the importance of a rest frame for Newtonian physics?
(e) What is an 'absolute rest frame'?
(f) Explain why the rest frame you gave as an example in (c) above is not an absolute rest frame.
(g) A consequence of Einstein's postulate is that Newton's assumption of an absolute rest frame is not valid. Explain why.

4. In 1905, Einstein wrote in *Annalen der Physik*, that '... light is always propagated in empty space with a definite velocity *c* which is independent of the state of [relative] motion of the emitting body ... The introduction of a 'luminiferous ether' will be superfluous in as much as the view here to be developed will not require an 'absolutely stationary space' provided with special properties.'



(a) What consequence of the constancy of the speed of light is Einstein referring to in this statement?
(b) Explain why Einstein made this statement. (Note that there is no evidence anywhere to show that Einstein knew about the Michelson-Morley experiment.)

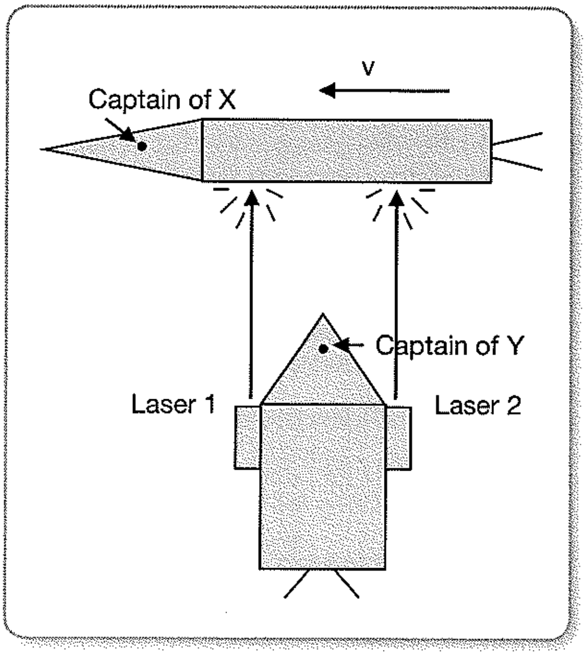
5. List four main consequences for science as a result of Einstein's postulate of the constancy of the speed of light.

SET 6 Time Dilation

1. Describe, with the aid of a suitable diagram the concept of a light clock, and explain the concept of 'proper time'.

2. Imagine a spaceship moving at various fractions of the speed of light as given in the table below. Calculate the missing values in the table.

Speed of ship (c)	Lorentz factor (also known as gamma or boost factor) $= \left(\frac{1-v^2}{c^2}\right)^{-\frac{1}{2}}$
0.1	
0.3	
0.5	
0.7	
0.9	
0.99	



3. (a) 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.

4. Calculate the missing values in the following table.

Time on spaceship (s)	Speed of ship (c)	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		

5. (a) 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.

6. Mesons have a life of 2.2 μs. However, mesons formed in the upper atmosphere as air particles are hit by cosmic rays take 15.6 μs to reach the ground. Calculate the speed of the meson.

7. (a) An astronaut travelling at 0.5 c takes 10 hours ship time to reach her destination. Calculate how much time has passed *on Earth* as measured by this astronaut.

(b) If the Earth observer recorded 10 hours on the Earth clock, what time would he measure as having passed on Earth?

8. 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.

9. A UFO flies past Earth at 0.2 c. An Earth observer watches the UFO for 5.0 s Earth time. Calculate how much time passes in the UFO as measured by the same observer on Earth.

10. 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?

11. Calculate how fast a spaceship would have to go so that each year on the ship would correspond to 3 years on Earth.

12. A spaceship moves at 6.8×10^7 m s^{-1}. Astronauts stand an 8-hour watch. Calculate:

(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.

13. 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.

14. 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?

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) Calculate the time taken for the astronaut to travel from Earth to the star as measured by the astronomer on Earth.

(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.

(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.

16. A muon formed in the Earth's atmosphere travels towards Earth at 0.99 c as measured by an Earth observer. The muon decays after 3.1×10^{-6} s in its reference frame.

(a) Calculate the distance travelled by the muon in its reference frame.

(b) Calculate the lifetime of the muon from the Earth frame of reference.

(c) Calculate the distance the muon travels in the Earth frame of reference.

SET 7 Length Contraction

1. Define proper length.

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_o?

(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 longer? Explain your answer.

3. 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.

4. A 100 m long Klingon space vessel flies past Saturn at 0.25 *c*. The diameter of Saturn as seen from Earth is 120 000 km. Calculate:

(a) Its diameter as seen by the Klingons.

(b) The length of the Klingon vessel as seen from Saturn.

5. A space shuttle is 38 m long and orbits Earth at about 30 000 km h^{-1}. Calculate its apparent length as seen by an astronomer on Earth.

6. An astronaut in the same space shuttle looks down on a 250 km section of the Great Wall of China.

(a) Calculate the length of this section as seen by the astronaut.

(b) If the astronaut saw the section to be 250 km long, calculate its real length on Earth.

7. (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?

8. Calculate the speed that would cause a length contraction of 15%.

9. A rocket ship from Jupiter is 400 m long. It cruises past Earth at 0.95 *c*. Calculate its length as seen by a stationary observer on Earth.

10. Astronomers measured the length of a meteorite passing Earth at 0.35 *c* to be 275 m. What would be its length if it was stationary on Earth?

11. A Klingon space vessel is moving at 0.40 *c* as it flies past the Enterprise. The Klingon captain measures the distance between his forward and rear laser cannons as 150 m.

Calculate their distance apart as measured by crew on the Enterprise.

12. An Earth observer measures a spaceship moving away from Earth at 0.8 *c* to be 100 m long. The astronaut in the ship sends a signal to Earth every hour as measured by a clock on the ship. Calculate:

(a) The distance the ship travels between signals as measured by the astronaut.

(b) The distance the ship travels between signals as measured by an Earth observer.

(c) The time between the signals as measured by the astronaut.

(d) The time between the signals as measured by the Earth observer.

(e) The length of the ship as measured by the astronaut.

(f) The length of the ship as measured by the Earth observer.

Set 8 Relativistic Mass

1. The mass of an electron at rest is 9.11×10^{-31} kg.
   (a) Calculate the mass of an electron in a TV, 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?

2. 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.

3. Find the percentage increase in the mass of a cricket ball which is:
   (a) Bowled at 15 ms^{-1}.
   (b) Bowled at 150 km h^{-1}.
   (c) Fired from an automatic bowling machine at 2.0×10^8 m s^{-1}.

4. An electron of 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?

5. An electron in a linear accelerator has a mass of 8.5×10^{-29} kg. How fast is it moving?

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. (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?

8. 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?

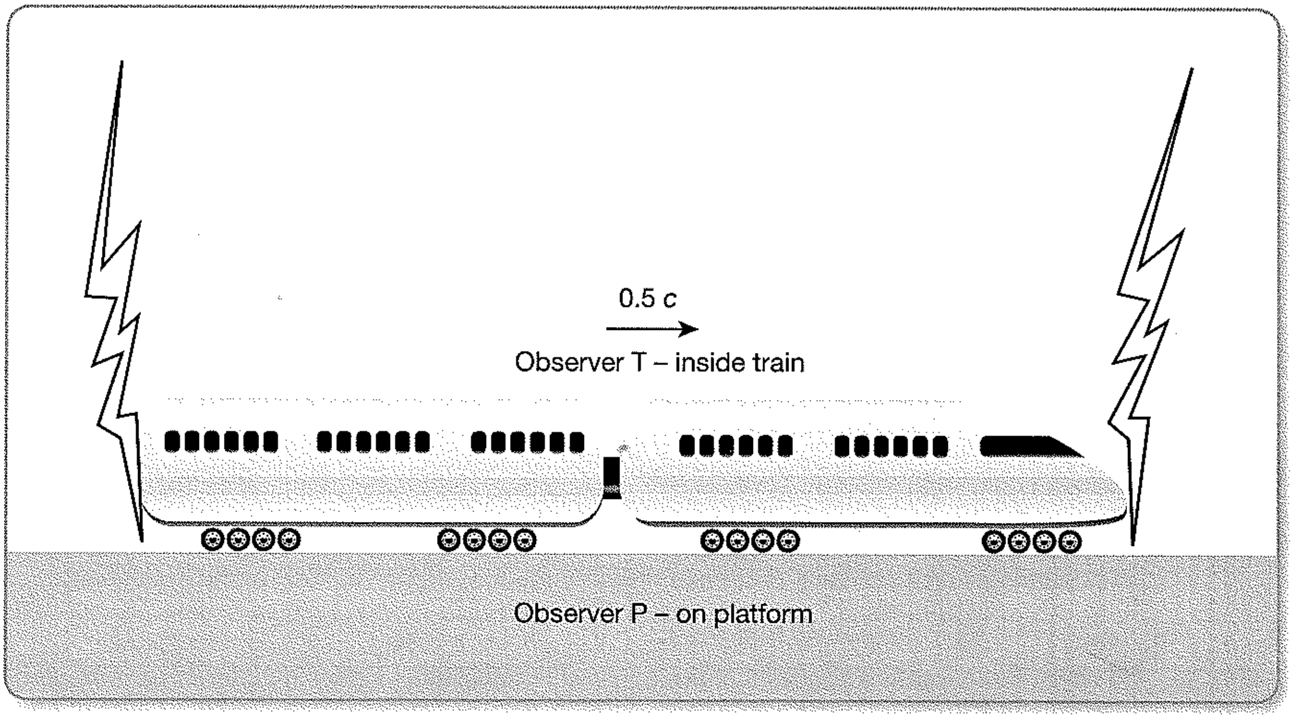
9. Two protons X and Y, each having a rest mass of 1.673×10^{-27} kg are moving at 0.6 c and 0.9 c respectively.
   (a) What is the difference in their relativistic masses?
   (b) What is the difference in their kinetic energies as calculated using Newtonian physics?
   (c) What is the difference in 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.

SET 9 Some Combined Relativity Questions

1. Einstein proposed a 'thought experiment' along the following lines.

Imagine a train of proper length 100 m passing through a station at half the speed of light. There are two lightning strikes, one at the front and one at the rear of the train, leaving scorch marks on both the train and the station platform.

Observer P is standing on the station platform midway between the two strikes, while observer T is sitting in the middle of the train. Light from each strike travels to both observers.



(a) If observer P on the station concludes from his observations that the two lightning strikes occurred simultaneously, explain why observer T on the train will conclude that they did *not* occur simultaneously.

(b) Which strike will T conclude occurred first?

(c) What will be the distance between the scorch marks on the train, according to P?

(d) What will be the distance between the scorch marks on the train, according to T?

(e) What will be the distance between the scorch marks on the platform, according to P?

(f) What will be the distance between the scorch marks on the platform, according to T?

2. An electron is travelling at a constant speed in a vacuum. A laboratory observer measures its speed as 95% of the speed of light and the length of its journey to be 100 m.

(a) Show that for these electrons, the gamma factor, $\gamma = 3.2$.

(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.)

3. Suppose that some time in the future it will be possible for astronauts to travel to Alpha Centauri, 4.2 light years away, at a constant speed of 0.95 c.

(a) How many years would it take for them to get there as measured by observers in the Earth's frame of reference?

(b) How many years would it take for them to get there as measured by the astronauts?

On arrival at Alpha Centauri, having forgotten their shopping list, 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?

4. An astronaut, moving away from Earth at relativistic speed, is observed on TV and is monitored by electronic devices in Mission Control on Earth. All readings are normal.

(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? Explain your answer.

(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.

5. A spaceship is on its way to Alpha Centauri, 4.2 light years from Earth, at 0.85 c.

(a) How long will observers on Earth predict this journey will take?

(b) How far do the observers on Earth measure the journey to be?

(c) How long will the astronauts predict this journey will take?

(d) How far will the ship travel in the time predicted by the astronauts?

(e) Explain how these two distances (answers (b) and (d)) are consistent with the fact that according to the astronauts and the Earth observers, the ship reaches Alpha Centauri at the same time.

6. Star Xenos is 9.6 light years away from Earth.

(a) At what speed would a spaceship have to travel to make this journey in 20 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 Xenos.

7. An astronaut is travelling in a spaceship at a constant speed of 0.6 c on a journey from Earth to Alpha Centauri. She is doing an experiment which involves a swinging pendulum. She measures the period of swing of the pendulum, as does an observer in Mission Control on Earth to check her results.

(a) Will they both measure the same period of swing for the pendulum? Explain your answer.

(b) Which observer would measure the period of the swing to be the same as if the experiment was carried out on Earth? Explain your answer.

(c) Which observer would measure a period longer than that which would be observed if the experiment was repeated on the surface of Earth? Explain your answer.

8. (a) Compare the passage of time on a spaceship as perceived by an Earth observer and by the astronaut of the spaceship.

(b) Knowing a little about time dilation, a doctor had the idea that he could put his patients with terminal diseases in a spaceship and have the spaceship orbit Earth at speeds close to the speed of light. He figured that 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.

SET 10 Relativistic Momentum

1. The relativistic momentum equation is shown in the box on the right.

$$p = \frac{m_0 v}{\sqrt{1 - \frac{v^2}{c^2}}} = \gamma m_0 v$$

The classical equation for momentum is: $p = mv$

(a) Use these two 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 an electron moving at various speeds by copying and completing the following table in your book. The mass of an electron is 9.11×10^{-31} 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.

2. (a) Particle A has half the mass but twice the speed of particle B. If the particles' momenta are p_A and p_B, then are their momenta equal, or does one have a higher momentum than the other? Justify your answer.

(b) Check your answer by imagining A having mass 2 and speed 0.5 *c*, and B having mass 4 and speed 0.25 *c*.

(c) Recheck your answer for A having mass 40 and speed 0.8 *c*, and B having mass 80 and speed 0.40 *c*.

3. At what speed is a particle's relativistic momentum twice its classical momentum?

4. (a) An electron in a particle accelerator tube is travelling at 0.866 *c*. What is the value of its relativistic momentum?

(b) Considering your answer to (a) above, what would be the value of its classical momentum?

(c) Explain how you arrived at this answer.

5. A spacecraft is travelling at 0.235 the speed of light. By what factor would its relativistic momentum increase if its speed doubled?

SET 11 Equivalence of Mass and Energy

1. (a) Recall the equation representing the equivalence of mass and energy.
(b) What is meant by the 'equivalence of mass and energy'?

2. (a) What is rest mass?
(b) Why is the concept of a rest mass needed?

3. (a) What is rest energy?
(b) When can rest energy be observed?

4. (a) A proton has a rest mass of 1.67×10^{-27} kg. What is its rest energy?
(b) One gram of protons is 6.02×10^{23} protons. What is the rest energy of one gram of protons?
(c) What mass of protons would have a rest energy of one joule?
(d) What mass of oxygen (atomic mass, $A = 16$) would have a rest energy of 1 joule?

5. (a) What would be the rest energy of 1 tonne of hydrogen gas? ($A = 1$)
(b) What would be the rest energy of 1 tonne of oxygen gas? ($A = 16$)
(c) What would be the rest energy of 1 tonne of uranium? ($A = 92$)

6. A 10 kg bowling ball is moving at 5 m s^{-1}.
(a) What is its kinetic energy?
(b) What is its rest energy?
(c) What is its total energy?

7. 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?

8. Assuming 100% conversion to energy, which nuclear fuel would release the most energy per kilogram, uranium or hydrogen? Explain your answer.

9. (a) What is mass defect as it applies to a nuclear transmutation?
(b) In general, what is the relationship between mass defect and the size of a nucleus? Explain.
(c) A deuterium nucleus contains 1 proton and 1 neutron. What can be said about the mass of the nucleus compared to the total mass of the protons and neutrons it contains? Explain your answer.
(d) What name do we give to the energy equivalent of the mass defect?
(e) In terms of binding energy, how does mass defect arise in a nuclear transformation?
(f) Explain the concept of binding energy per nucleon.
(g) Explain why binding energy per nucleon is a more useful concept than binding energy.
(h) Nucleus X has a higher binding energy per nucleon than nucleus Y. Explain what this means in terms of the stability of the two nuclei.

10. (a) Find the *KE* possessed by a 2 tonne truck moving at 60 km h^{-1}.
(b) What mass would have this amount of energy as its rest energy?
(c) If the energy released when one atom of uranium decays by a particular pathway is 3.12×10^{-11} J, how many atoms of uranium would need to decay to release the same energy as the truck has?
(d) A biro has a mass of about 15 g. What is its rest energy?
(e) How many atoms of uranium have the equivalent rest energy of one biro?

11. The binding energy of $^{8}_{16}O$ is 7.977 MeV. What is the mass defect for an atom of this element in kg and amu?

12. A typical nuclear reaction which releases energy from uranium is:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{136}_{54}Xe + ^{88}_{38}Sr + 12(^{1}_{0}n)$$

Where the masses of each of the particles involved, in amu are:

$$^{235}_{92}U = 235.1170$$

$$^{1}_{0}n = 1.008665$$

$$^{136}_{54}Xe = 135.9072$$

$$^{88}_{38}Sr = 87.9056$$

(a) Calculate the mass defect for the reaction in amu.

(b) Given that 1 amu = 1.661×10^{-27} kg, calculate the mass defect in kilograms.

(c) From this, calculate the energy produced per atom of uranium.

(d) Given that 1 tonne of brown coal yields about 6.75 gigajoules (1 GJ = 10^9 J) of energy, calculate how much coal would produce the same energy as one atom of uranium.

(e) How much energy would 1.0 kg of uranium produce if conversion was 100%?

(f) Calculate how much coal would be needed to produce the same amount of energy as 1 kg of uranium if conversion to energy was 100%.

(g) Calculate how many atoms of uranium would produce the same amount of energy as 1 tonne of coal according to this reaction.

(h) How much U-235 does this represent?

(i) An average household uses about 16 GJ of electrical energy per year. How much coal needs to be burned to produce this amount of energy?

(j) How much uranium would produce this energy by the reaction shown above?

13. In the cartoon Einstein is contemplating the equation for which principle in physics?

14. If a deuterium nucleus has a mass of 1.53×10^{-3} amu less than its components, what is its binding energy? Give your answer in joules and MeV.

15. If the mass defect for a helium nucleus, $^{2}_{4}He$, is 0.03 amu, what is its binding energy per nucleon in joules and MeV?

16. What, in joules and MeV, is the energy equivalent of 5.0×10^{-3} kg?

17. What, in joules and MeV, is the energy equivalent of a mass of 0.026 kilograms?

18. If the masses of a proton and a neutron are 1.007277 amu and 1.008665 amu respectively, what is the binding energy per nucleon in a hydrogen atom, mass 2.01473 amu?

SET 12 Mass-Energy Relationship and Nuclear Energy

1. Consider the following expression: ${}^{A}_{Z}X$

(a) What does each symbol used in the expression stand for?

(b) How many electrons would element X have?

(c) How many protons would element X have?

(d) How many neutrons would element X have?

(e) What would be different if we had a different isotope of X?

(f) Explain what an isotope is.

2. Copy the following tables into your book and complete them.

${}^{235}_{92}U$	
A	
Z	
Number of electrons	
Number of protons	
Number of neutrons	

${}^{238}_{92}U$	
A	
Z	
Number of electrons	
Number of protons	
Number of neutrons	

${}^{138}_{55}Cs$	
A	
Z	
Number of electrons	
Number of protons	
Number of neutrons	

3. (a) Explain the term radioactive decay.

(b) What one thing is always produced as a result of radioactive decay?

(c) What are the three most common types of radioactive decay?

(d) What is an alpha particle?

(e) Write a general nuclear equation for alpha decay. (Imagine that atom ${}^{A}_{Z}X$ undergoes alpha decay.)

(f) What is a beta particle?

(g) Write a general nuclear equation for beta decay. Imagine that atom ${}^{A}_{Z}X$ undergoes beta decay.)

(h) When does gamma decay usually occur?

(i) Explain the process of nuclear fission.

(j) What are the two types of nuclear fission that exist?

(k) What is always released as a result of nuclear fission?

(l) How can nuclear fission be induced?

(m) Explain the process of nuclear fusion.

(n) What is always released as a result of nuclear fusion?

(o) What is the equation which is used to calculate the amount of energy released during fission and fusion? Define the symbols you use.

4. Calculate the mass defect and then the energy released by the following reactions. In (e) and (f) you will need to identify the elements X and Y first.

(a) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{133}_{55}Cs + ^{96}_{37}Rb + 2^{1}_{0}n$

(b) $^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$

(c) $^{210}_{81}Tl \rightarrow ^{210}_{82}PB + ^{0}_{-1}e$

(d) $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$

(e) $^{222}_{86}Rn \rightarrow ^{A}_{Z}Y + ^{4}_{2}He$

(f) $^{234}_{90}Th \rightarrow ^{A}_{Z}X + ^{0}_{-1}e$

(g) $^{226}_{88}Ra \rightarrow ^{222}_{86}Rn + ^{4}_{2}He$

(h) Explain the implication of your answer for the mass defect and energy values for equation (f).

5. Calculate the mass defect for nuclear reactions which release the following energies.

(a) 3.25 MeV

(b) 1.96 MeV

(c) 8.45 MeV

(d) 12.2 MeV

(e) 5.76 MeV

(f) 2.47×10^{-13} J

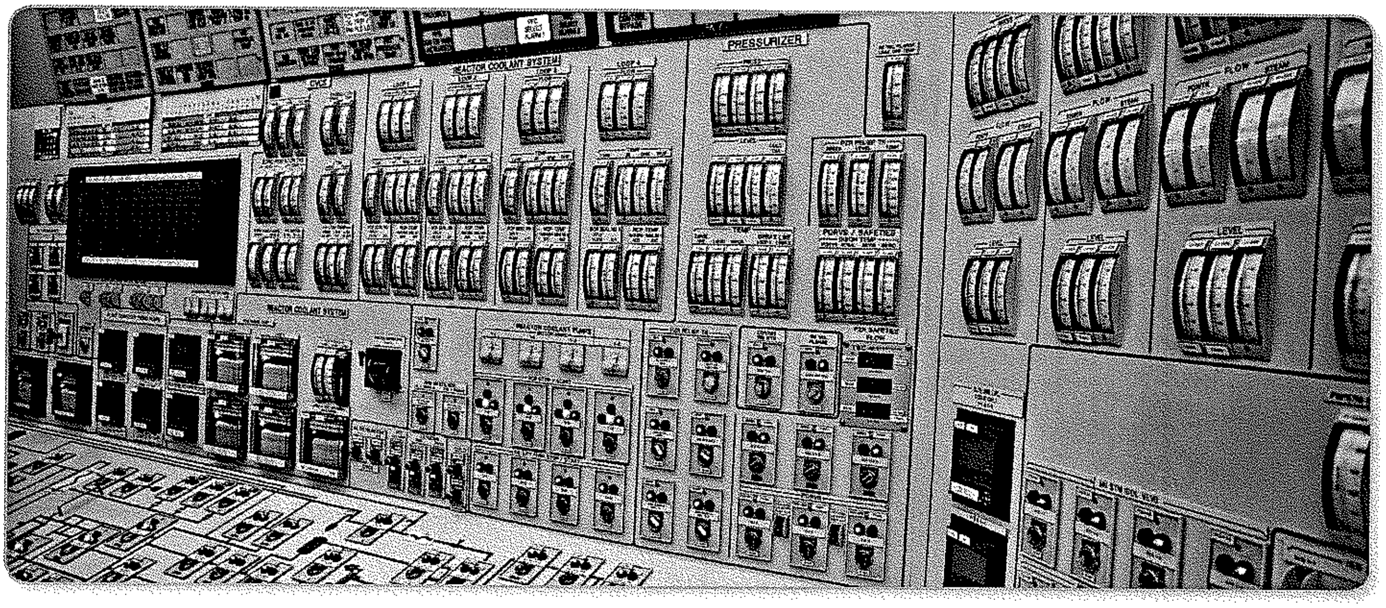
(g) 5.73×10^{-13} J

(h) 3.78×10^{-13} J

(i) 8.93×10^{-12} J

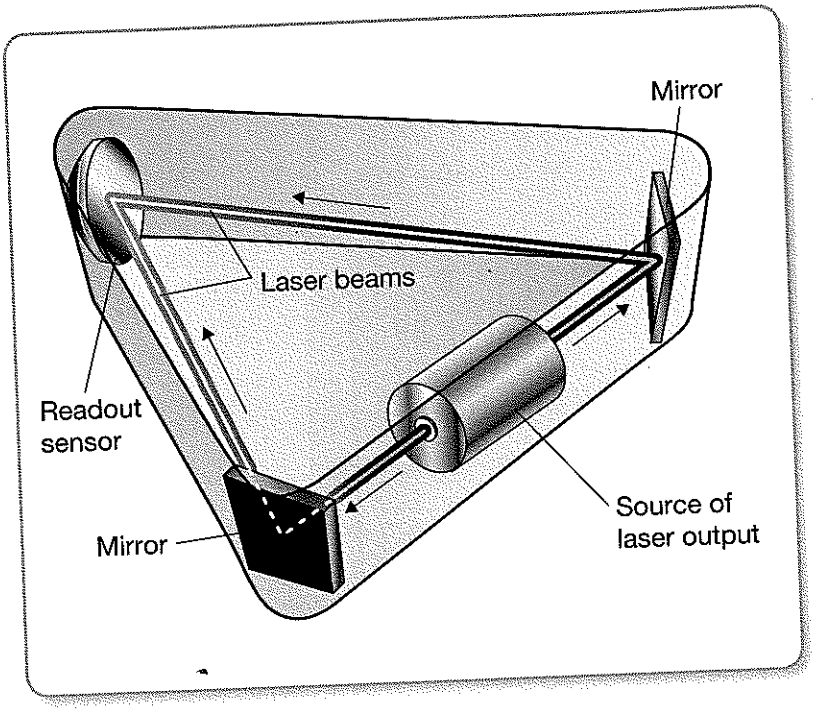
(j) 7.54×10^{-12} J

Particle	Mass (amu)
$^{141}_{56}Ba$	140.914411
$^{133}_{55}Cs$	132.905453
$^{0}_{-1}e$	0.0005486
$^{1}_{1}H$	1.0078825
$^{2}_{1}H$	2.014102
$^{3}_{1}H$	3.016048
$^{3}_{2}He$	3.016029
$^{4}_{2}He$	4.002603
$^{92}_{36}Kr$	91.926156
$^{1}_{0}n$	1.008665
$^{210}_{82}Pb$	209.984189
$^{234}_{91}Pa$	234.043308
$^{218}_{84}Po$	218.008973
$^{226}_{88}Ra$	226.03089
$^{96}_{37}Rb$	95.93427
$^{222}_{86}Rn$	222.017578
$^{234}_{90}Th$	234.04360
$^{210}_{81}Tl$	209.99074
$^{235}_{92}U$	235.04393



SET 13 Ring Laser Gyroscopes

1. (a) What are gyroscopes?
(b) How do mechanical gyroscopes work?
(c) How do ring laser gyroscopes differ from conventional mechanical gyroscopes?
(d) What is the Sagnac effect?
(e) What causes the Sagnac effect?
(f) How is the Sagnac effect utilised in ring laser gyroscopes?
(g) What are the advantages of ring laser gyroscopes over mechanical gyroscopes?
(h) Where are ring laser gyroscopes used?
(i) Why are ring laser gyroscopes used in these applications rather than mechanical gyroscopes?



2. Match the sentence halves below to obtain a brief outline as to how a ring laser gyroscope works.

First half sentences

(a) A ring laser gyroscope consists of two
(b) The two laser
(c) In the absence of rotation or movement, the path lengths
(d) If the laser beam paths are the same length, the detector will show total constructive
(e) If the apparatus rotates, rocks or tumbles, there will be a
(f) This will result in a net phase
(g) As a result, there will be a destructive
(h) This is known
(i) The signal from the output sensor will vary in
(j) So the amplitude of the signal gives a
(k) A computer will analyse the output signal and convert

Second half sentences

(a) interference of the two beams.
(b) difference in the path lengths of the two laser beams.
(c) minute difference in the path lengths travelled by the two beams.
(d) laser beams having travelling in opposite directions.
(e) measure of the rocking motion of the vehicle concerned.
(f) amplitude depending on the degree of interference.
(g) of the two laser beams will be the same.
(h) it to an orientation figure for pilots to read.
(i) interference pattern formed at the detector.
(j) beams each reflect off a mirror to a detector.
(k) as the Sagnac effect.

3. (a) Describe the effect known as 'lock-in' and why it can occur in a ring laser gyroscope.
(b) How is the problem of lock-in averted in a ring laser gyroscope?
(c) What is this process known as?

SET 14 Medical Uses of Radioisotopes

1. What are radioisotopes?

2. Compare atoms of the isotopes of oxygen-16 and oxygen-18.

3. Distinguish between diagnostic and therapeutic medicine.

4. Most radioisotopes used for medical purposes are gamma sources. Explain why.

5. In Australia, only patients in Sydney hospitals can be offered the full range of radioisotope medical processes. Explain why this is so.

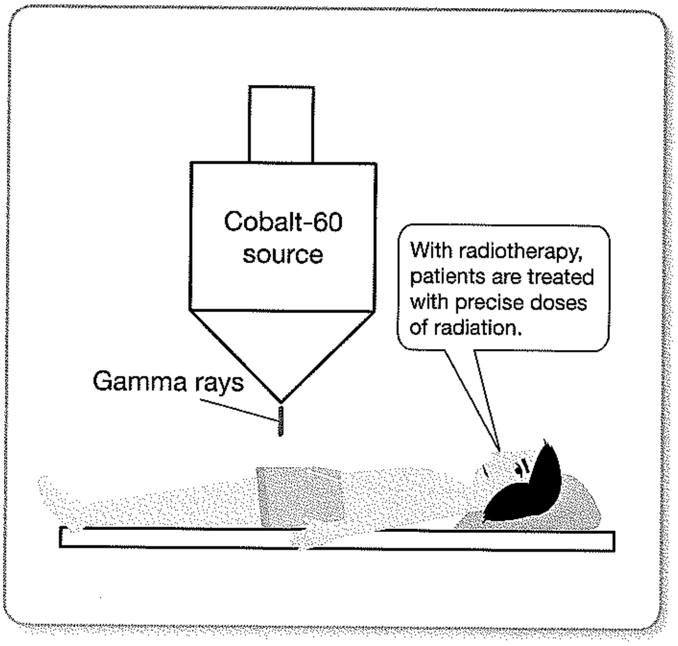
6. All hospitals and small medical centres can use radiotherapy with patients, but only a few hospitals can use chemotherapy. Explain why.

7. Assess the need to consider the half-life of radioisotopes on patients and on hospitals.

8. What are the advantages of using radioisotopes to produce an image of an organ inside the body.

9. Doctors can target particular organs in the body using radioisotopes. Explain how this is done.

10. (a) Research an isotope used in chemotherapy and outline its use.



(b) Why is Co-58 not used for chemotherapy?

11. When we talk about the use of radioisotopes, one of the common applications is as a 'tracer'. Explain this idea as it is used in the medicine

12. Assess the medical use of radioisotopes.

13. Assess the impact on society of the medical use of radioisotopes.

14. What is an essential property of radioisotopes used for medical purposes?

(A) They produce gamma radiation to kill cancerous cells.

(B) They have a relatively short half-life.

(C) They are inexpensive to produce.

(D) They occur naturally.

15. The use of radioisotopes in medical imaging is an important tool for doctors and patients. Why?

(A) It reduces the need for exploratory surgery.

(B) It gives a more accurate diagnosis than surgery.

(C) It is much less expensive than surgery.

(D) It provides a faster diagnosis than surgery.

16. Why are radioisotopes which produce gamma radiation the most commonly used for medical purposes?

(A) They have the shortest half-life.

(B) They are the most common and easiest to produce in a reactor.

(C) They are less expensive to produce than alpha and beta emitters.

(D) Alpha and beta particles do not penetrate tissue very well.

17. All hospitals can use radiotherapy with patients but only a few can use chemotherapy. Why?

(A) Radiotherapy involves long half-life isotopes while chemotherapy uses short half-life isotopes.

(B) Radiotherapy involves short half-life isotopes while chemotherapy uses long half-life isotopes.

(C) Specialist training is needed by doctors before they can use chemotherapy as a treatment.

(D) Radiotherapy involves X-rays which all hospitals can produce.

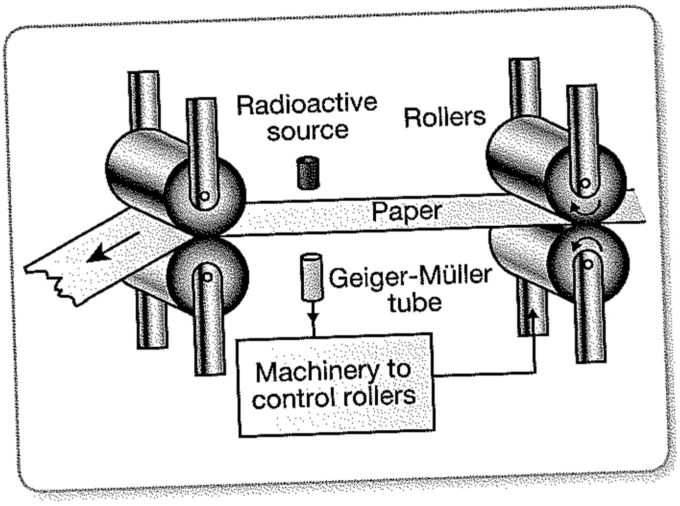
SET 15 Industrial Uses of Radioisotopes

1. Identify the three main properties of radioisotopes that must be considered before using them in an industrial situation.

2. (a) Predict what type of radiation source would be needed to control the thickness of paper. Justify your answer.
   (b) Predict what type of radiation source would be needed to control the thickness of metal sheeting. Justify your answer.
   (c) Assess the safety issues involved in these two procedures if the radiation you indicated was to be used.

3. Radioisotopes can be used to determine the level of liquid stored in a tank or the level of grain in a grain silo.
   (a) With the use of a diagram, explain how this might be done.
   (b) Explain what type of emitters would be needed to do these two jobs.

4. The diagram shows a radioactive isotope used to measure and control the thickness of paper.

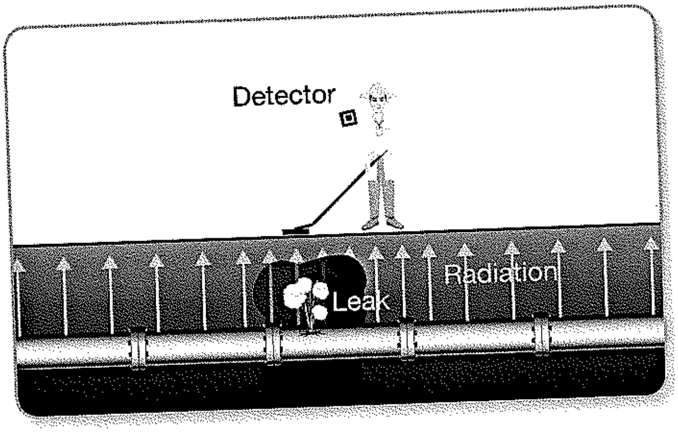


   (a) Would the same radioisotopes be used to measure the thickness of paper, glass and metal sheeting? Explain your answer.
   (b) Even if we discount the safety aspects, it would be inefficient to use a gamma emitter to gauge the thickness of paper. Explain why.

5. (a) What is meant by a radioactive tracer?
   (b) Outline the function of a tracer isotope.
   (c) Why are radioactive tracers useful?
   (d) Identify an industrial use of a radioactive isotope acting as a tracer. Identify the tracer used and relate its radioactivity to that particular use.
   (e) Explain why gamma emitters are mostly used in industrial applications of radioisotopes.
   (f) Explain why an alpha or beta emitter would not do this job well.

6. One of the main radioisotopes used in home smoke detectors is americium-241.
   (a) Give three reasons why this radioisotope is chosen.
   (b) What is the slight risk involved in using this isotope?
   (c) If this risk exists, why is it used?

7. The diagram shows a radiation detector (Geiger-Müller) counter being used to detect a leak in an underground pipe.



   (a) Explain the type of emitter being used.
   (b) The diagram shows gamma radiation along the entire length of the pipe. Why would this be the situation?
   (c) How can the leak be detected if the radiation is picked up along the whole length of the pipe?

8. Assess the impact of the industrial use of radioisotopes on society.

9. Which choice best describes a radioisotope?
   (A) Any radioactive isotope of an element.
   (B) A radioactive element produced in a nuclear process.
   (C) An isotope which has beneficial applications.
   (D) An isotope of an element which can be used for various purposes.

10. (a) What is the 'half-life' of a radioisotope?
   (A) Half the time it is useful.
   (B) Half the time it remains radioactive.
   (C) The time it takes for half its mass to decay.
   (D) The time it takes for its radioactivity at any given time to fall to half its value.

   (b) Extension: If a radioactive isotope produced 100 particles per second, how many half-lives would pass before this dropped to less than 10 particles per second?

11. What would be an essential property of radioisotopes used to detect flaws or cracks in metal structures?
   (A) They need to be safe for use by humans.
   (B) They would need to be gamma emitters.
   (C) They would need to be isotopes of elements heavier than the atoms of the metal.
   (D) They would need to have a very short half-life.

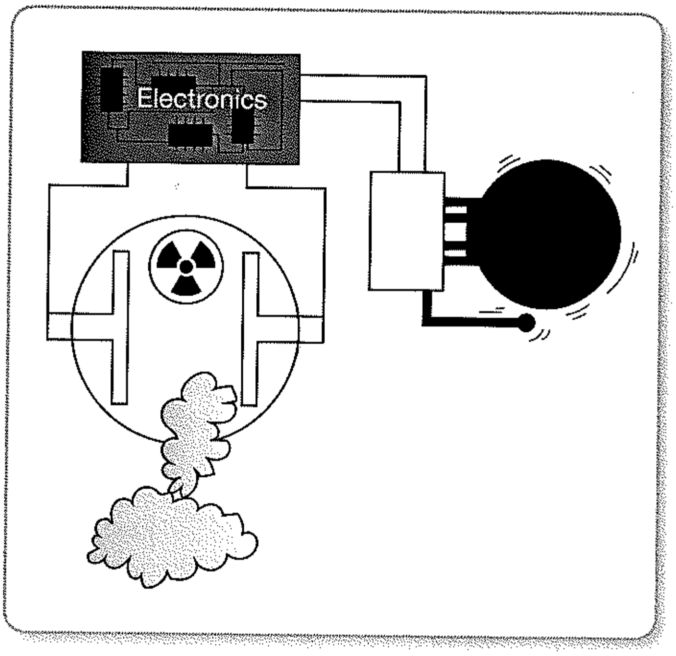
12. Radioisotopes can be used in paper mills to monitor the thickness of the paper as it is being made. What type of emitter would be used for this purpose?
   (A) Alpha.
   (B) Beta.
   (C) Gamma.
   (D) Either alpha or beta.

13. What type of emitter is mostly used in industrial applications of radioisotopes?
   (A) Alpha.
   (B) Beta.
   (C) Gamma.
   (D) Either alpha or beta.

14. What are the properties of americium-241 which make it useful in household smoke detectors?
   (A) It emits gamma rays and has a long half-life.
   (B) It emits gamma rays and has a short half-life.
   (C) It emits alpha rays and has a long half-life.
   (D) It emits alpha rays and has a short half-life.

15. What is the main reason that radioisotopes iridium-192 or cobalt-60 are used to detect flaws in jet engine parts?
   (A) They are gamma emitters.
   (B) They are alpha emitters.
   (C) They are easily produced.
   (D) They are less expensive than other isotopes.

16. The diagram shows a schematic of a smoke detector. Explain briefly how this works.



SET 16 Agricultural Uses of Radioisotopes

1. Common radioisotopes used in agriculture are those of carbon, hydrogen, phosphorus and nitrogen. Suggest why these might be used.

2. One of the purposes of a radioisotope in agriculture is to trace the path of a pesticide through the food chains.

(a) How might this be done?

(b) Give a reason why we might want to follow the path of pesticides through a food chain.

(c) How does the term 'tagging' relate to this process?

3. (a) Suggest three advantages of using radioactive tracers in agriculture.

(b) Suggest disadvantages of using radioactive tracers in agriculture.

4. (a) Gamma radiation is used to sterilise some food products before they are packaged for storage. What is the benefit of doing this?

(b) Many are against the use of genetically modified food products. Outline the cases for and against their use.

(c) Radiation is used to kill viruses (and bacteria) in foodstuffs to increase their shelf life. Explain why doctors don't make more use of radiation therapy to kill viruses and bacteria in people.

5. (a) Explain the idea of 'biological control'.

(b) Clarify the use of radioisotopes in the biological control of insect pests.

(c) Assess the use of radioisotopes in this process of biological control compared to the use of insecticides.

(d) Explain how sterilising a large number of pest insects and then releasing them into the wild acts to control the numbers of those pest insects.

(e) Why won't this strategy work beyond the current population of pest insects?

(f) If the sterilising strategy only works for one generation, assess its value.

6. What does the term 'tracer' mean as it applies to the use of radioisotopes in humans or plants?

(A) The path the radioisotope takes through the organism can be traced onto a map constructed by a computer.

(B) The radioisotope destroys the unhealthy cells in the plant or person and this can be monitored by detecting how much radiation remains.

(C) The path of the isotope through the organism can be followed by detecting the radioactivity the isotope gives off.

(D) The radioisotope follows every possible pathway through the plant or person until it detects unhealthy tissue.

7. Which of these agricultural uses of radioisotopes is the least controversial?

(A) As tracers to determine chemical processes.

(B) Biological control of pests.

(C) Genetic modification of organisms.

(D) Sterilisation of food products.

8. Which statement best describes how radioisotopes are used in biological control?

(A) Males are sterilised by exposing them to radioactivity then released into the environment.

(B) Radioactive isotopes are seeded in the environment to kill the pests.

(C) Infected crops are sprayed with fertiliser laced with the radioactive isotope.

(D) Radioactive food baits are placed in the environment where the pests are.

9. (a) Which of the following isotopes would be least useful as a tracer in plants?

(A) C-14

(B) Ca-45

(C) P-32

(D) N-15

(b) Justify your answer.

SET 17 The Nuclear Problem

1. Evaluate the following statement which is one scientist's analysis of background radiation.

> On average, each person on Earth is struck by about 15 000 particles of background radiation every second. This compares to a typical X-ray which involves 100 billion X-rays.
>
> While this may seem to be very dangerous, the probability for a particle of radiation entering a human body to cause a cancer is only one chance in 30 million billion (3×10^{16}). This has been estimated to cause about 1% of all cancers.

2. (a) List five concerns that people have over our use of nuclear energy.

(b) List five advantages of nuclear energy.

3. Radiations from the waste products of nuclear reactors are estimated to be about 0.2% of the exposure from background radiation which has been estimated to cause about 1% of all cancers in humans.

On this estimate, radiation due to nuclear technology should eventually increase our cancer risk by 0.002%. This would, on average, reduce life expectancy by about an hour.

By comparison, the life expectancy reduction from electricity generation, burning coal, oil, or gas (mainly due to effects of pollution), is estimated to be between 3 and 40 days.

(a) Comment, according to this data, on the relative danger to humans of background radiation and danger from radioactive waste products.

(b) Should we believe estimates like these? Justify your answer.

(c) If we assume the estimates are correct, what message should be given to the general population about the risks involved if Australia was to consider building several nuclear power plants to supplement or replace our fossil fuel stations?

4. Risks of reactor accidents involving a meltdown of the reactor core are estimated by 'probabilistic risk analysis' (PRA). In general:

- A fuel meltdown might be expected once in 20 000 years of reactor operation.
- In 2 out of 3 there would be no deaths.
- In 1 out of 5 there would be 1000+ deaths.
- In 1 out of 100 000 there would be 50 000 deaths.
- The average for all meltdowns would be about 400 deaths.
- Note that air pollution from coal is estimated to cause 10 000 deaths per year, so there would have to be, on average, 25 meltdowns per year for nuclear power to be as dangerous as coal burning.

(a) Use this information to comment on each of the following statements.

(i) Because the Chernobyl reactor accident involved a core meltdown, it is very unlikely that there will be another meltdown within the next 20 000 years.

(ii) The data indicates that nuclear reactors are very safe and unlikely to melt down.

(iii) One in every five reactor meltdown accidents will involve 50 000 deaths.

(iv) Pollution from fossil fuel energy sources is more dangerous than a reactor meltdown.

(v) The average number of deaths from nuclear meltdown accidents is 400.

(b) Who do you think might produce information like this and for what purpose?

(c) Should governments take notice of this type of research when making decisions as to whether or not to implement nuclear power? Justify your answer.

5. Consider this research extract.

'A long-term study done with the survivors of the two atomic bombs dropped on Japan showed an increase of about 400 additional cancer deaths per 100 000 people in the group studied. The study showed zero extra genetic diseases in the children of these people'.

(a) Is this statement self-contradictory? Explain your answer.

(b) Could we use this research evidence to mount an argument that nuclear radiation does not cause genetic diseases and is therefore safe in this regard? Explain your answer.

6. It is estimated that the high level radioactive waste generated by one nuclear power plant will eventually, over millions of years (through contribution to background radiation) cause one death for every 50 years of operation per reactor.

It is also estimated, if we assume that, despite the packaging and burying, low level radioactive waste material will eventually become dispersed into the soil. The death toll from this low level waste is estimated to be about one death for every 1000 years of operation per reactor.

(a) On the basis of this information, which would appear to present the most danger to humans, high or low level waste? Justify your answer.

(b) Which storage strategy, low level burial for low level waste or deep level burial for high level waste would seem to be safest? Justify your answer.

7. (a) Explain the difference between high level and low level radioactive waste.

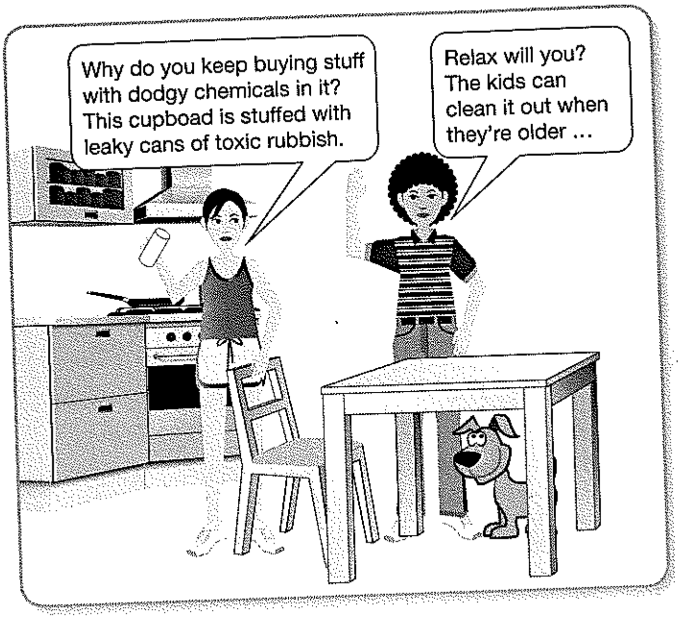
(b) Outline the different methods of disposing of both high and low level waste.

(c) Suggest three environmental conditions that should be paramount in making a decision as to where to bury low level waste from nuclear reactors.

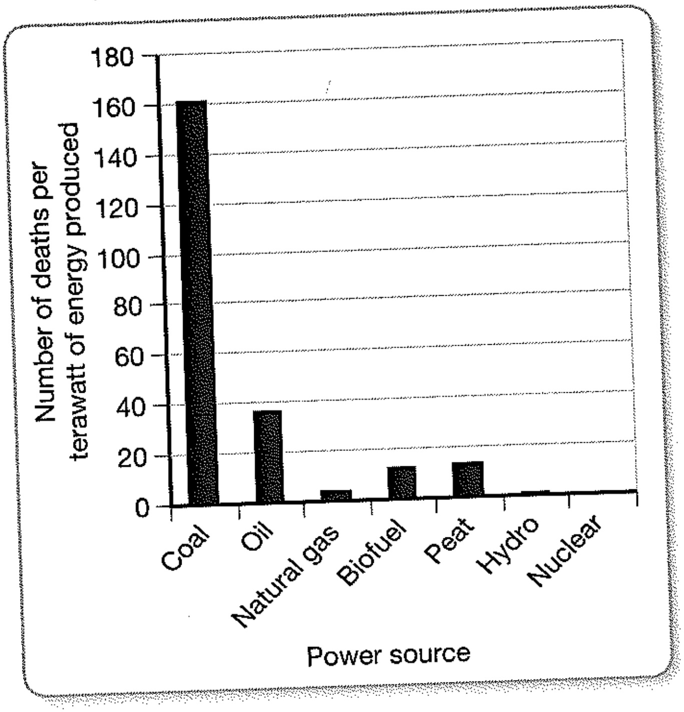
(d) What are the major considerations for selecting a site for deep burial of high level radioactive waste products?

(e) Suggest a reason we do not fire radioactive waste materials into the Sun.

8. How does the cartoon below reflect the thoughts of some nuclear waste disposal strategies?



9. Consider the following graph which shows the number of deaths in various power industries per terawatt of energy produced.



(a) How much energy is a terawatt?

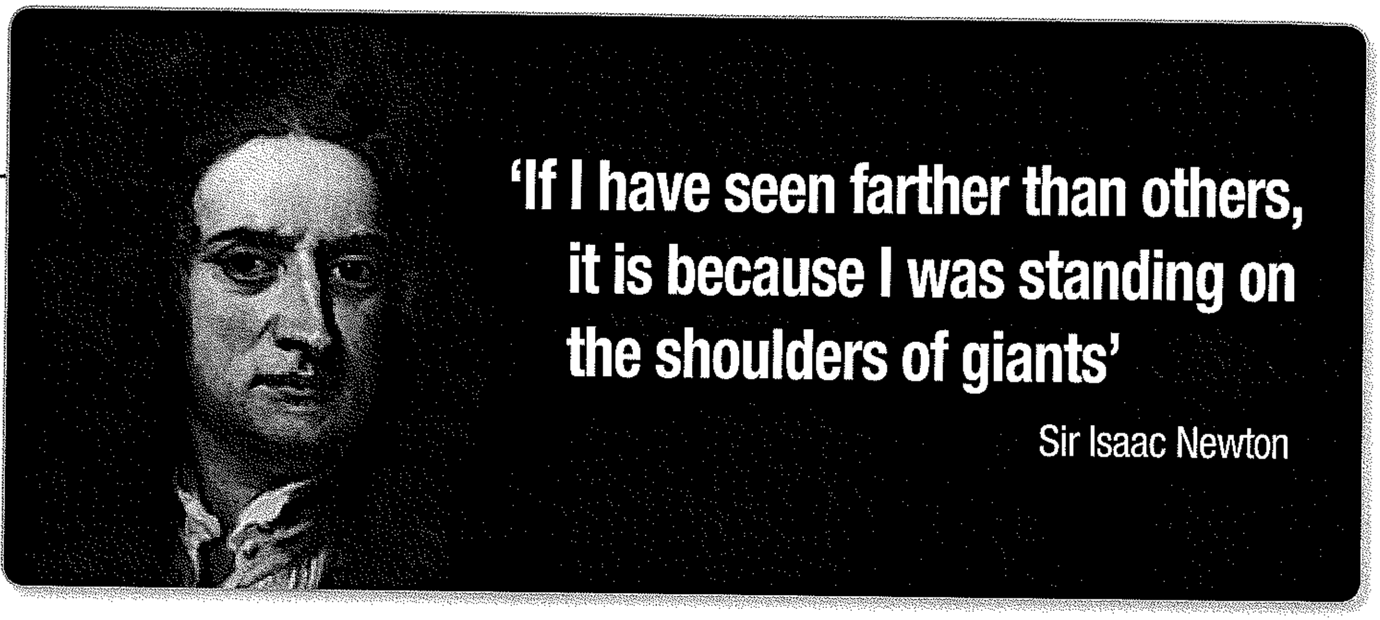
(b) How many 100 W light globes could be run 24 hours per day for a year with this much energy?

(c) Comment on the relative danger of nuclear energy based on this data.

SET 18 Development of Relativity

The picture shows a well known phrase paraphrased by Sir Isaac Newton in a letter to a rival scientist, Robert Hooke in 1676, commenting on Hooke's achievements in the following way.

'What Descartes did was a good step. You have added much in several ways, especially in taking the colours of thin plates into philosophical consideration. If I have seen a little further it is by standing on the shoulders of giants.'



The original saying is thought to have been made in 1149 by theologian John Salisbury.

'We are like dwarfs sitting on the shoulders of giants. We see more, and things that are more distant, than they did, not because our sight is superior or because we are taller than they, but because they raise us up, and by their great stature add to ours'.

The work of Albert Einstein in the late 1800s and early 1900s is a prime example of the concept in this saying. Your task in this set is to research the work of the scientists listed to find out how they became the giants on whose shoulders Einstein stood. Dates have been given to allow you to narrow your search as each scientist did many things, only a few of which impacted on Einstein's thinking. End your research with a brief summary of Einstein's ideas on special relativity and a comment relating this to 'the shoulders of the giants before him'.

The scientists (in order of their relevant work)

1632	Galileo Galilei	1886	Hendrik Lorentz	1900	Poincaré
1687	Sir Isaac Newton	1886	Michelson-Morley	1900	Joseph Larmor
1804	Thomas Young	1887	Michelson-Morley	1902	Poincaré
1810	François Arago	1887	Heinrich Hertz	1902	Walter Kaufmann
1818	Augustin-Jean Fresnel	1889	George FitzGerald	1903	Wilhelm Wien
1845	George Stokes	1892	Lorentz	1904	Lorentz
1851	Hippolyte Fizeau	1893	JJ Thomson	1904	Poincaré
1873	James Clerk Maxwell	1895	Lorentz	1905	Poincaré
1881	JJ Thomson	1898	Henri Poincaré	1905	Albert Einstein
1881	Albert Michelson	1899	Lorentz		

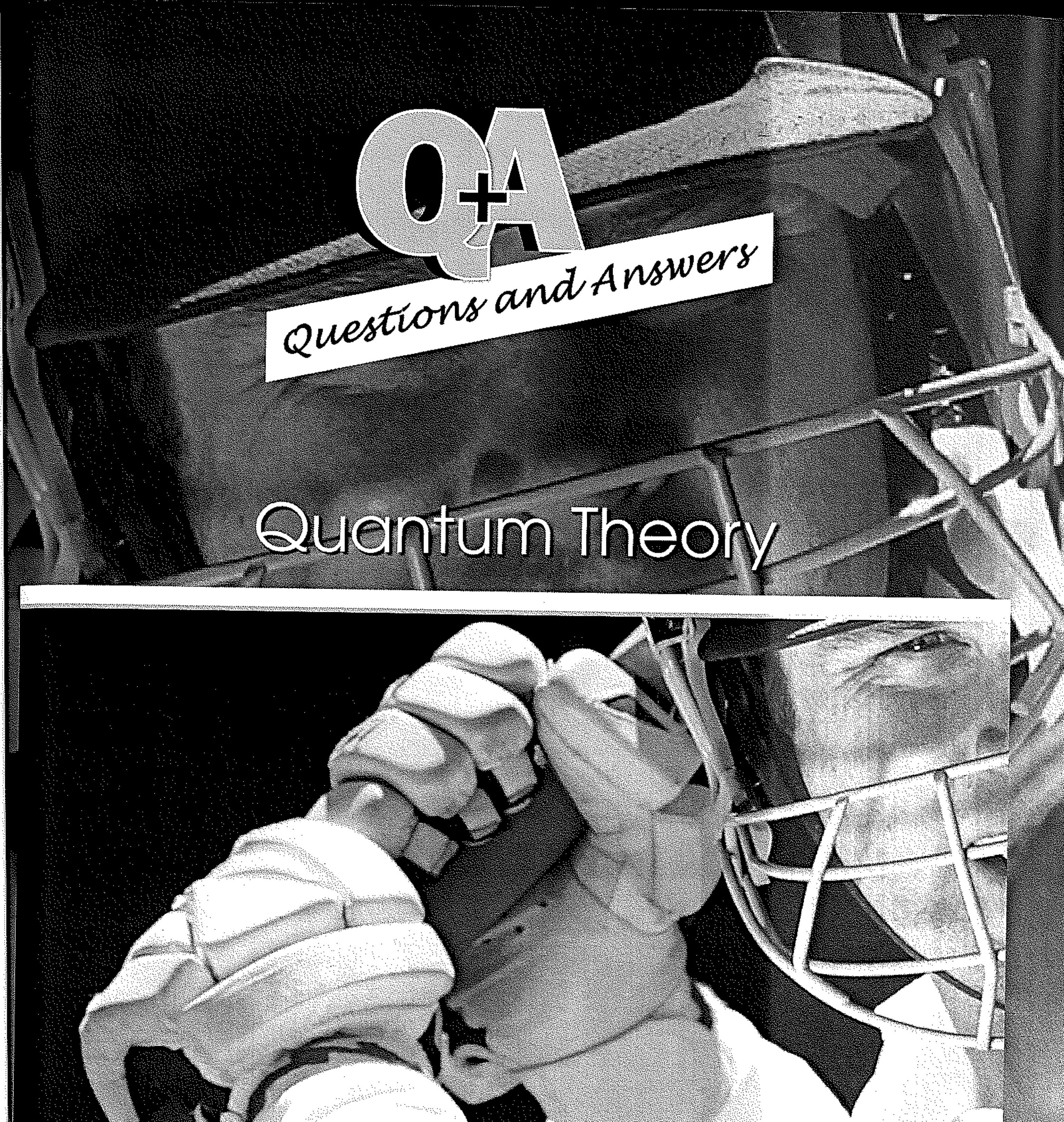
Notes

Science Press

Q+A

Questions and Answers

Quantum Theory



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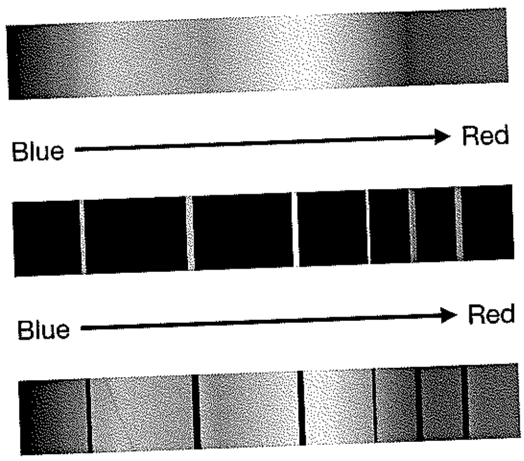
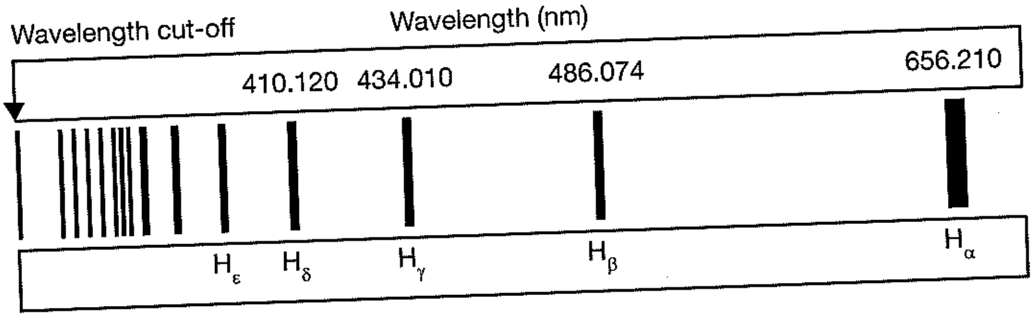
SET 19 Atomic Spectra

1. (a) What are the three different types of atomic spectra?
(b) Briefly describe the appearance of each.
(c) Describe the relationship between the emission and absorption spectrum of the same element.
(d) What is the most common example of a continuous spectrum?
(e) Briefly describe how each of the other two types of spectra can be produced from a continuous spectrum.
(f) Describe the production of each type of spectrum in terms of electron behaviour.

2. The diagrams show three different atomic spectra.
(a) Identity the continuous, emission and absorption spectra.
(b) Account for the structure of each (i.e. how is each formed).
(c) Identify the short wavelength end of each spectrum.
(d) Identify the high frequency end of each spectrum.
(e) Which end of each spectrum is produced by electron transfers with the highest energy?



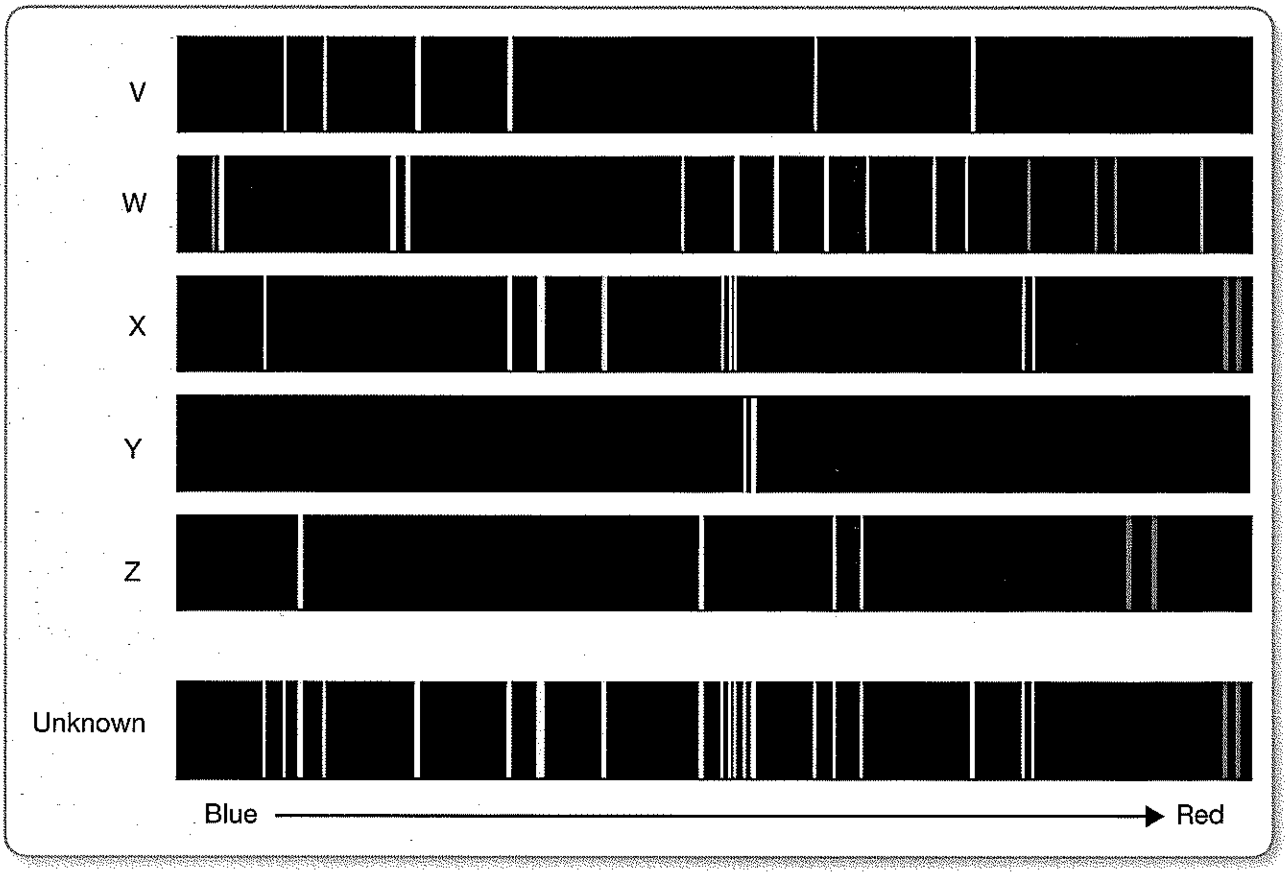
3. The diagram represents the spectrum of hydrogen.



The hydrogen spectrum

(a) Which of these lines would you see as blue?
(b) Which of the lines would have the highest frequency?
(c) Which line represents an electron transfer with the most energy?

4. 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.

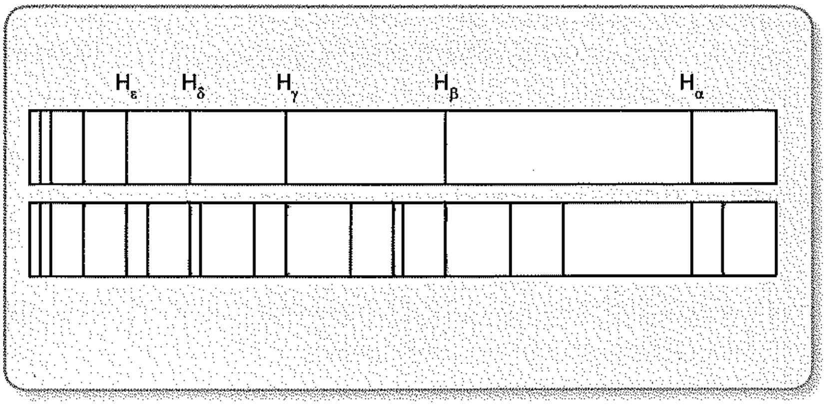
(c) How do we know that the top two spectra represent different elements?

(d) The spectra of elements are sometimes referred to as the 'fingerprints' for the elements. Why is this analogy made?

5. 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.

(b) What evidence is there that elements other than hydrogen are in this star?



SET 20 Max Planck – The Beginning of Quantum Theory

1. (a) State the three problems facing scientists in the late 1800s in their efforts to explain radiation emitted from hot objects.

(b) Explain, with the aid of a diagram, the concept of a cavity radiator.

(c) Explain the concept of a black body.

(d) Why did Planck develop the idea of a cavity radiator to do his black body radiation experiments?

(e) Explain how a cavity acts as a black body.

2. (a) How did Planck explain the emitted radiation from hot objects?

(b) State the three ideas in the theory Planck proposed to explain the observations in black body radiation.

(c) Planck's statements do not explain why the peak radiation in a black body radiation curve indicated its surface temperature. Use the kinetic theory of matter to explain this observation and show how it fits in with Planck's ideas.

(d) Describe the difference between the factors affecting the amount of energy carried by a matter wave, and the amount of energy carried by an electromagnetic wave.

(e) Explain the idea of a quantum of energy.

3. (a) What is an electron volt?

(b) What is the joule equivalent of an electron volt?

(c) Why do we have a unit like the electron volt?

4. Which phrase best explains the idea of 'quanta' of energy?

(A) Discrete bursts.

(B) Finite values.

(C) Small packages.

(D) Specific amounts.

5. 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.

(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.

6. 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.

7. What is meant by the idea of quanta?

(A) Charged particles can carry only particular amounts of energy depending on their frequency.

(B) The energy gaps between electron orbits in atoms can have only 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.

8. 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.

9. Which choice best describes the source of the energy emitted by a hot object as proposed by Planck?

(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.

10. Which choice best describes the source of the energy emitted by a hot object as proposed by modern quantum theory?

(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.

11. Which of the following was *not* an observation from Planck's black body radiation experiments?

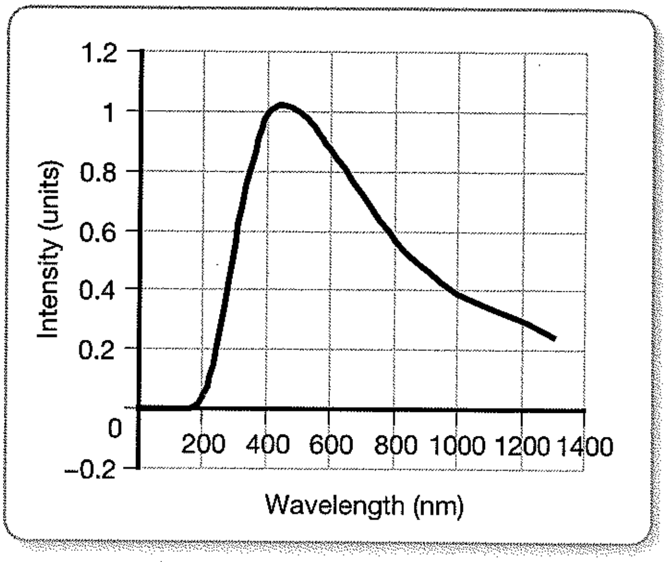
(A) The general shape of the radiation curve is the same for all materials.

(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.

12. 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.

13. 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.

SET 21 Wien's Displacement Law

1. (a) State Wien's displacement law.
   (b) Sketch a series of graphs to illustrate Wien's displacement law.
   (c) Explain the shape of these graphs.
   (c) Explain why it is called Wien's *displacement* law rather than just Wien's law.

2. Give three examples of Wien's law or our use of Wien's law.

3. 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, and
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 1600 K?
   (b) The average temperature of space is 2.725 K. It is thought that this energy is remnant energy from the Big Bang event. What is the wavelength of the radiation in space according to this data?
   (c) The surface temperature of the star Betelgeuse is about 2400 K. What is the peak radiation frequency of the radiation curve for Betelgeuse, and that colour would we perceive it to be?

4. (a) The surface temperature of Rigel is 12 500 K. What will be the peak wavelength of the light it emits in its black body radiation curve?
   (b) What colour in the visible spectrum should this light be?
   (c) Acrux has a surface temperature of 30 000 K. What will be the peak wavelength of the light it emits in its black body radiation curve?
   (d) What colour in the visible spectrum should this light be?
   (e) Vega has a surface temperature of 9500 K. What will be the peak wavelength of the light it emits in its black body radiation curve?
   (f) What colour in the visible spectrum should this light be?
   (g) Wolf 359 has a surface temperature of 3000 K. What will be the peak wavelength of the light it emits in its black body radiation curve?
   (h) What colour in the visible spectrum should this light be?

5. (a) Lizards 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 lizards which are at a daytime temperature of 20°C.
   (b) What is the frequency of this radiation?
   (c) Where is this in the electromagnetic spectrum?
   (d) Could we use an appropriate detector to find lizards in the forest under these conditions?

SET 22 Energy from the Sun

1. (a) What is the Stefan-Boltzmann law, also known as Stefan's law?

(b) Give the mathematical formula for Stefan's law, defining each term in the equation.

2. (a) The radius of the Sun is 6.9×10^5 km. In square metres, what is its total surface area?

(b) The energy output of the Sun is 6.41×10^7 W for every square metre of surface area. What is the total energy output of the Sun?

(c) What is the total energy output per second of a star better known as?

(d) Using the Stefan's law equation, derive an equation for the luminosity, L, of a star.

(e) Using this equation, calculate the surface temperature of the Sun based on the data given and calculated in your answers above.

(f) How accurate is this figure?

(g) Although the error is small, what could account for it?

3. The solar luminosity measured at the top of the Earth's atmosphere is known as the solar constant (I_o). This can be calculated by dividing the total energy emitted from the Sun by the surface area over which the sunlight falls at the position of the Earth.

(a) Taking the distance of the Earth from the Sun as 150 000 000 km, calculate the total surface area of the total sphere around the Sun at this distance.

(b) Calculate the area of the surface of the Earth exposed to the Sun's radiation. Take the radius of Earth as 6780 km.

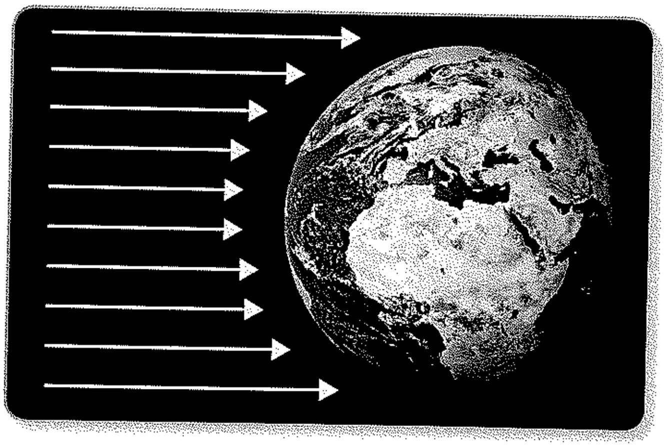
(c) What fraction of the sphere around the Sun at the Earth's distance (answer (a)) is the surface area of the Earth exposed to the Sun's radiation?

(d) Use your answer to (c) to calculate the amount of solar energy falling on the exposed surface of the Earth.

(e) Now determine the solar energy falling on each square metre of the Earth's surface by dividing your answer to (d) by your answer to (b), i.e. the solar constant.

4. Taking the intensity of the Sun's energy at the surface of the Sun as 6.41×10^7 W and assuming that the energy source is at the centre of the Sun, use the inverse square law to calculate the intensity of the solar radiation at the Earth's surface. (That is compare the intensity at the surface of the Sun with the intensity at 150 000 000 km from the surface which is at Earth.)

5. Consider the diagram showing the Sun's rays hitting the curved surface of the Earth.



(a) This diagram indicates that the calculations made above are all incorrect. Why?

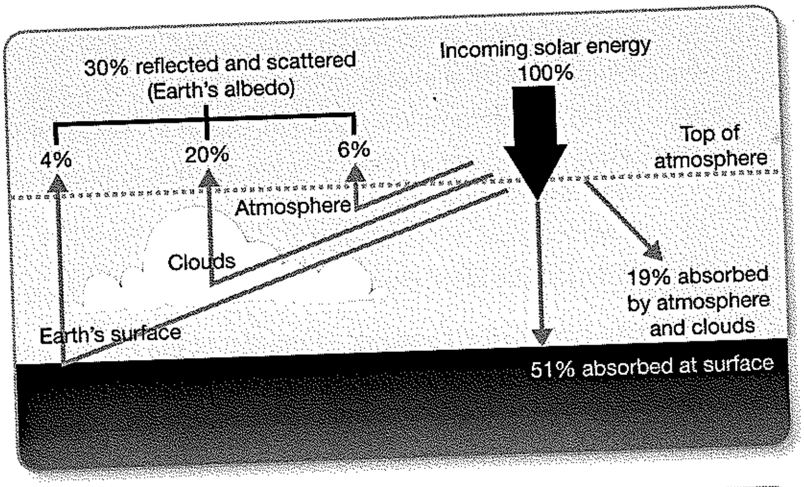
(b) If the curvature of the Earth was taken into account, how would this affect the magnitudes of the calculations made above?

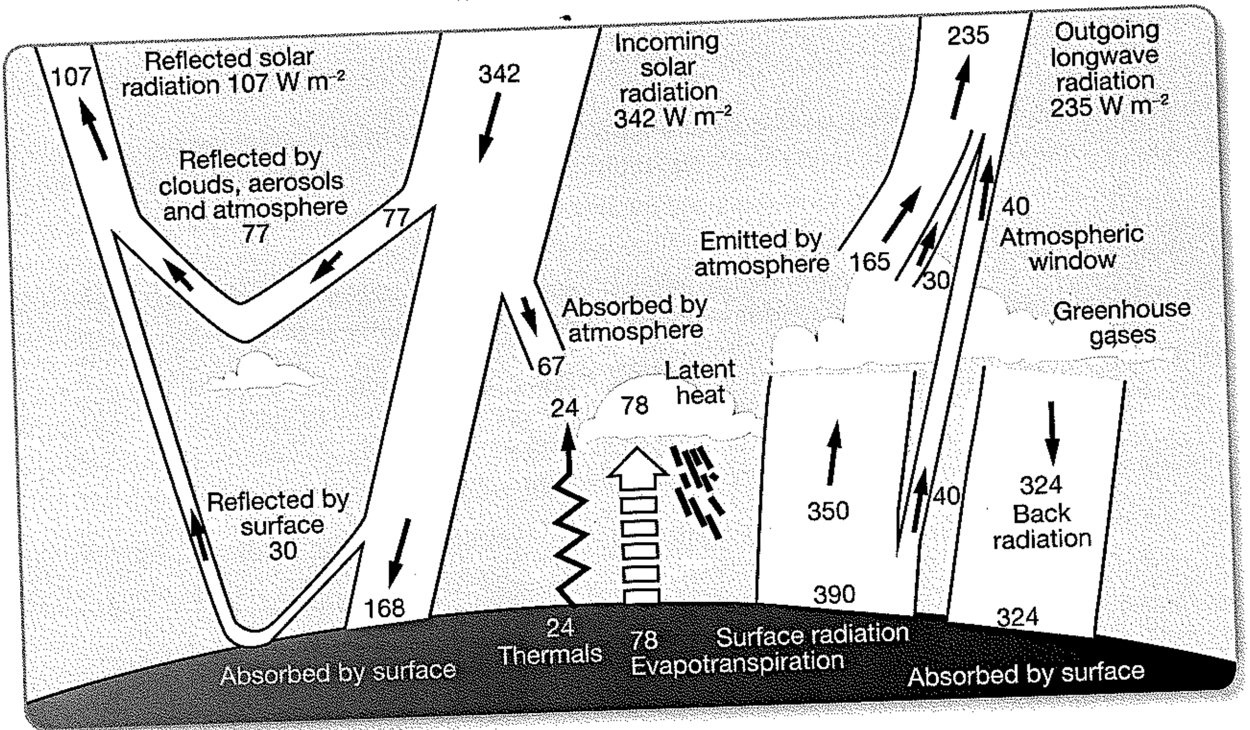
(c) Why should installers of solar energy panels take this idea into consideration when determining how many panels are required to generate a particular amount of solar electricity?

SET 23 The Earth's Energy Balance

1. (a) What is meant by the term 'Earth's energy balance'?
   (b) One discussion taking place across the world today is that of climate change. What is believed, by those who maintain that climate change is occurring, to be the cause of climate change?
   (c) Give four reasons why the opponents of climate change disbelieve that it is occurring.

2. The diagram shows what happens to incoming solar energy.
   (a) Comment on the use of this diagram by a teacher to illustrate the Earth's energy balance.
   (b) Explain why the diagram below is a better diagram to use.





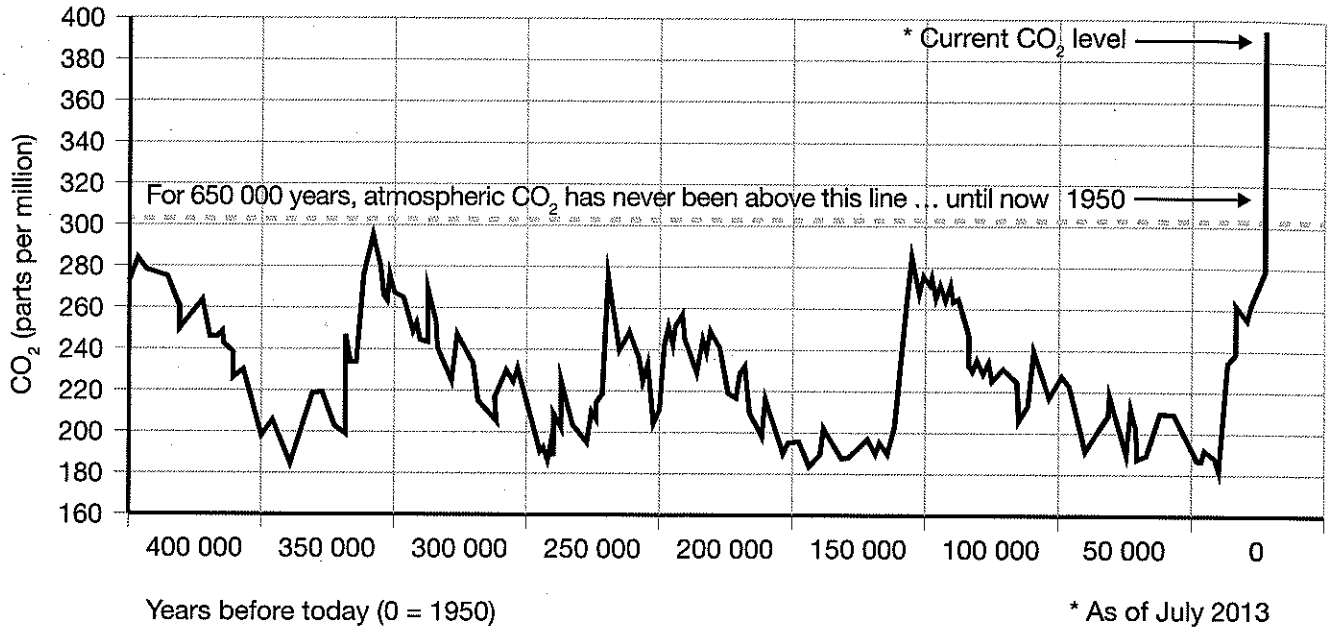
   (c) Show that in this diagram, the energy input to the Earth's surface is balanced by the energy output from the surface.
   (d) Show that in this diagram, the energy input to the Earth's atmosphere is balanced by the energy output from the atmosphere.
   (e) Show that in this diagram, the energy input to the Earth from space is balanced by the energy output from Earth to space.
   (f) According to these figures, there is no imbalance anywhere, so how is global warming accounted for in a diagram like this? Explain your answer.

3. (a) What is the greenhouse effect?

(b) What is/are the main cause(s) of the greenhouse effect?

(c) Opponents of the greenhouse effect being responsible for the increase in the Earth's temperature state that the current levels are within the range of past variations in the Earth's temperature over time and may be due to other, natural causes. Give three possible natural causes for the increase in greenhouse gases in the atmosphere.

(d) Comment on the validity of the idea expressed in (c) after looking at the following graph.



(e) Two students were discussing the greenhouse effect.

Mary said: 'If there is an increase in carbon dioxide in the air, then plants will photosynthesise more efficiently and grow faster, thus maintaining the balance'.

John said: 'But the increased carbon dioxide will result in an increase in the greenhouse effect and this will cause the surface temperature to rise, evaporating more moisture from the soil and limiting plant growth'.

Evaluate these two statements.

4. You may need to do some research to answer this question.

A seldom discussed impact of increased carbon dioxide levels in the atmosphere is the increase in ocean water temperature and acidity and its effect on phytoplankton.

(a) What is phytoplankton?

(b) What are the two main roles of phytoplankton in maintaining an energy balance on Earth?

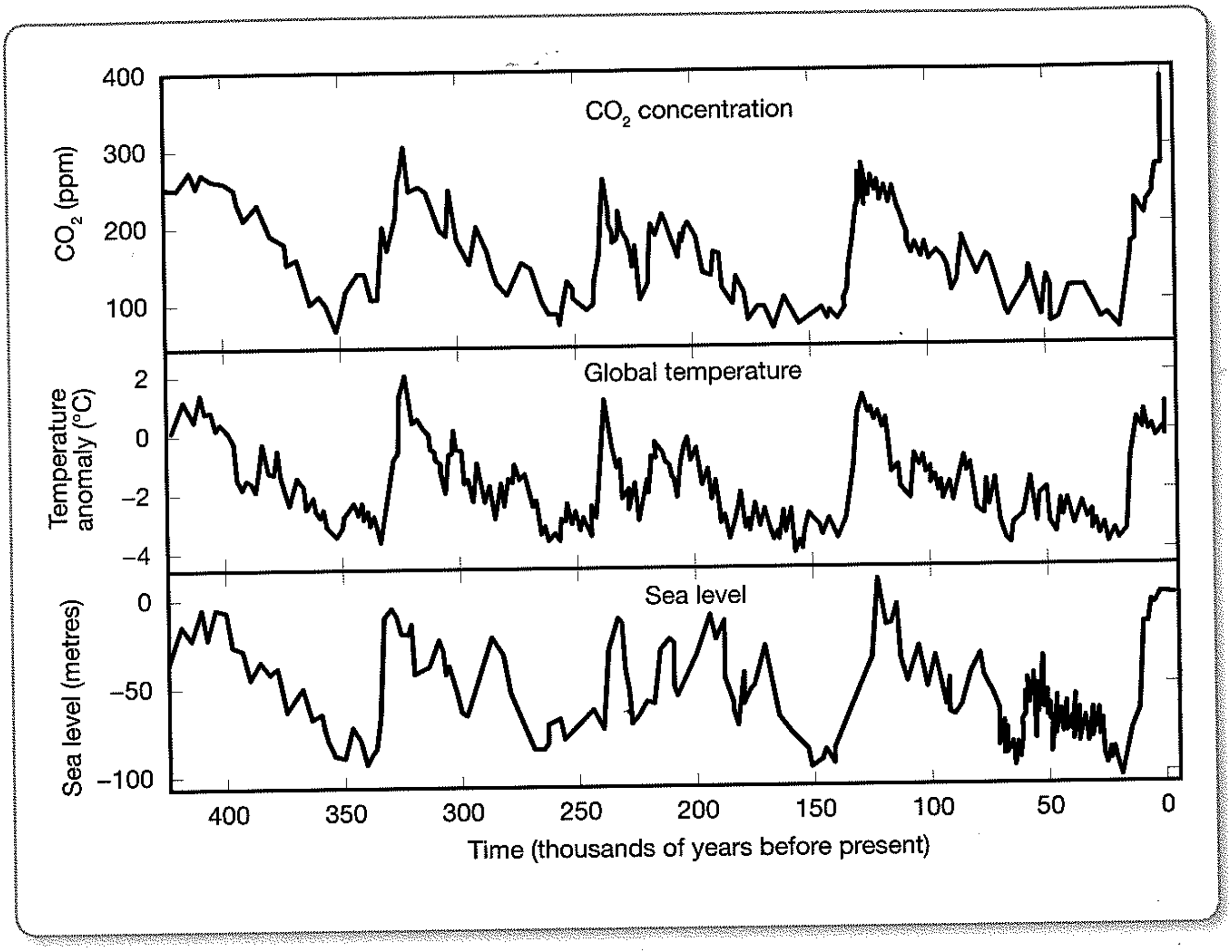
(c) What will be the effect of more carbon dioxide dissolving in ocean waters on the ocean water?

(d) What may be the effect of this change on phytoplankton?

(e) What might be the effects on phytoplankton of an increase in temperature of the ocean's surface waters.

(f) How would this (answer (e)) impact on the food chains of Earth?

5. Consider the following graphs.



(a) Comment on the correlation between the three sets of information given in the graphs.

(b) How do the carbon dioxide levels since 1950 affect this correlation?

(c) Would data like this support the opponents or the proponents of global warming? Justify your answer.

(d) What has been set at zero on the *y*-axis scaling?

(e) Hypothesise what the major cause of the changes in sea level would have been over the 400 000 years.

(f) According to this data, what is the cause of the changes in global temperature shown?

6. Consider the following.

- In 1910, Glacial National Park in Montana had 150 glaciers. Today it has 25.
- Analysts predict that food and water shortages due to global warming may lead to increased military conflicts across the world.
- In the last 20 years it is estimated that over one million species of organisms on Earth have become extinct due to global warming, and that another one million will become extinct by 2050.
- 'Once people can feel the effects of global warming in their lives it wil be too late to prevent catastrophic disasters'. – Elizabeth Kolbert, 'The Sixth Extinction'.

Observations and predictions like these (and there are many many more – all bad) should stimulate governments, businesses, even individuals across the world to take steps to reduce their impact on global warming. Why don't they?

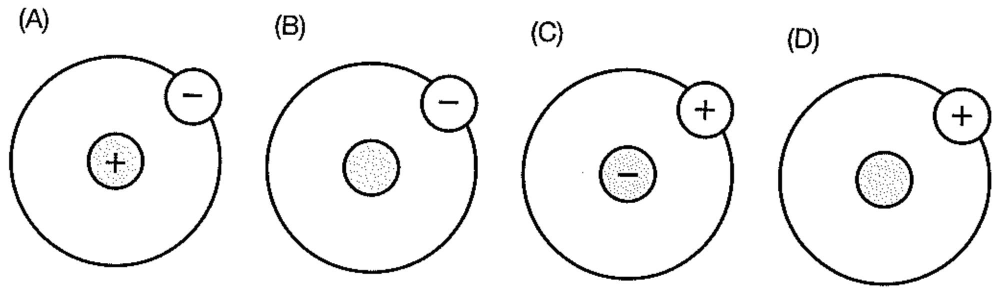
SET 24 The Rutherford Atom

1. (a) Describe the Rutherford model of the atom.

(b) What evidence or observations led Rutherford to devise this model?

(c) Describe the model of the atom that existed before Rutherford's model and who proposed it.

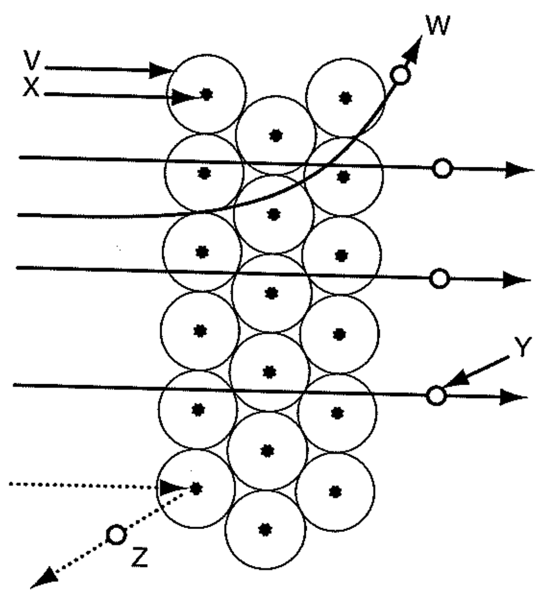
(d) Which diagram best illustrates Rutherford's model of the atom?



(e) What was the major weakness in the Rutherford model of the atom?

(f) Given your answer to (e), what was the implication of this for the model?

2. The diagram shows a schematic of Rutherford's alpha particle experiment.



(a) What are alpha particles?

(b) Write the chemical formula for an alpha particle.

(c) Explain why Rutherford used gold foil in this experiment.

(d) Explain why Rutherford used alpha particles in his experiment.

(e) Identify the labelled parts of the diagram.

(f) What was Rutherford's explanation for most alpha particles passing through the gold foil undeflected?

(g) What charge did Rutherford allocate to the nuclei of gold?

(h) Suggest why the sign of the charge on a gold nucleus could be negative or positive according to the results of this experiment.

(i) What observation led Rutherford to suggest that atoms had a small nucleus?

(j) What does the deflection of alpha particles by atoms in the gold foil suggest about the gold foil?

(k) At the time Rutherford was working on developing a new model for the atom, other scientists, like Max Planck were working on areas that were to impact significantly on our understanding of matter and its structure. Suggest a reason why Rutherford did not include these new ideas in his model.

(l) Assess the significance of Rutherford's model of the atom.

(m) Identify the weaknesses in the Rutherford model.

SET 25 The Bohr Atom

1. (a) Outline the historical influence on Bohr which led to his development of his model of the atom.
   (b) Outline the main ideas in Bohr's model of the atom.
   (c) How did Bohr's model explain the formation of spectral lines?

2. Find the missing values in the table.

	Energy (J)	Energy (eV)	Wavelength (m)	Frequency (Hz)
(a)		160		
(b)		10.0		
(c)		1.6		
(d)	4×10^{-12}			
(e)	5×10^{-18}			
(f)	9×10^{-16}			
(g)				4×10^{8}
(h)				6×10^{16}
(i)				8.5×10^{21}
(j)			5×10^{-7}	
(k)			1.5×10^{-11}	
(l)			2.5	

3. Calculate the photon energy in joules and electron volts of the following.
   (a) A radio wave of frequency 4×10^{6} Hz.
   (b) A microwave of frequency 8×10^{10} Hz.
   (c) Red light of frequency 4.0×10^{14} Hz.
   (d) Yellow light of wavelength 550 nm.
   (e) Green light of wavelength 425 nm.
   (f) Blue light of wavelength 380 nm.
   (g) Ultraviolet light of wavelength 200 nm.
   (h) X-rays of frequency 4×10^{20} Hz.
   (i) Gamma rays of frequency 5×10^{23} Hz.

4. (a) Explain the significance of the hydrogen spectrum in the development of the Bohr model of the atom.
   (b) Why was the hydrogen spectrum important to the development of the Balmer equation?
   (c) Why was the hydrogen spectrum important to the development of future models of the atom?

5. (a) 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 at the same time.
      (B) Electrons are in stable, circular orbits.
      (C) Electrons in stable orbits do not emit electromagnetic radiation.
      (D) Electrons absorb or emit energy when they change orbits.
   (b) What is a postulate as used in this context?

6. 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 orbit to another.

7. Why did Bohr state that electrons in stable orbits did not emit electromagnetic radiation? Because:
   (A) This did not fit in with the idea of quanta.
   (B) The orbits were assumed to be circular.
   (C) Normal atoms did not emit electromagnetic radiation.
   (D) Energy was emitted when electrons changed energy levels.

8. 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.

9. (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) Explain your answer.

10. How do the 'n's used in the Balmer and Rydberg equations relate to each other?

(A) They both refer to the quantum number of the electrons.

(B) They both refer to the orbits of the electrons.

(C) Balmer's refers to quantum numbers, Rydberg's refers to energy levels.

(D) Balmer's refers to energy levels, Rydberg's refers to quantum number levels.

11. (a) Why are all the energy values in the first spectrum energy diagrams negative?

(A) They represent energy emitted when electrons fall from higher to lower energy levels.

(B) They represent energy absorbed when electrons fall from higher to lower energy levels.

(C) They represent energy emitted when electrons move from lower to higher energy levels.

(D) They represent energy absorbed when electrons fall from lower to higher energy levels.

(b) Extension: Explain your answer.

12. Which choice is correct?

	Energy is emitted from an atom when:	Energy is absorbed by an atom when:
(A)	An electron moves from a lower energy level to a higher energy level.	An electron moves from a higher energy level to a lower energy level.
(B)	An electron moves from a higher energy level to a lower energy level.	An electron moves from a lower energy level to a higher energy level .
(C)	The atom loses an electron.	The atom is ionised.
(D)	The atom is ionised.	The atom loses an electron.

13. The diagram represents an atom as described by Bohr.

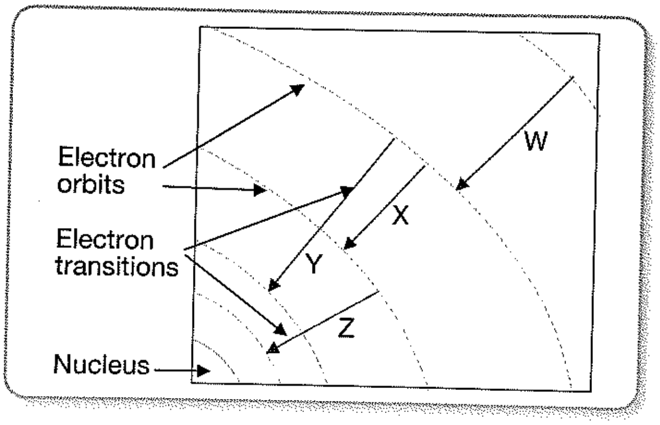
Which electron transition is part of the Balmer series?

(A) W

(B) X

(C) Y

(D) Z



SET 26 Energy Levels and the Bohr Atom

1. (a) Explain the origin of the Balmer equation.
   (b) Explain the origin of the Rydberg equation
   (c) Where does the Bohr model fit in with these equations?
   (d) What was the prediction made by the Rydberg equation that gave credibility to both the equation and to Bohr's model?
   (e) What other prediction did Bohr make about the hydrogen spectrum following his development of his model and his studying the Rydberg equation?
   (f) Explain how Bohr's model explained the missing lines in the absorption spectrum of very hot hydrogen compared to cold hydrogen.

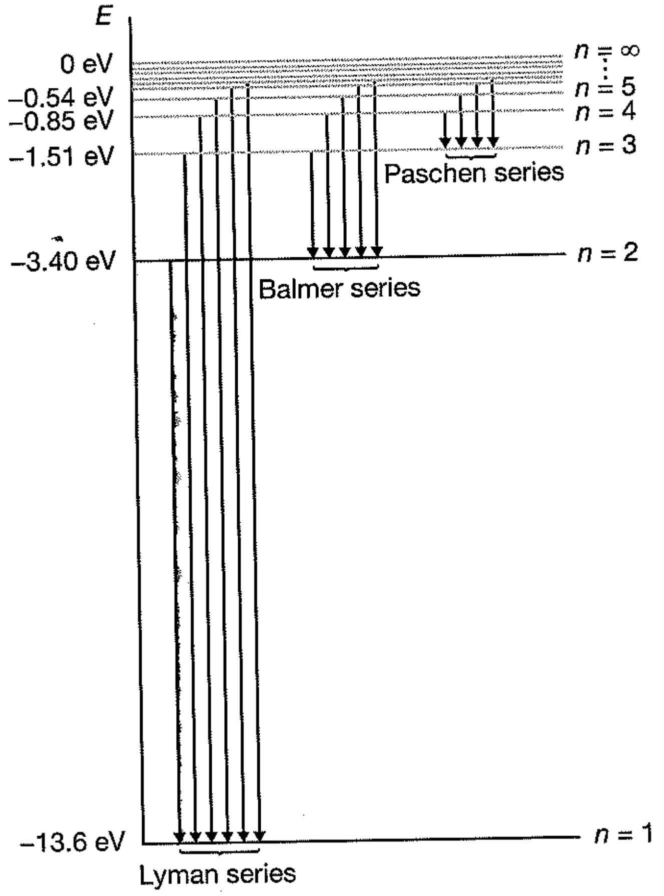
2. The diagram shows the electron transitions for the Lyman, Balmer and Paschen series in the hydrogen spectrum.

   The Rydberg equation is:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

   Where $R_H = 1.097 \times 10^7 \text{ m}^{-1}$
   n_i = initial level of electron
   n_f = final level of electron

   Use the Rydberg equation to verify the energy values of the following electron transitions as shown on the diagram:
   (a) From $n = 2$ to $n = 1$
   (b) From $n = 5$ to $n = 1$
   (c) From $n = 3$ to $n = 2$
   (d) From $n = 4$ to $n = 2$
   (e) From $n = 4$ to $n = 3$
   (f) From $n = 5$ to $n = 3$

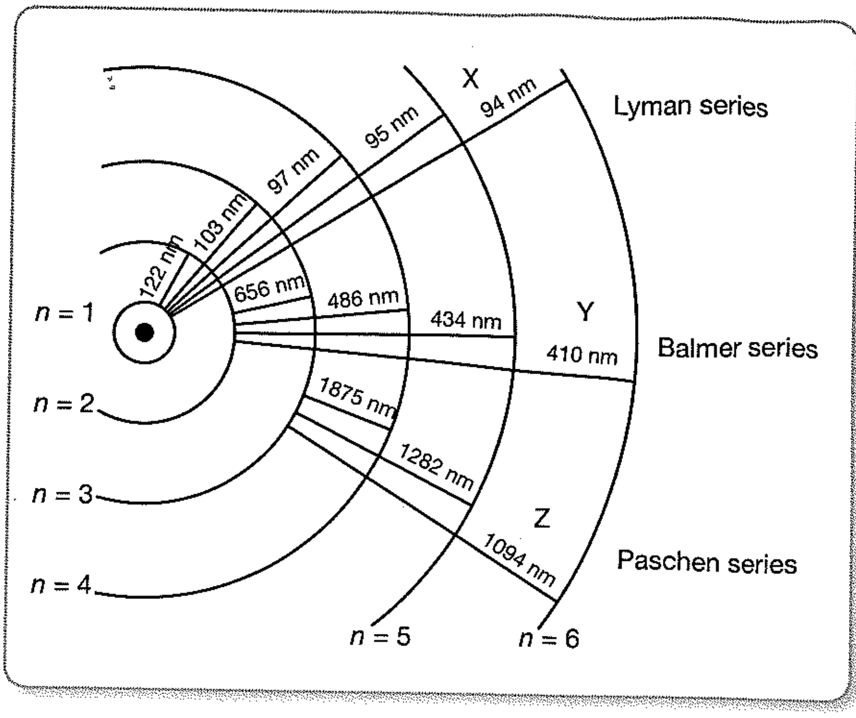


3. Two spectral lines for a particular element have frequencies 1.81×10^{14} Hz ($n = 6$ to $n = 3$) and 1.06×10^{14} Hz ($n = 4$ to $n = 3$).
   (a) Calculate the energy for each of these transfers in joules and eV.
   (b) Use this information to predict the energy value of another hydrogen line.
   (c) Use this information to predict the frequency of another hydrogen line.
   (d) State the energy level transfer for this frequency.

4. The diagram shows some of the spectral series of the hydrogen spectrum.

(a) Identify the series X, Y and Z.

(b) Why was the Balmer series discovered a significant time before the other series?



5. Using the information in the diagram, calculate the frequencies of the following electron transitions.

(a) $n = 5$ to $n = 3$

(b) $n = 4$ to $n = 2$

(c) $n = 1$ to $n = 6$

(d) $n = 3$ to $n = 2$

(e) $n = 2$ to $n = 6$

6. For each of the electron transfers in Question 5, calculate the energy involved in joules and in eV.

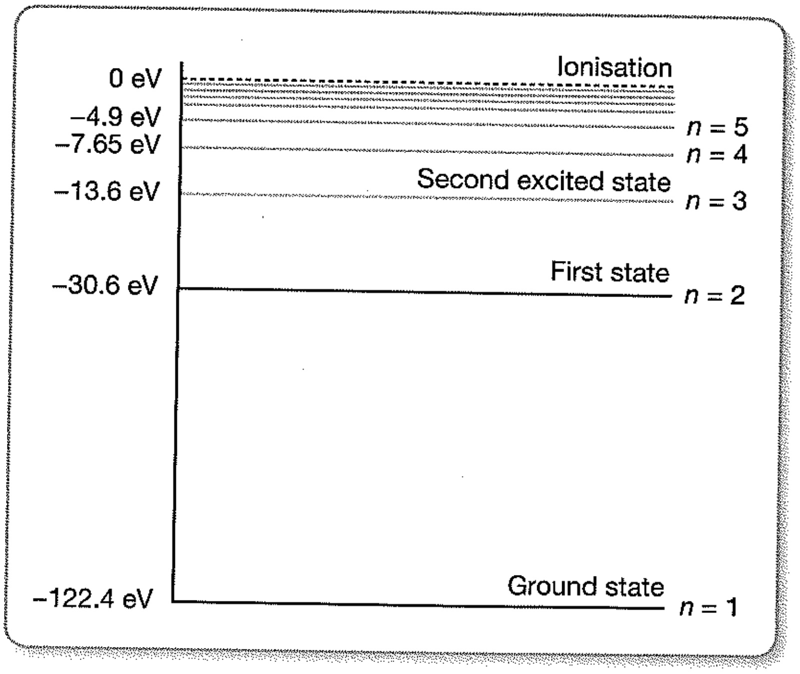
7. The diagram shows the energy levels in atoms of element X.

(a) What evidence is there in the diagram to allow us to say that X is not hydrogen?

(b) Explain why the energy values for diagrams like this are usually expressed as negative values.

(c) What would be the frequency of a photon of light which caused an electron in this atom to jump from $n = 2$ to $n = 4$?

(d) What type of electromagnetic radiation (minimum frequency) would ionise this element? Justify your answer.



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.

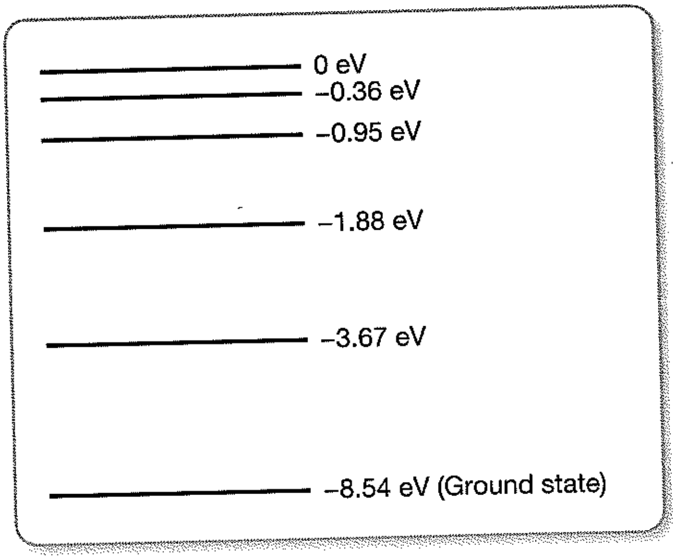
(b) Explain your answer.

9. (a) Which electron transfer represents the shortest wavelength line in an emission spectrum?
   (A) From $n = 2$ to $n = 6$.
   (B) From $n = 3$ to $n = 6$.
   (C) From $n = 6$ to $n = 2$.
   (D) From $n = 6$ to $n = 3$.
   (b) Justify your answer.

10. (a) Two lines in the spectrum of element X represent energy values of 2.5 eV and 0.65 eV. Predict the values of two other lines in the spectrum of element X?
   (A) 0.25 and 1.85 eV.
   (B) 1.85 and 3.15 eV.
   (C) 1.85 and 2.25 eV.
   (D) 1.95 and 3.15 eV.
   (b) Explain your answer.

Use the following information to answer the next SIX questions.

The diagram represents the energy levels for an atom of element X.



11. (a) What electron jump would a photon of energy 1.89 eV cause?
   (A) From $n = 2$ to $n = 3$.
   (B) From $n = 2$ to $n = 4$.
   (C) From $n = 3$ to $n = 4$.
   (D) It would not cause an electron jump.
   (b) Explain your answer.

12. (a) Which is equivalent in energy to an electron moving from $n = 5$ to $n = 2$?
   (A) An electron moving from $n = 5$ to $n = 4$ then from $n = 4$ to $n = 2$.
   (B) An electron moving from $n = 5$ to $n = 2$ then from $n = 2$ to $n = 3$.
   (C) An electron moving from $n = 6$ to $n = 3$.
   (D) An electron moving from $n = 4$ to $n = 3$ then from $n = 3$ to $n = 2$.
   (b) Justify your answer.

13. (a) How many spectral lines could an electron produce falling from $n = 4$ to end at $n = 2$?
   (A) One only.
   (B) Two.
   (C) Three.
   (D) Four.
   (b) Justify your answer.

14. (a) What is the ionisation energy of the atom?
   (A) +0.36 eV
   (B) +4.87 eV
   (C) –8.54 eV
   (D) +8.54 eV
   (b) Explain your answer.

15. (a) An electron falls from $n = 4$ to $n = 2$. What energy would be released?
   (A) 0.95 eV
   (B) 1.52 eV
   (C) 2.72 eV
   (D) 3.31 eV
   (b) Explain your answer.

16. (a) Find the energy of the second line in the 'Balmer' series of this element.
   (A) 1.79 eV
   (B) 2.72 eV
   (C) 4.87 eV
   (D) 6.66 eV
   (b) Explain your answer.

SET 27 Limitations of the Bohr Model

1. (a) Use the Balmer equation given below to calculate the wavelength (in nm) of the radiation emitted in the energy level transfers given in the Balmer series of the hydrogen spectrum.

$$\lambda = b\left(\frac{n^2}{n^2 - 2^2}\right)$$

Where λ = wavelength in nm
b = 364.5 nm

Spectral line	Transfer from	λ (calculated) nm	λ (experimental) nm
H_α	3		656.21
H_β	4		486.07
H_γ	5		434.01
H_δ	6		410.12
H_ε	7		396.81
H_ζ	8		388.75
H_η	9		383.40
H_θ	10		379.50

(b) Compare your values with the experimentally measured values given in the table and comment on these comparisons in terms of the accuracy of each prediction.

(c) Use the Rydberg equation given below to calculate the wavelength (in nm) of the radiation emitted/absorbed in the energy level transitions given for each element.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^2} - \frac{1}{n_i^2}\right)$$

Where $R_H = 1.097 \times 10^7\ m^{-1}$
n_i = initial level of electron
n_f = final level of electron

Spectral line	Transfer from	λ (calculated) nm	λ (experimental) nm
H_α	3		656.21
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H_δ	6		410.12
H_ε	7		396.81
H_ζ	8		388.75
H_η	9		383.40
H_θ	10		379.50

(d) Compare your values with the experimentally measured values given in the table and comment on these comparisons in terms of the accuracy of each prediction.

(e) The table shows some of the spectral lines in the Lyman and Paschen series for hydrogen. Use the Rydberg equation to calculate the wavelengths of each of these lines.

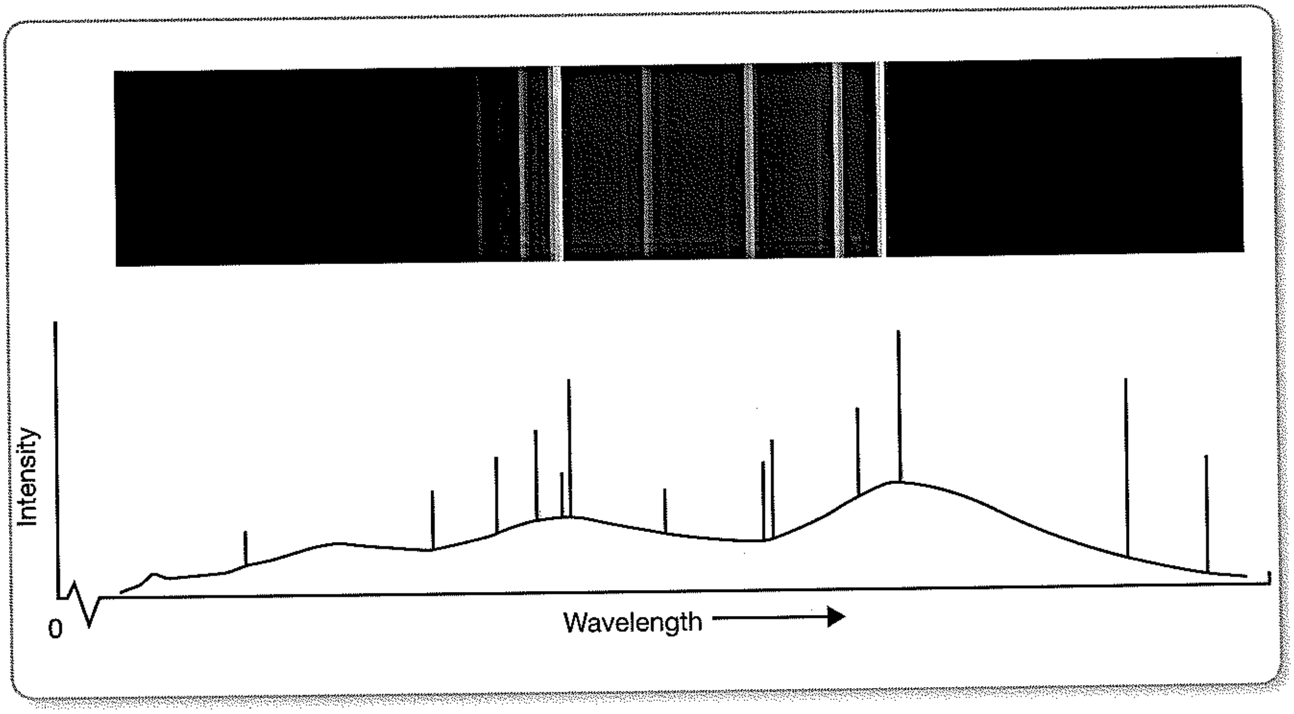
Spectral line	Transfer from	λ from Rydberg (nm)	λ experimental (nm)
Hydrogen Paschen	6 to 3		1099.45
Hydrogen Paschen	5 to 3		1280.80
Hydrogen Paschen	4 to 3		1882.38
Hydrogen Lyman	6 to 1		93.83
Hydrogen Lyman	5 to 1		95.13
Hydrogen Lyman	4 to 1		97.4
Hydrogen Lyman	3 to 1		103.1
Hydrogen Lyman	2 to 1		121.8

(f) Compare your values with the experimentally measured values given in the table and comment on these comparisons in terms of the accuracy of each prediction.

(g) Comment on the use of the Rydberg equation to predict the wavelengths of the lines in the hydrogen spectrum.

(h) Outline how your answers above illustrate a weakness in the Bohr atom. Suggest a reason for this weakness.

2. The diagram shows the spectrum of an element.



(a) What weakness in the Bohr model of the atom does this diagram illustrate?

(b) What is the current hypothesis for what is being observed here?

(c) In the hydrogen spectrum, the line representing the electron transfer from $n = 2$ to $n = 1$ is the brightest. Suggest a reason for this.

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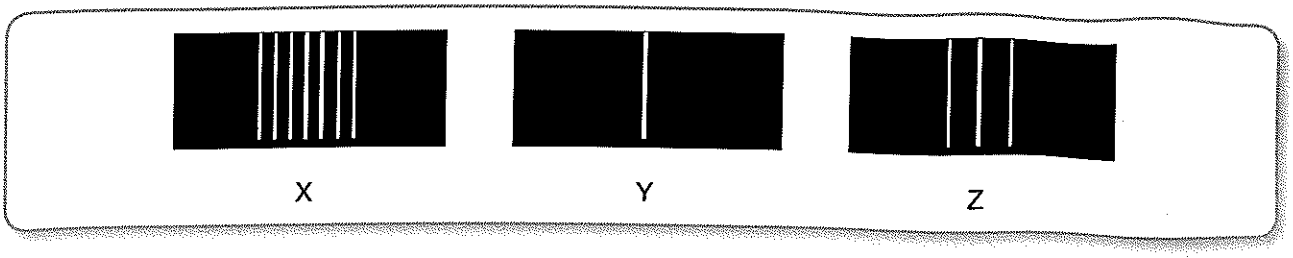
3. The diagrams show a spectral line in the hydrogen spectrum under normal conditions, when the hydrogen was burned between the poles of a strong magnet, and when the hydrogen was burned between the poles of very strong magnets.



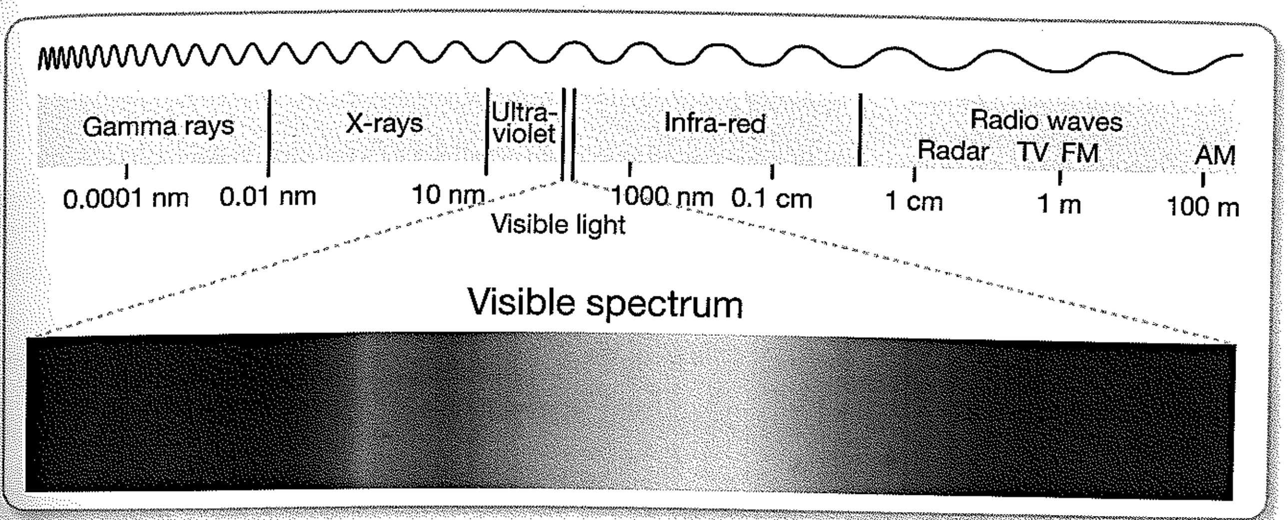
(a) Which observation, X, Y or Z, corresponds to the normal, strong magnetic field and very strong magnetic field?

(b) What names are given to these observations?

(c) What weakness in the Bohr model of the atom does this diagram illustrate?

(d) What explanation is given to explain this observation?

4. The diagram shows an uncoloured version of the continuous spectrum within the total spectrum of electromagnetic radiation.



(a) The Bohr model of the atom cannot account for a continuous spectrum. Why not?

(b) Which end of this spectrum is the high energy end? Justify your answer.

(c) The Bohr model cannot account for gamma and X-rays. Why not?

(d) There was no attempt by Bohr to account for anything but the visible spectrum. Explain why not.

5. Another major weakness in the Bohr model was more philosophical. What was this other weakness of the Bohr model?

6. (a) Actually, Bohr's postulates, made as a foundation for his model are also weaknesses in the model. What were Bohr's three postulates?

(b) Explain why each of these is a weakness in the model.

(c) If the Bohr model had such obvious weaknesses, why was it accepted, not only by the scientists of the day, but by scientists for many years to follow?

(d) Despite its weaknesses, the Bohr model is widely taught in high school as the 'current' model of the atom. Explain why this is so.

(e) If the Bohr model has so many weaknesses should it not be discarded? Justify your answer.

SET 28 Bohr and De Broglie

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?

(b) What was the more specific idea he had about electrons in 1924?

(c) How did de Broglie's idea about electrons support the Bohr model of the atom?

(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?

2. Consider the diagram.

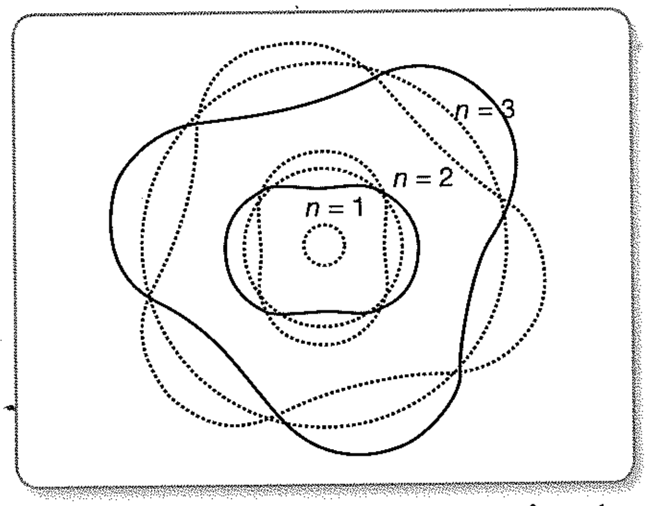
(a) What is this diagram showing?

(b) Write an equation for wavelength of the electron in the first orbit in this diagram ($n = 1$).

(c) Write an equation for wavelength of the electron in the second orbit in this diagram ($n = 2$).

(d) Write an equation for wavelength of the electron in the third orbit in this diagram ($n = 3$).

(e) Write an equation for wavelength of the electron in the nth orbit in this diagram ($n = n$).



3. Find the de Broglie wavelength of a 20 kg ball moving at 25 m s^{-1}.

4. (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) Would the de Broglie wavelength of a proton at the same speed, mass 1.673×10^{-27}, be larger or smaller than this? Explain your answer.

5. Proton X is travelling at 0.02 c. Proton Y is travelling at 0.04 c. Compare their de Broglie wavelengths.

6. 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?

7. What is the wavelength of an electron (mass 9.11×10^{-31} kg) travelling at 7.5×10^{5} m s^{-1}?

8. What is the wavelength in metres of a proton travelling at 60% of the speed of light? Take the mass of the proton as 1.673×10^{-27} kg.

9. Find the wavelength of a hydrogen atom (mass 1.674×10^{-27} kg) moving at 25 m s^{-1}.

10. Find the velocity of an atom of helium, mass 6.649×10^{-27} kg, with a de Broglie wavelength of 2800 nm.

11. Find the wavelength of an object weighing 10 kg and moving at 160 km h^{-1}.

12. A bullet of mass 15 g travels at 1600 m s^{-1}. Find the de Broglie wavelength of the bullet at that speed.

13. Calculate the velocity of an electron (mass 9.109×10^{-31} kg) having a de Broglie wavelength of 5.4×10^{-10} m.

14. Calculate the velocity of a neutron, mass 1.675×10^{-27} kg, with a wavelength of 4.2×10^{-11} m.

15. Find the de Broglie wavelength of a neutron (mass 1.675×10^{-27} kg) moving at 0.01 c.

16. A bird of mass 150 g flies at 12 m s^{-1}. Find the de Broglie wavelength of the bird at that speed.

17. Calculate the velocity of an insect of mass 0.5 g having a de Broglie wavelength of 1.06×10^{-29} m.

SET 29 Pauli, Quantum Numbers and the Exclusion Principle

1. (a) What was the stimulus for Pauli to begin thinking about the changes to atomic structure that he eventually proposed?

(b) State the four proposals Pauli put forward in regards to the quantum numbers of electrons.

(c) State the Pauli exclusion principle that related to these quantum numbers.

(d) Which of these proposals related to the solution to the Zeeman effect?

2. (a) Bohr and Pauli had two similarities in their ideas about the structure of atoms. What were these similarities?

(b) What advantages did Bohr and Pauli have in developing their ideas that atomic scientists before them did not have?

(c) Contrast the motives Bohr and Pauli had for studying atomic structure.

(d) In what way did Pauli's work support that of Bohr?

(e) Explain the scientific importance of Bohr and Pauli arriving at the same idea from different directions.

3. Explain how the cartoon is a very simplified statement of the Pauli exclusion principle.

4. (a) What was Pauli's contribution to atomic structure?

(A) He was able to measure the momentum of electrons in orbit.

(B) He was able to explain the shape of the different electron orbits.

(C) He defined electrons in terms of four different quantum numbers.

(D) He derived the same equations as Bohr and de Broglie from a different perspective.

(b) What was the implication of this idea for the distribution of electrons around nuclei?

5. (a) What is the basic idea in the Pauli exclusion principle?

(A) Any atomic orbit can hold a maximum of two electrons with opposite spin.

(B) There are four quantum numbers needed to define any electron in an atom.

(C) The principal quantum number is the orbital quantum number.

(D) Electrons must occupy suborbits within their main orbits.

(b) What observations about the sizes of atoms did this explain?

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SET 30 Schrödinger, Heisenberg and Dirac

1. In 1923, Pauli, Heisenberg and Schrödinger were all working on an alternate to the Bohr model of the atom.

(a) What type of alternate model were they trying to develop?

(b) Why was an alternate model deemed necessary?

(c) Why was the Schrödinger model accepted by the scientific world rather than Heisenberg's model?

(d) On what evidence was the new model based?

(e) While this physics course discusses the new model(s) briefly, no detail is required. Explain why.

(f) As a result of the new model, what changes were made to Bohr's solar system model?

(g) Why were theses changes made?

2. In 1925 and 1926 a debate raged between Heisenberg and his closest colleagues on the one hand, supporting the 'matrix mathematics' form of quantum mechanics, and Erwin Schrödinger and his colleagues on the other (stimulated by de Broglie's matter wave theory), who supported a 'wave mechanics' model.

(a) Schrödinger is quoted in 1926 as saying: 'I knew of Heisenberg's theory, of course, but I felt discouraged, not to say repelled, by the methods of transcendental algebra, which appeared difficult to me, and by the lack of visualisability!'

This caused Heisenberg to respond: 'The more I think about the physical portion of Schrödinger's theory, the more repulsive I find it. What Schrödinger writes about the visualisability of his theory 'is probably not quite right,' in other words it's rubbish.'

Discuss the attitude of these two scientists towards each other's work. (*Note:* Scientific answer not expected here.)

(b) Outline the reactions of other physicists of the day to the models being developed by Heisenberg and Schrödinger making sure you give the reason(s) for the difference in these attitudes.

(c) Most physicists were slow to accept Heisenberg's 'matrix mathematics' and its predictions for atomic structure. Explain why.

(d) Most physicists welcomed Schrödinger's more understandable 1926 wave mechanics model, often called the 'electron cloud' model, than Heisenberg's model. Explain why.

(e) In May 1926 Schrödinger published a proof that Heisenberg's matrix mechanics and his own wave mechanics gave the same results. How does a discovery like this relate to the scientific method?

(f) Intense debates by scientists of the period showed that neither Schrödinger's nor Heisenberg's model could explain all atomic behaviour satisfactorily and as a result later scientists were to modify their ideas.

(i) Does this imply that their model was incorrect and therefore useless?

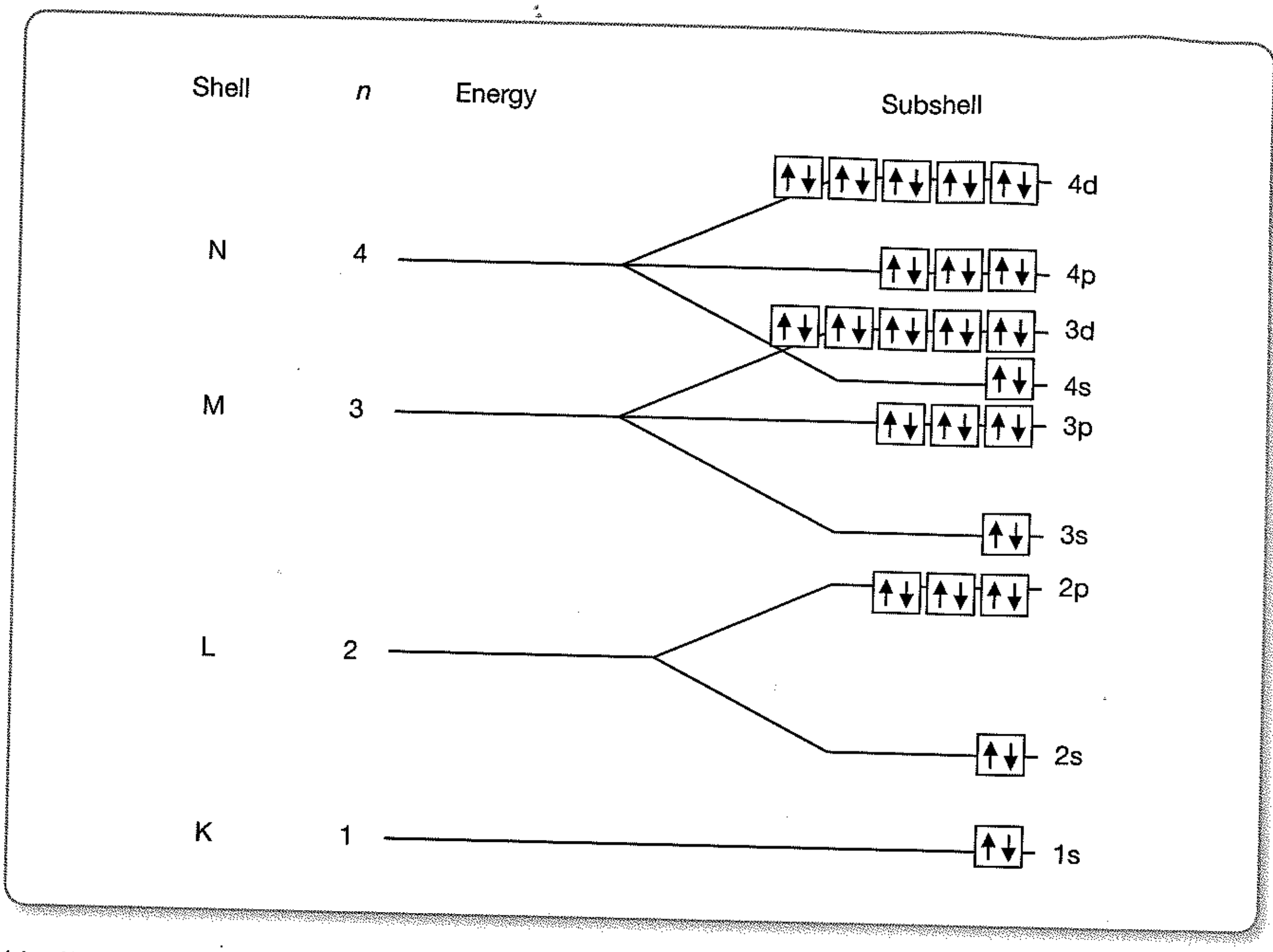
(ii) What does this show about the nature of scientific discovery in general?

3. (a) Outline Paul Dirac's contribution to the developing quantum model of atomic structure in. the 1920s.

(b) What additional concept did Dirac's mathematics predict?

(c) Dirac's equations were developed by combining Heisenberg's and Schrödinger's work. In 1934, Heisenberg reworked Dirac's equations resulting in a new model. What improvements resulted from this reworking of Dirac's equations?

4. The diagram below summarises some of the ideas developed by Schrödinger, Heisenberg and Pauli. Use it to answer this question.



(a) What aspect of atomic structure is the diagram showing?

(b) What do the letters K, L, M and N represent?

(c) What do the numbers 1, 2, 3 and 4 in the column headed '*n*' represent?

(d) What do the labels 1s, 2s, 2p etc on the right-hand side of the diagram represent?

(e) These labels suggest that the particular labels 4s and 3d are out of order. What is the reason for this?

(f) What do the arrows in the boxes represent?

(g) What does each box containing the two arrows represent?

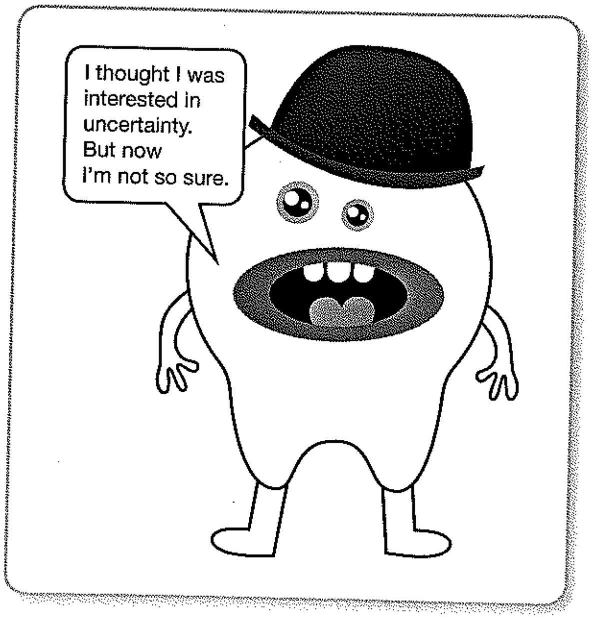
(h) Why are the arrows drawn in different directions?

(i) Why was this model proposed by these scientists?

(j) Outline how this model can be used to explain the Zeeman effect.

5. (a) The Heisenberg uncertainty principle is very often confused with the observer effect. *Clearly* distinguish between the two ideas.

(b) Give the most common example often quoted when discussing the Heisenberg uncertainty principle.



SET 31 Albert Einstein and the Photoelectric Effect

1. (a) What is the photoelectric effect?

(b) Who first observed the photoelectric effect, when, and in what situation did this person observe the photoelectric effect?

(c) Some texts state that this person, in discovering the photoelectric effect, shone ultraviolet light on the apparatus he was using in his intended experiment, and noticed that this caused what has now become known as the photoelectric effect. What is incorrect in this statement and why?

(d) It was left to other scientists to follow up on this person's observation of the photoelectric effect. Why?

2. (a) What property of a water wave determines the amount of energy it carries?

(b) What property of a soundwave determines the amount of energy it carries?

(c) What property of electromagnetic radiation determines the amount of energy it carries?

(d) What observation, which caused serious problems for scientists attempting to understand and explain the photoelectric effect supports your answer to (c)?

(e) What property of photoemitting materials was invented to explain this observation?

3. Scientists made the following observations in their experiments with the photoelectric effect. Some of these observations were unable to be explained by existing theories. For each observation outline Einstein's explanation of the observation.

(a) As the light intensity falling on the photocathode increases, the current flowing increases, but the energy of each electron does not increase.

(b) As the anode voltage increases, the photoelectric current increases but to a maximum value.

(c) If the polarity of the anode voltage is reversed, there is a particular value for each metal which stops the photoelectric current, the stopping voltage.

(d) If the frequency of the incident light on the photocathode drops below a threshold frequency (f_0), no photoelectrons are emitted, no matter how intense the light.

4. One of the observations scientists observed about the photoelectric effect was that no matter how intense the incident light was, if its frequency was below a particular level, no photoemission would occur.

(a) What is this 'particular level' now known as?

(b) Explain the observation scientists expected according to classical theory.

(c) Distinguish between classical and quantum theories.

5. 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?

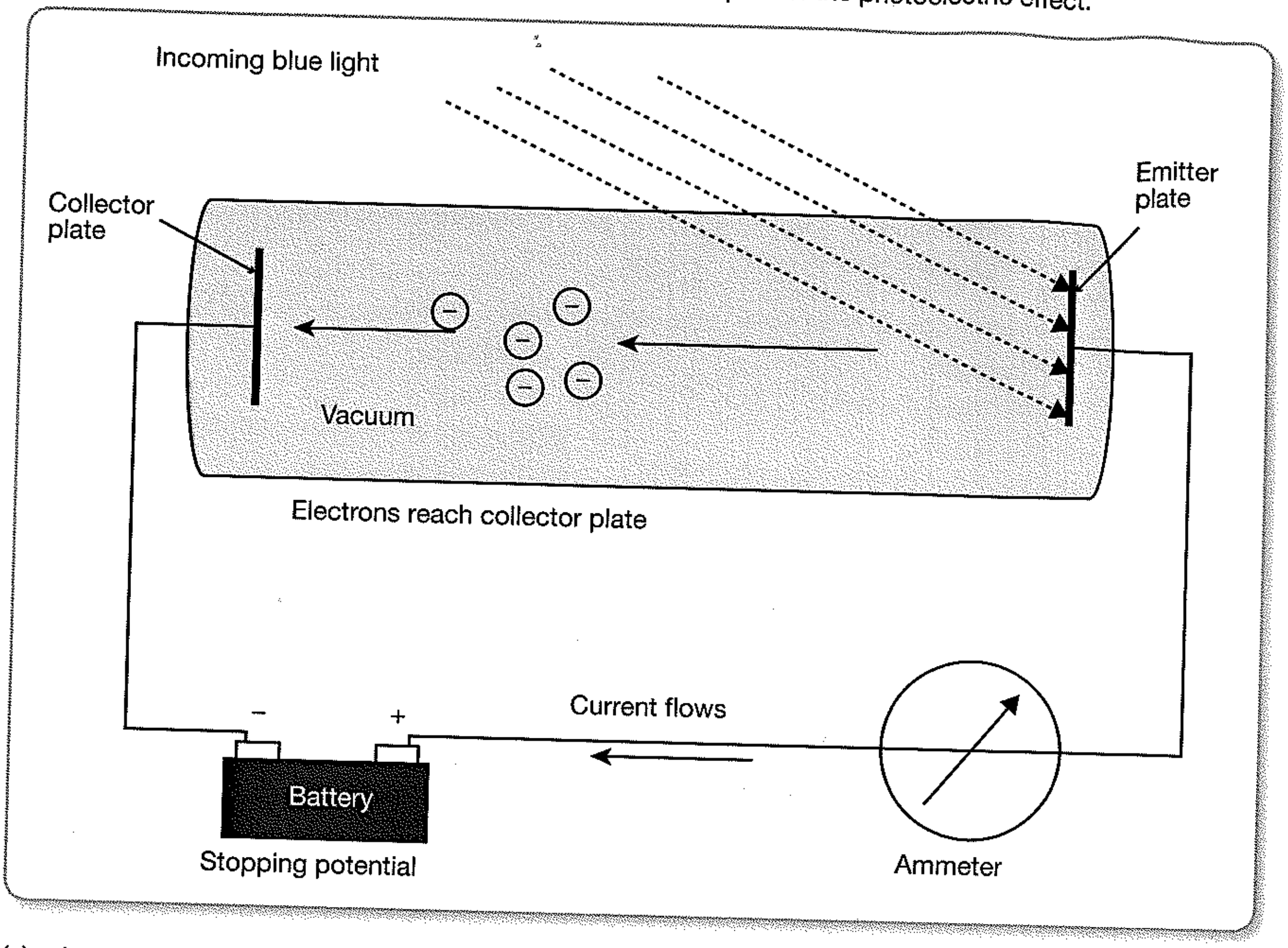
(b) How does Einstein's explanation explain this observation?

(c) Explain the statement: 'Intense light is not light with more energy, it is simply more photons, each with the same energy.'

6. (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. The diagram shows apparatus used to study a particular aspect of the photoelectric effect.



(a) In terms of the energy involved, describe what happens to the atoms on the surface of the cathode when the blue light hits them.

(b) As a result of this energy exchange, describe the energy of each electron as it leaves the surface of the emitter.

(c) Describe the subsequent motion of the electrons towards the collector (anode) justifying your answer.

(d) In order to obtain the vital readings required in this experiment, describe the next step(s) the student doing the experiment would take.

(e) What would be the purpose of these steps (answer (d)?

(f) What hypothesis is the student working on in taking these steps?

(g) Identify what can be determined by doing this.

(h) Describe what the equations $hf - \Phi = \frac{1}{2}mv^2 = qV_s$ have to do with this experiment.

(i) Justify the direction of the current flow shown in the diagram above.

(j) Predict what would happen to the reading on the ammeter if the blue light was replaced with a source of ultraviolet light. Justify your answer.

(k) Predict what would happen to the reading on the ammeter if the blue light was replaced with a red light. Justify your answer.

(l) Predict what would happen if the intensity of the blue light was increased.

(m) How would an increase in the intensity of the incident blue light affect the results of the experiment? Justify your answer.

SET 32 More about the Photoelectric Effect

1. (a) Light above the threshold frequency is shone on a photoemitting cathode. How does the kinetic energy of the photoelectrons change as the intensity of the light increases?

(A) It increases.
(B) It decreases.
(C) It stays the same.
(D) It increases to a maximum value.

(b) Justify this answer.

2. (a) Which beam of light is most likely to cause photoemission of electrons from a surface?

(A) Yellow beam.
(B) Red beam.
(C) Green beam.
(D) Blue beam.

(b) Justify this answer.

3. (a) A photoemitter produces a small photocurrent when dull yellow light shines on it. Which statement predicts what happens when intense orange light shines on it?

(A) Photocurrent decreases because orange light has longer wavelength.
(B) Photocurrent decreases because orange light is more intense than the yellow light.
(C) Photocurrent increases because orange light has higher frequency than the yellow light.
(D) Photocurrent decreases because orange light has higher frequency than the yellow light.

(b) Justify this answer.

4. How much energy does a photon with wavelength 450 nm have?

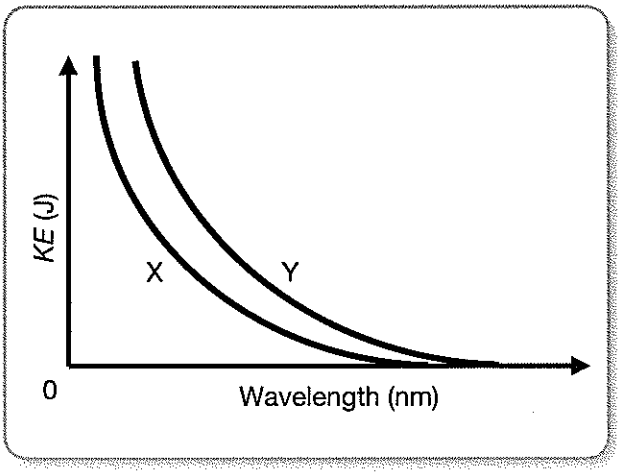
(A) 2.98×10^{-24} J (B) 2.98×10^{-26} J (C) 4.42×10^{-21} J (D) 4.42×10^{-19} J

5. (a) Monochromatic light causes a photocurrent from a surface. What happens if the intensity of this light gradually increases?

(A) The photocurrent will gradually increase.
(B) The photocurrent will gradually increase to a maximum value.
(C) There will be no change in the photocurrent.
(D) The photocurrent will increase to a maximum value then start to decrease again.

(b) Justify this answer.

6. 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.



(a) 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.

(b) Justify this answer.

7. (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.

8. 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

(a) Which metals will emit electrons when they are hit by photons of frequency 7.5×10^{14} hertz?

(A) Aluminium and magnesium only.

(B) Aluminium, magnesium and zinc only.

(C) Zinc, sodium and caesium only.

(D) Zinc and caesium only.

(b) Justify this answer.

9. (a) 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?

(A) 1.14 eV

(B) 1.82 eV

(C) 4.14 eV

(D) 7.86 eV

(b) Justify this answer.

10. What will increase the current from a photoemitter?

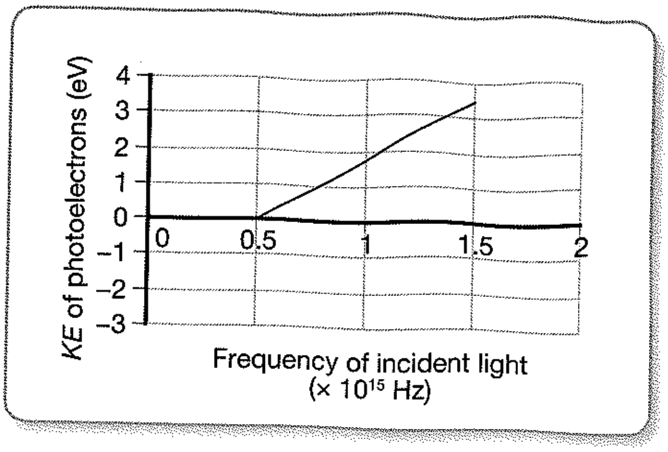
(A) Shine more intense light on it.

(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.

11. Consider the following information about a photoemitting substance, X.



What is the value of the work function for substance X?

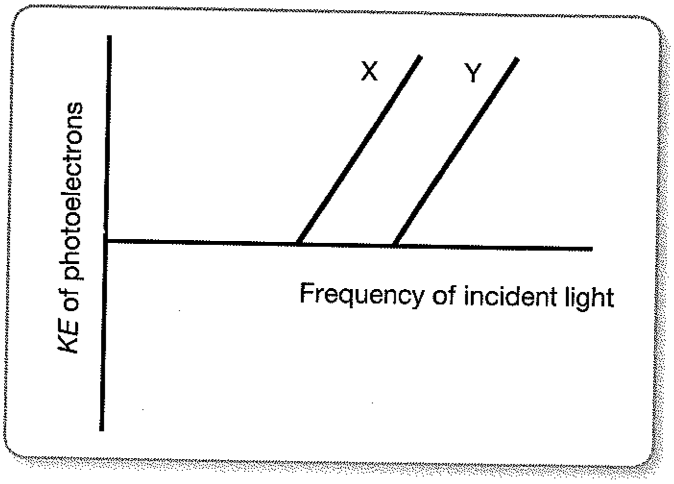
(A) 1.0 eV

(B) 1.5 eV

(C) 1.75 eV

(D) −1.75 eV

12. Consider the following diagram showing the emission properties of two different photoemitters X and Y.



Which statement about X and Y is correct?

(A) X is a better conductor than Y.

(B) X has a higher threshold frequency than Y.

(C) X has a higher work function than Y.

(D) X emits photoelectrons more easily than Y.

13. Sodium has a work function of 2.28 eV. Which of the following incident lights is most likely to cause photoemission from its surface?

(A) Green

(B) Orange

(C) Red

(D) Yellow

14. Which correctly defines threshold frequency?

(A) Minimum frequency of light falling on an emitter to cause emission of electrons.
(B) Maximum frequency of light falling on an emitter to cause emission of electrons.
(C) Minimum frequency of the photoelectrons emitted from a cathode when light shines on it.
(D) Maximum frequency of the photoelectrons emitted from a cathode when light shines on it.

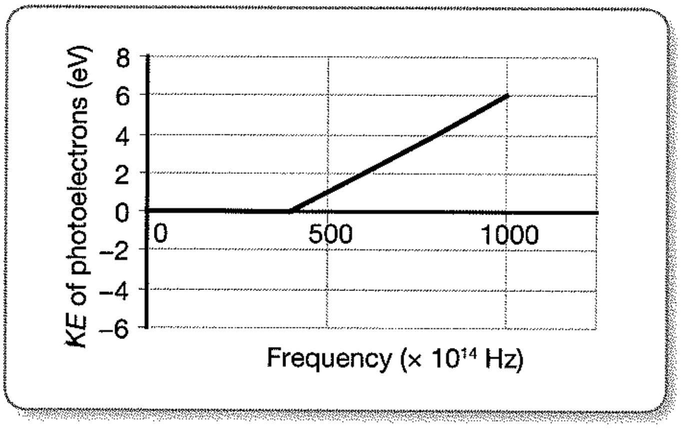
15. Why is the current produced in a photocell proportional to the intensity of the incident light?

(A) Current is proportional to the total number of electrons emitted from the cathode.
(B) Current is proportional to the total number of electrons emitted from the anode.
(C) Current is proportional to the number of electrons per second emitted from the cathode.
(D) Current is proportional to the number of electrons per second emitted from the anode.

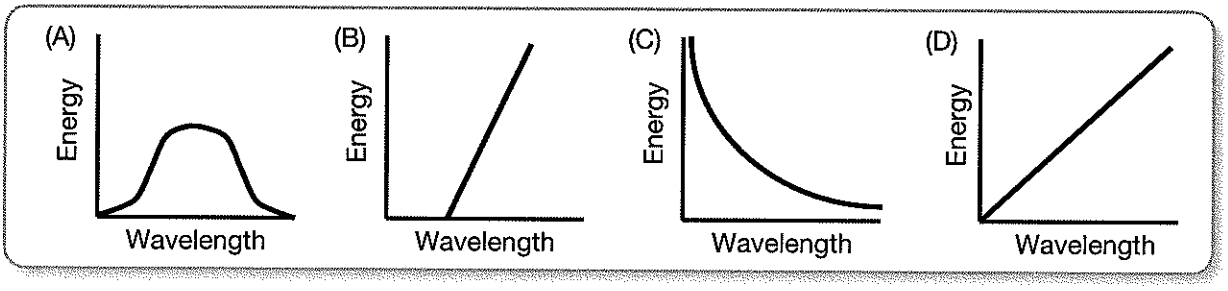
16. The graph shows the kinetic energy of electrons emitted by a particular photoemitter when light of different frequencies shines on it.

Which statement is correct?

(A) The threshold frequency is 400 nm.
(B) The work function is 4 eV.
(C) The maximum energy of the emitted electrons is 6 eV.
(D) The threshold energy is −3.0 eV.

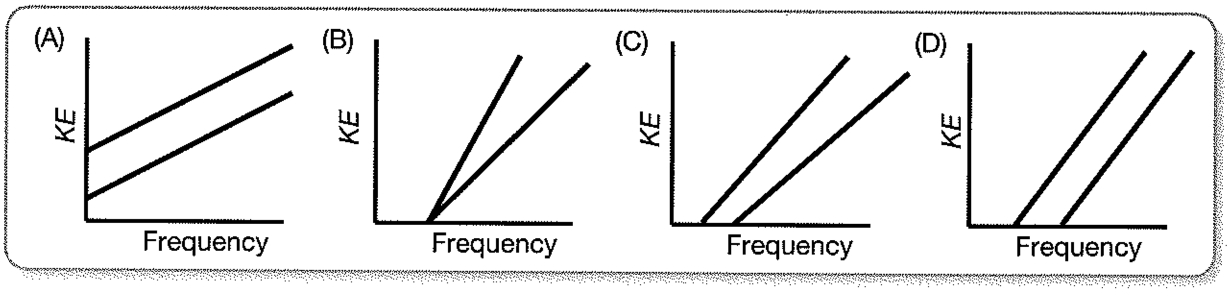


17. (a) Which graph best shows the relationship between the energy (y-axis) carried by a photon and the wavelength (x-axis) of the photon?



(b) Justify this answer.

18. (a) Which graph best shows the relationship between the kinetic energy of photoelectrons and the frequency of the incident radiation for two different metals?

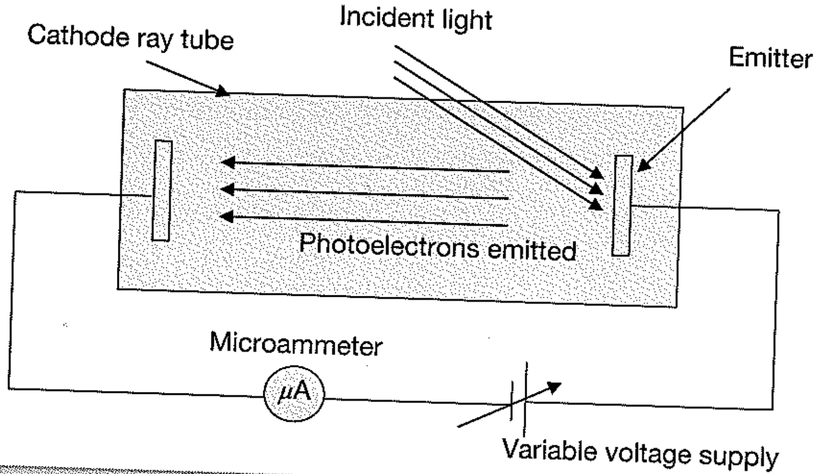


(b) Justify this answer.

SET 33 A Work Function Experiment.

1. Students set up the circuit shown to measure the work function of a photoemitter. They shone light of varying wavelengths onto the emitter and measured the voltage required to reduce the current flow in the circuit to zero.

Their results are shown in the table.



Wavelength of incident light (nm)	Frequency of incidentlight ($\times 10^{15}$ Hz)	Energy carried by light beam (eV)	Stopping voltage (V)	Kinetic energy of emitted electrons (eV)	Work function of emitter (eV)
100			4.1	8.8	
150			2.8	4.6	
200			2.0	2.6	
250			1.4	1.4	
300			1.0	0.5	
350			0.6	No electrons emitted	
400			0.4	No electrons emitted	
450			0.0	No electrons emitted	
				Average work function	

(a) Explain the concept of the 'stopping voltage' and how it is used to find the work function of a photoemitter.

(b) Copy the table into your workbook and calculate the values for the empty columns and the average value for the work function of the emitter.

(c) Plot the frequency of the incident light (x-axis) against the kinetic energy of the emitted electrons in eV (y-axis).

(d) Extend your graph to determine a value for the work function of the emitter.

(e) Compare your two values for the work function and account for any difference.

(f) Which of the two values is the more reliable? Justify your answer.

(g) Use your graph to determine the threshold frequency of the emitter.

SET 34 Interference Supports the Dual Wave/Particle Model

1. (a) Define diffraction.

(b) What is the relationship between diffraction and interference of waves?

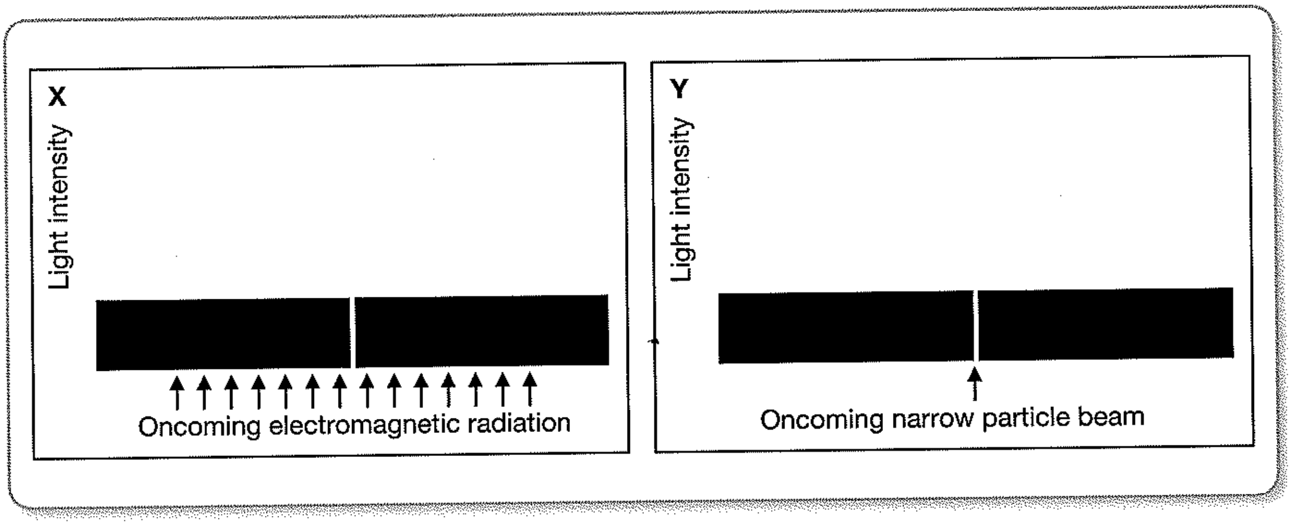
2. (a) What is the 'dual wave/particle' model of electromagnetic radiation?

(b) Why is this dual model needed?

(c) What is the only property of electromagnetic radiation that requires a wave nature to explain it?

(d) What is the only property of electromagnetic radiation that requires a particle nature to explain it?

3. Imagine two, identical, solid, opaque barriers, X and Y, with a small hole in their centres as shown.



(a) Copy the diagrams into your workbook and complete them to show the pattern of the radiation on the opposite sides of the barriers in terms of its intensity in front of and either side of the hole if:

(i) The radiation has a wave nature.

(ii) The radiation has a particle nature.

(b) Who is credited as the first physicist to study the pattern shown in situation X?

(c) Modern experiments using a single incident light photon, the name given to Einstein's light particles, produces a pattern similar to that produced by the beam of radiation in X. What does this say about Einstein's photons?

(d) Does this (your answer to (c)) upset our ideas about the nature of electromagnetic radiation? Justify your answer briefly.

(e) Discuss whether the wave, the particle or the dual model for electromagnetic radiation is correct.

4. (a) Who was the first scientist to propose that matter could behave as a wave?

(b) What was he attempting to explain by proposing this? Recall his explanation.

(c) What other weakness in the Bohr model does this idea solve?

5. Consider this true statement: Photons are massless particles and act like waves as long as there is no measurement performed on them. The moment a measurement is performed on the photons, they start behaving like particles. This can be stated another way: When light interacts with matter, it changes from being a wave to being a particle.

How does this fact affect your understanding of physics?

Q+A

Questions and Answers

The Standard Model

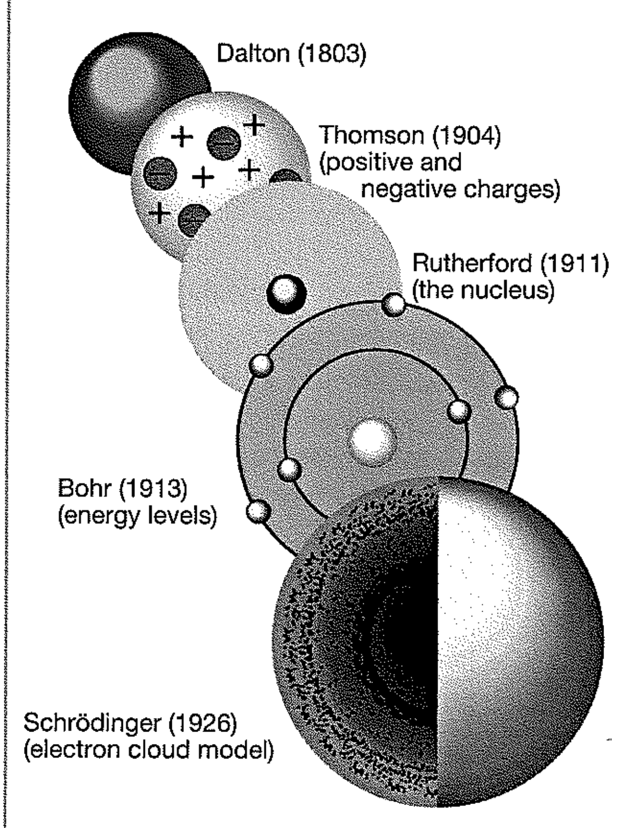
Science Press

SET 35 The Standard Model of Matter

1. What is 'the standard model'?

2. The diagram shows part of the historical development of the model of the atom.

   Why was it thought necessary to change these models over time?



3. What was the main discovery that led to the changes incorporated into the model of the atom by the standard model?

4. (a) What is a fundamental particle?

   (b) What were the fundamental particles in the model prior to the standard model?

   (c) What are the fundamental particles in the standard model?

   (d) What role, if any, did fundamental particles play in the development of the standard model. Justify your answer.

5. Did the discovery of quarks and other leptons indicate that the Bohr model was wrong? Justify your answer.

6. We still use the Bohr model in our teaching and learning, especially in chemistry (understanding valencies and chemical bonding), and in our understanding of many properties of matter in physics (for example, in explaining the photoelectric effect, emission of electromagnetic radiation from hot objects and the like).

   If the Bohr model has been replaced by the standard model, justify its continued use.

7. It is thought by scientists that quarks may be composed of smaller particles.

   (a) What would this mean for the definition of quarks as fundamental particles?

   (b) What would be the fundamental particles if this was true?

   (c) How would this discovery affect the classification of leptons as fundamental particles?

   (d) What would this mean to the standard model?

   (e) If this is found to be true, does this mean that all the work done on the standard model and its application to the properties of matter has been wasted? Justify your answer.

   (f) What might be stimulating scientists to consider the possibility that quarks are made of smaller particles?

   (g) What has this not been proposed much earlier than recently?

8. (a) What are nucleons?

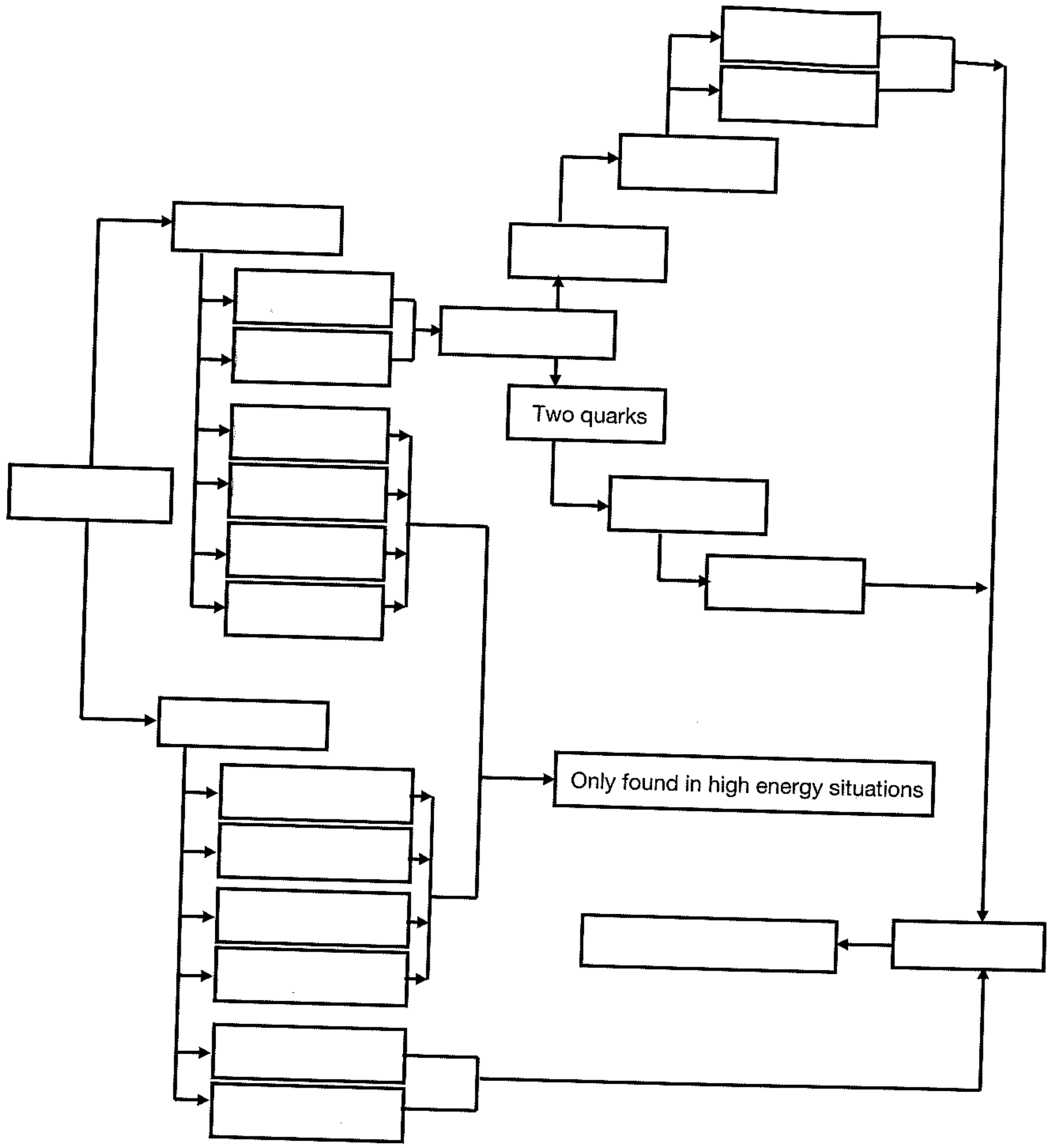
   (b) Identify three nucleons.

9. Explain why it was necessary to invent the strong nuclear force.

10. What scientific discoveries prompted scientists to start looking for new particles in the nucleus.

SET 36 Components of the Standard Model

1. Complete the following diagram to show the components of the standard model of matter.



2. Distinguish between hadrons and baryons.

3. Name the antimatter partner to a neutrino.

4. Which particle is a hadron?

(A) Electron
(B) Electron neutrino
(C) Meson
(D) Proton

5. An electron is a:

(A) Boson
(B) Hadron
(C) Lepton
(D) Meson

6. Which particles are fundamental?

(A) Baryons
(B) Hadrons
(C) Mesons
(D) Quarks

7. Which of the following is a baryon?

(A) Meson
(B) Muon
(C) Neutron
(D) Neutrino

8. What are fermions?

(A) Particles which make up quarks.
(B) Particles which obey the Pauli exclusion principle.
(C) Particles discovered by Fermi.
(D) Particles found in nuclei.

9. Which choice identifies the quark composition of a proton and a neutron?

	Proton	Neutron
(A)	d, d, u	u, u, d
(B)	d, d, u	u, u, u
(C)	u, u, d	u, u, u
(D)	u, u, d	u, d, d

10. Which fundamental particles make up the matter we can see?

(A) Mesons and baryons.
(B) Mesons and leptons.
(C) Protons, neutrons and electrons.
(D) Up and down quarks, electrons and electron neutrinos.

11. The nucleus of atoms contains:

(A) Baryons and a leptons.
(B) Baryons and a hadrons.
(C) Two baryons.
(D) Two leptons.

12. What is a fundamental particle of matter?

(A) One which occurs naturally.
(B) One which occurs as part of nuclei.
(C) One which is a combination of two or more other particles.
(D) One which cannot be subdivided into smaller particles.

13. Which particles are responsible for the strong nuclear force?

(A) Gluons.
(B) W and Z bosons.
(C) Photons.
(D) Mesons.

14. Which force binds particles together in the nucleus?

(A) Gravitational force force.
(B) Electromagnetic force.
(C) Strong nuclear force.
(D) Weak nuclear force.

15. What is a nucleon?

(A) A particle made up of three quarks.
(B) Any particle found in a nucleus.
(C) Either a proton or a neutron.
(D) An uncharged particle in a nucleus.

SET 37 More about Quarks

1. Match the sentence halves below to make a summary of the properties of quarks.

(a) Quarks are one of the

(b) There are six of them and they have the names

(c) They are grouped in pairs, called generations, according to their charge

(d) Quarks are fermions (fundamental particles) and respond to the

(e) Being fermions, quarks obey the Pauli exclusion principle

(f) The four quantum numbers are the principal quantum number (the energy level),

(g) The quantum numbers of fundamental particles

(h) In terms of the quantum numbers, what the Pauli exclusion principle is saying is that

(i) All quarks have a baryon number of

(j) Antiquarks have a baryon number of

(k) Quarks join together to form the larger particles of

(l) The are two types of hadrons – the baryons consisting of three quarks and the

(m) Mesons are extremely unstable and decay

(A) describe their properties and location.

(B) which states that in an atom, no two fermions can have the same four quantum numbers.

(C) almost as soon as they form into other particles.

(D) up (u), down (d), charm (c), strange (s), top (t) and bottom (b).

(E) $+\frac{1}{3}$ and a lepton number of 0.

(F) and masses, which seem to increase from generation to generation.

(G) a magnetic, a momentum and a spin quantum number.

(H) mesons which contain a quark and an antiquark.

(I) electromagnetic, weak, gravitational and strong interactions.

(J) $-\frac{1}{3}$ and a lepton number of 0.

(K) two fermions cannot occupy the same position at the same time.

(L) two families of fundamental particles.

(M) matter collectively known as hadrons.

2. Complete the following table.

Quark	Generation	Symbol	Charge	Baryon number	Lepton number
Up					
Down					
Charm					
Strange					
Top					
Bottom					

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3. Complete the following table.

Antiquark	Generation	Symbol	Charge	Baryon number	Lepton number
Antiup					
Antidown					
Anticharm					
Antistrange					
Antitop					
Antibottom					

4. Determine the charge on each of the following baryons. Show working to justify your answer.

(a) c c s (b) c s s (c) t t b (d) t b b

5. Determine the charge on each of the following hadrons. Show working to justify your answer.

(a) $c\,\bar{s}$ (b) $\bar{c}\,s$ (c) $t\,\bar{b}$ (d) $\bar{t}\,b$

6. The only meson found in normal matter is the pi meson. There are three types of pi mesons, all made of a combination between either an up or an antiup quark and an antidown or down quark.

(a) Positive pi = pi$^+$ (π^+)

(b) Negative pi = pi$^-$ (π^-)

(c) Neutral pi = pi^0 (π^0)

For each of the three pi mesons, hypothesise possible quark/antiquark combinations so that the charge they carry is as given.

7. A new particle, discovered in 2003 has been called a pentaquark, because it is composed of 5 quarks. The quarks it contains include d, d, u,u and one other quark, antidown.

(a) What will be the charge on the pentaquark?

(b) Where does this particle fit into the standard model?

(c) Does the standard model need to be modified to include this particle?

(d) Does this particle prove the standard model incorrect? Explain your answer.

SET 38 More about Leptons

1. Match the sentence halves below to make a summary of the properties of leptons.

(a) Leptons are any fermions that respond
(b) Leptons do not take
(c) Only the electron and the electron neutrino
(d) The other leptons, the muon, muon neutrino, tau and tau neutrino,
(e) The electron, muon and tau carry
(f) Leptons have a baryon number
(g) For each lepton there is
(h) Antileptons have a baryon number of 0 and
(i) All leptons and antileptons
(j) Being discrete particles, the masses

(A) a charge of −1, the neutrinos have a charge of 0.
(B) obey the Pauli exclusion principle.
(C) also an antilepton.
(D) only to electromagnetic, weak, and gravitational forces.
(E) of the leptons are more easily determined.
(F) are found in normal matter.
(G) and a lepton number of −1.
(H) are also found only in energetic nuclear disintegration.
(I) part in strong interactions.
(J) of 0 and a lepton number of 1.

2. Complete the following table.

Lepton	Generation	Symbol	Charge	Baryon number	Lepton number

3. Complete the following table.

Antilepton	Generation	Symbol	Charge	Baryon number	Lepton number

SET 39 Baryon Numbers

1. Match the sentence halves below to make a summary of baryon numbers.

(a) With the development of quark theory in the

(b) Quarks are assigned

(c) The proton and neutron were each

(d) When antiprotons and antineutrons were discovered

(e) Antiquarks are assigned a

(f) Mesons, particles that are made up of a quark and

(g) Particles that are not made up of quarks

(h) The electron, positron, and photon

(i) Muons, antimuons, taus, antitaus, various

(A) baryon number of $-\frac{1}{3}$.

(B) were each given a baryon number of 0.

(C) 1960s, baryon number became a property of the quarks.

(D) all have a baryon number of 0.

(E) a baryon number of $+\frac{1}{3}$.

(F) neutrinos and bosons are all given a baryon number of 0.

(G) in 19656 they were given a baryon number of −1.

(H) antiquark, have a net baryon number of 0.

(I) given a baryon number of +1.

2. Why did scientists propose the existence of the concept of a baryon number?

3. State the law of conservation of baryon number.

4. In statements such as the law of conservation of baryon number, what is a 'closed system'?

5. Account for the proton and neutron each having a baryon number of +1.

6. Account for the antiproton and antineutron each having a baryon number of −1.

7. Account for mesons having a baryon number of 0.

8. Consider the particle interactions in the table. Determine whether or not charge and baryon number are conserved in each.

Interaction	Charge conserved?	Baryon number conserved?	Is reaction possible in terms of charge and baryon number? If 'no', give reason
(a) $p + p \rightarrow p + \pi^+$			
(b) $e^- + p \rightarrow \nu_e + n$			
(c) $p + n \rightarrow p + n + \pi^+$			
(d) $n \rightarrow p + e^- + \overline{\nu}_e$			
(e) $\nu_e + \tau^- \rightarrow e^- + \nu_\tau$			
(f) $\nu_e + n \rightarrow p + e^-$			
(g) $\nu_\tau + n \rightarrow p + \tau^-$			
(h) $n + p \rightarrow \pi^+ + \pi^-$			

SET 40 Lepton Numbers

1. Define lepton number.

2. (a) State the law of conservation of lepton number.

(b) The law refers to generations of leptons. What are these?

3. Complete the table to show information about leptons.

Electron generation	Symbol	Lepton number ($L_{(e)}$)	Muon generation	Symbol	Lepton number ($L_{(\mu)}$)	Tau generation	Symbol	Lepton number ($L_{(\tau)}$)
Electron								
Electron neutrino								
Positron								
Electron antineutrino								

4. Complete the rules governing the conservation of lepton numbers which must be applied when we write interaction equations or diagrams.

If a lepton and a neutrino are on the same side of the equation for an interaction:

(a) Electrons, negative muons and negative tau must be accompanied by ____________

(b) Positrons, positive muons and positive tau must be accompanied by ____________

If a lepton and a neutrino are on the opposite side of the equation for an interaction:

(a) Electrons, negative muons and negative tau must have ____________ on the other side.

(b) Positrons, positive muons and positive tau must have ____________ on the other side.

5. Consider the following reaction: $\tau^- \rightarrow \mu^- + \overline{\nu}_\mu + \nu_\tau$

Complete the table below to determine whether or not this obeys the law of conservation of lepton numbers.

Lepton number	τ^-	$\rightarrow$	μ^-	$\overline{\nu}_\mu$	ν_τ	Conserved or not?
L_e						
L_μ						
L_τ						

6. Complete the table below to determine whether or not this obeys the law of conservation of charge, baryon and lepton numbers.

Note that the symbols you will not recognise in these equations are all symbols for various high energy mesons. For example, K = kaon meson, Λ = lambda meson, Ω = omega meson, Σ = epsilon meson, Ξ = xi baryon. Note that some of these mesons may carry a neutral, positive or negative charge.

Note also that the symbol γ = photon (force particle which has no charge, baryon and lepton numbers = 0).

Reaction	Charge conserved	Baryon number conserved	L_e conserved	L_μ conserved	L_τ conserved	Reaction feasible on these criteria?
$K^+ \rightarrow \mu^+ + \nu_\mu$						
$\Lambda \rightarrow p + \pi^-$						
$\mu^- \rightarrow e^- + \bar{\nu}_{e-} + \nu_\mu$						
$\Omega^- \rightarrow \Xi^0 + \pi^-$						
$\Sigma^0 \rightarrow \Lambda + \gamma$						
$n \rightarrow p + e^- + \nu_e$						
$\Delta^+ \rightarrow \pi^+ + \pi^0$						
$\Xi^0 \rightarrow p + \pi^0$						
$\Sigma^+ \rightarrow p + K^0$						
$n \rightarrow p + e^- + \bar{\nu}_{e-}$						

7. Identify the missing particle in the following interactions so that all the conservation laws are followed.

(a) $n \rightarrow p + e^- + \boxed{}$

(b) $\boxed{} + n \rightarrow p + e^-$

(c) $\pi^+ \rightarrow \mu^+ + \boxed{}$

(d) $p \rightarrow n + \nu_e + \boxed{}$

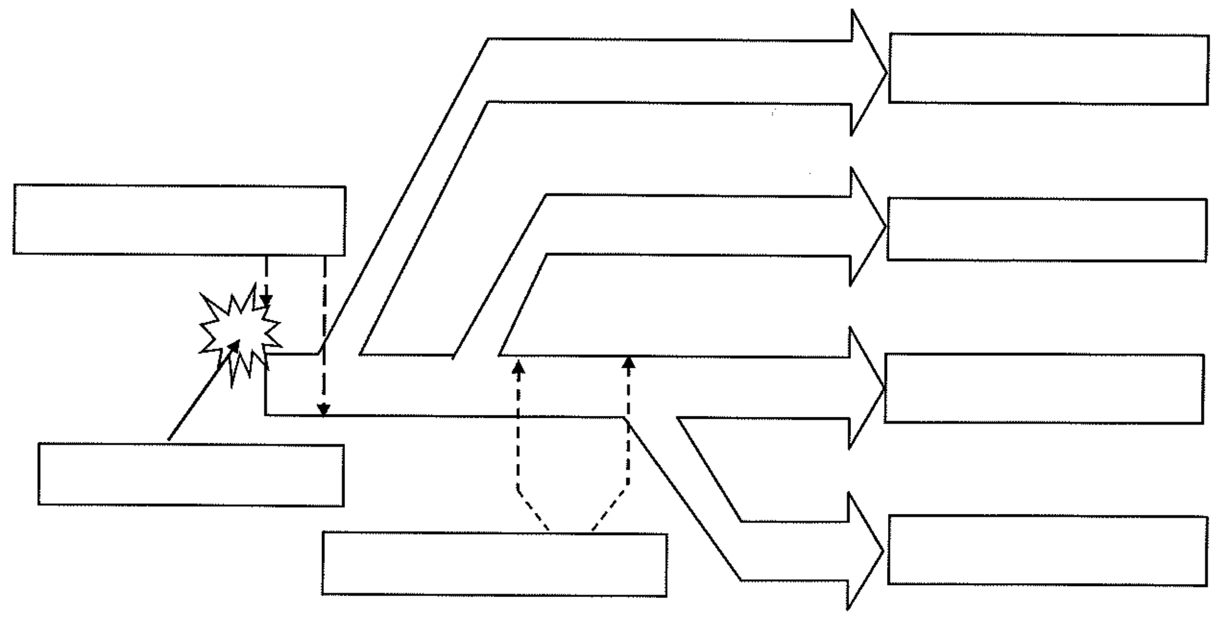
(e) $\mu^- \rightarrow e^- + \nu_e + \boxed{}$

SET 41 The Four Fundamental Forces

1. Complete the diagram to show information about the four fundamental forces.

Force	Electromagnetic force	Strong nuclear force	Weak nuclear force	Gravitational force
Bosons involved				
Number of bosons				
Charge on the bosons				
Boson acts on …				

2. Complete the diagram to show the evolution of the fundamental forces by placing appropriate labels on it.



SET 42 More about Bosons

1. Complete the following table to summarise information about the force interaction particles, bosons.

Boson	Force responsible for	What it does
Photon	Electromagnetic force	• Binds • Acts over • Includes
W-Boson	Weak nuclear force	• Interacts with • Carries either • Either emitted • Acts over
And		
Z-Boson	Weak nuclear force	• Interacts with • Carries • Emitted or absorbed • Acts over
Gluon	Strong nuclear force	• Binds • Binds • Acts over
Graviton	Gravity	• Draws masses • Acts over • (Not yet discovered.)
Higgs boson	Giving particles mass	• Proposed to be • Discovered in

SET 43 Simple Reaction Diagrams

1. (a) What are Feynman diagrams?

(b) What are the two uses for Feynman diagrams?

2. Clarify, in some detail, the following conventions used in drawing Feynman diagrams.

(a) Lines.

(b) Time direction.

(c) Arrowheads.

(d) Particle labels.

(e) Exchange particles.

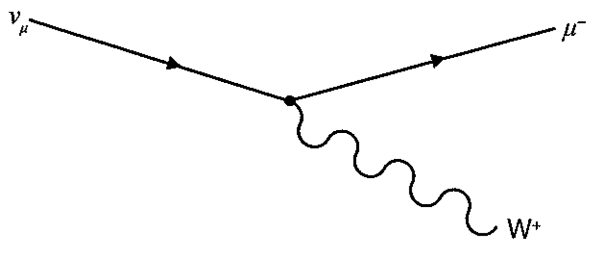
(f) Vertices.

3. Draw a typical Feynman diagram and place the following labels on it.

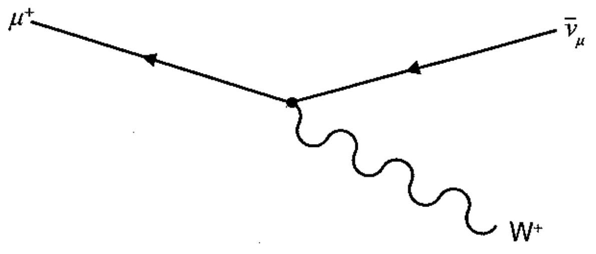
- Antiparticle leaves vertex
- Interaction particle enters vertex
- Particle enters vertex
- Product
- Reactants
- Time passes
- Vertex

4. Identify the interaction shown in each of the Feynman diagrams below.

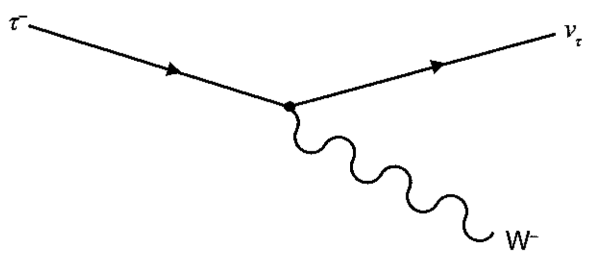
A



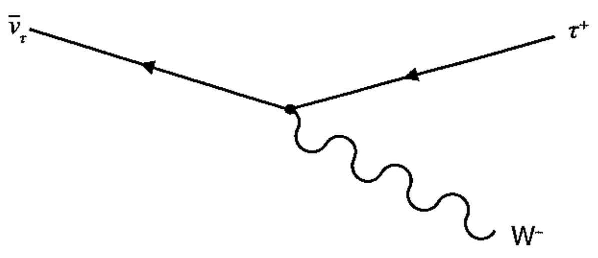
B



C

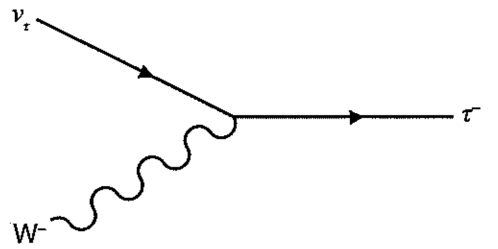


D



5. Describe what each of the following Feynman diagrams is showing.

A



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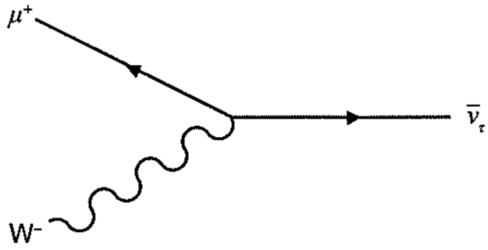
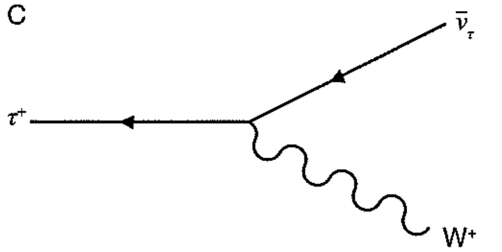


C



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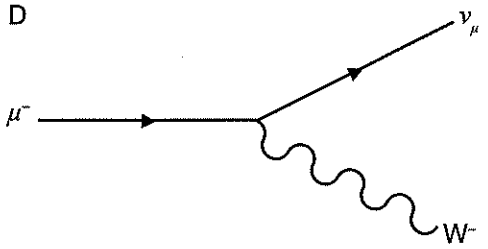
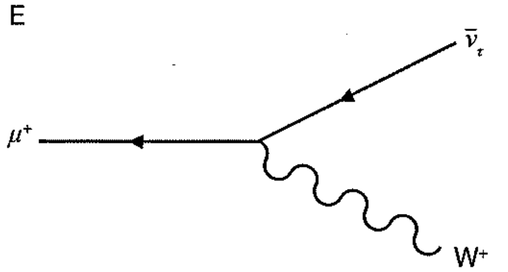
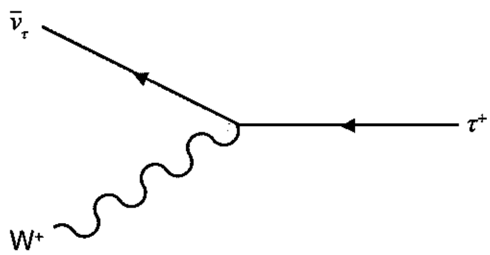


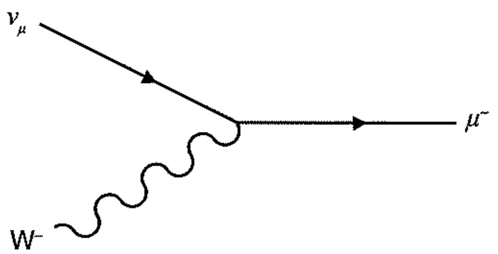
E



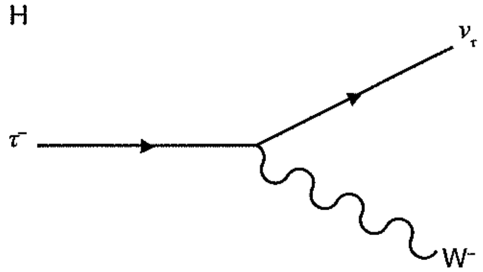
F



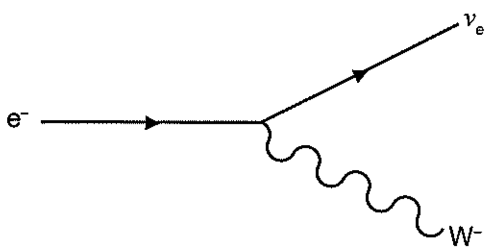
G



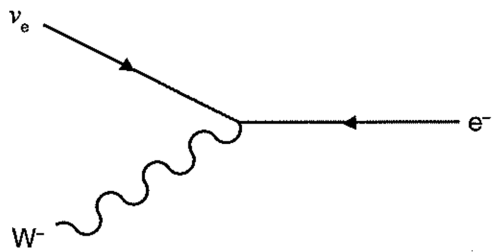
H

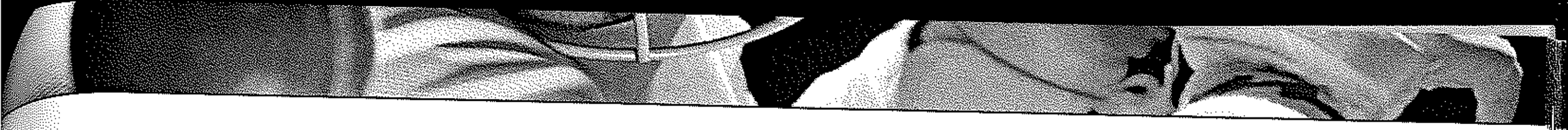


I



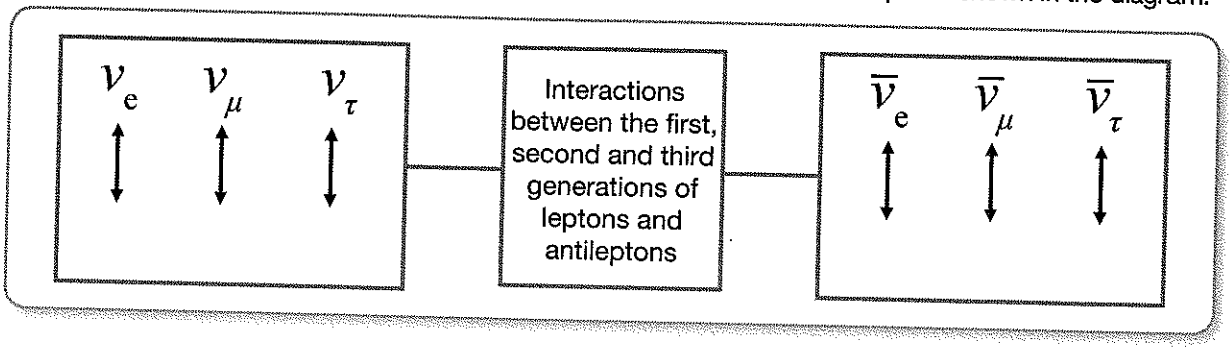
J





SET 44 Lepton Weak Interactions

1. (a) Write in the appropriate pair particle for each generation of leptons and antileptons shown in the diagram.



(b) Why have particle physicists grouped the leptons and antileptons into generation pairs like this?

2. Complete the sentences by matching the halves.

(a)	Feynman vertices as used in this book are read	(A)	charge is also conserved.
(b)	Feynman vertices are sometimes drawn (not in this book) to be read	(B)	its generation partner will leave the vertex.
(c)	In all particle interactions lepton number	(C)	also be conserved.
(d)	In all particle interactions baryon number must	(D)	from left to right.
(e)	In all particle interactions	(E)	the boson an appropriate charge.
(f)	Charge conservation is done by assigning	(F)	must be conserved.
(g)	If two particles emerge from a vertex, then they must be a	(G)	from bottom to top.
(h)	If a lepton enters a vertex, then	(H)	matter-antimatter pair of the same type.

3. Draw Feynman diagrams for the following interactions.

(a) Negative tau absorbs a boson.

(b) Negative tau emits a boson.

(c) Electron and positron annihilate to produce a boson.

(d) Exchange particle emits a muon and another particle.

(e) Down quark absorbs a boson to produce an up quark.

(f) Down quark emits a boson to produce an up quark.

(g) Positive muon absorbs a boson.

(h) Positive muon emits a boson.

(i) Muon neutrino absorbs a negative boson.

(j) Muon neutrino emits a positive boson.

(k) Up quark absorbs a boson.

(l) Up quark emits a boson.

(m) Tau neutrino absorbs a negative boson.

(o) Tau neutrino emits a positive boson.

SET 45 Crossing Symmetry

1. Clarify the idea of 'crossing symmetry'.

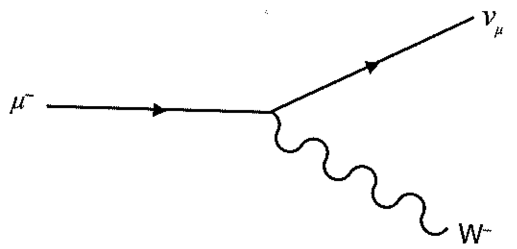
2. Consider the following particle interaction.

$$W + X \rightarrow Y + Z$$

Write five equations to show three different crossing symmetry actions on this equation.

3. In the space provided below, explain, with the use of the vertex diagram provided, what happens to the particles and the arrows in a Feynman diagram when a crossing symmetry is performed so that the muon neutrino is moved to the opposite side of the reaction.

Before



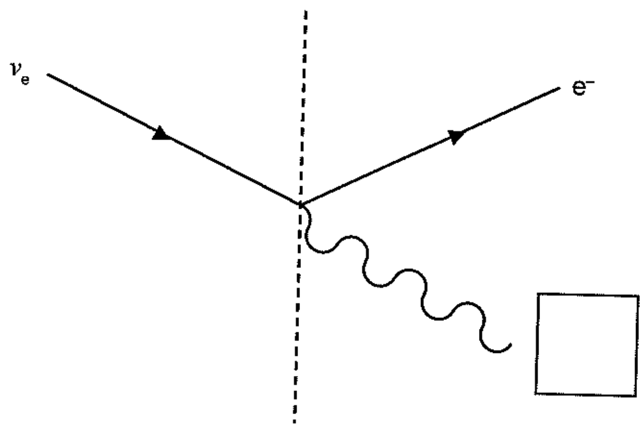
After

4. Consider the particle interaction in the Feynman diagram.

(a) Identify the missing particle.

(b) Redraw the diagram to show the interaction when a crossing symmetry is carried out on the electron neutrino and the electron.

(c) Redraw the Feynman diagram to show the interaction when only the electron is crossed over.



SET 46 Crossing Symmetry Predictions

1. (a) Explain the idea of crossing symmetry.

(b) What is the purpose of crossing symmetry?

(c) Clarify, with appropriate examples, the nature of the particles and the arrows which accompany them.

2. (a) Explain the idea of time reversal as it relates to Feynman diagrams.

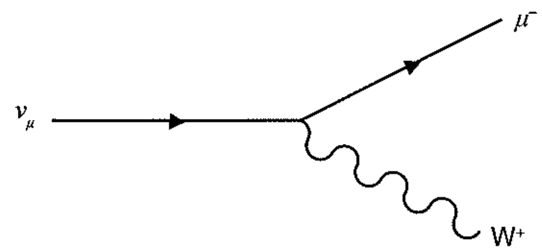
(b) How does time reversal relate to particles in Feynman diagrams?

(c) What is the scientific viewpoint of time reversal?

3. Consider the basic Feynman vertex shown.

There are at least four other particle interactions that can be predicted from this basic vertex by rotating the particles about the vertex or by applying crossing symmetry to the particles.

In the spaces below, draw Feynman diagrams to show these predictions and describe what each is predicting could happen.



A

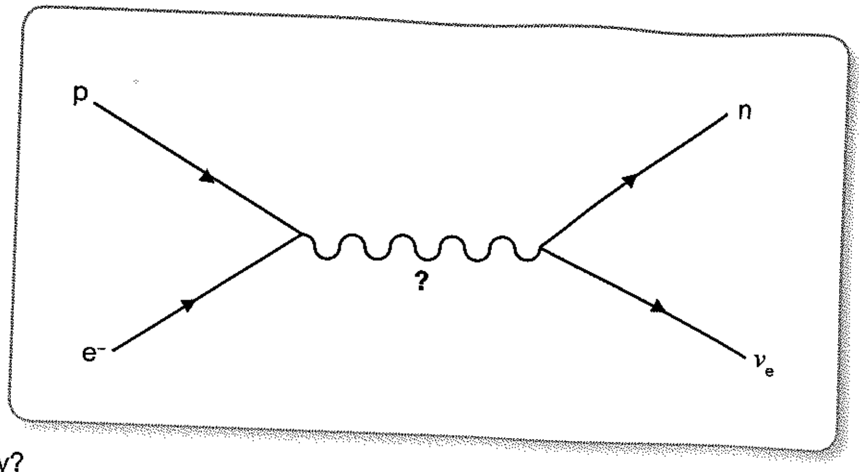
B

C

D

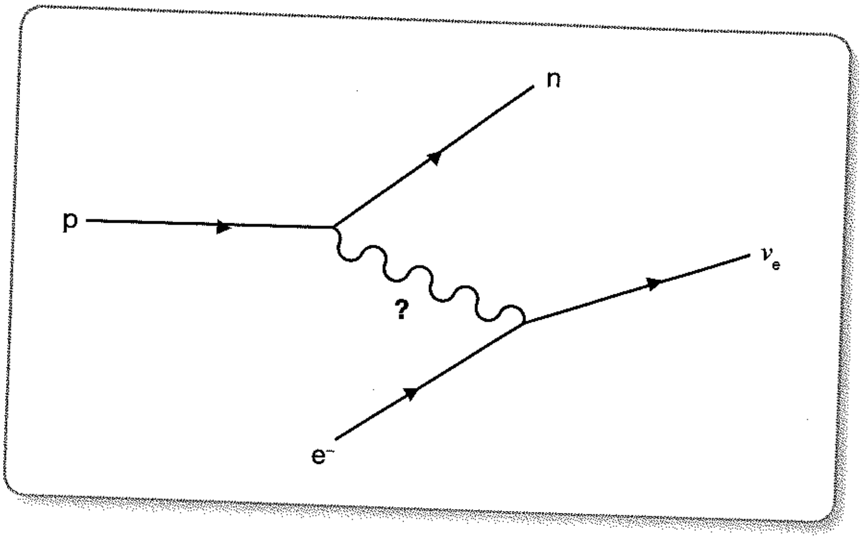
SET 47 More Complicated Vertices

1. Consider the Feynman diagram.
   (a) What is the net charge on the particles entering the vertex?
   (b) What is the net charge on the particles exiting the vertex?
   (c) What is the nature of the exchange particle between the entering and exiting particles? Explain your answer.
   (d) What charge must it carry? Why?
   (e) What happens to the exchange particle?



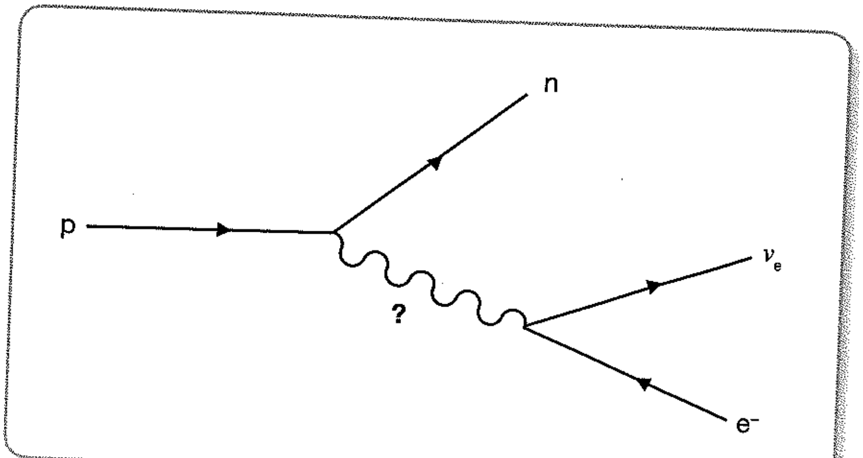
This Feynman diagram could be drawn like this.

(f) Explain how this version of the diagram more clearly illustrates the interactions that occur between the particles, and how it makes the boson involved easier to identify.



Now consider this Feynman diagram.

(g) Identify the exchange boson in this interaction. Justify your answer.
(h) Describe the interaction shown by the diagram.
(i) Is charge conserved at the second interaction vertex? Explain.

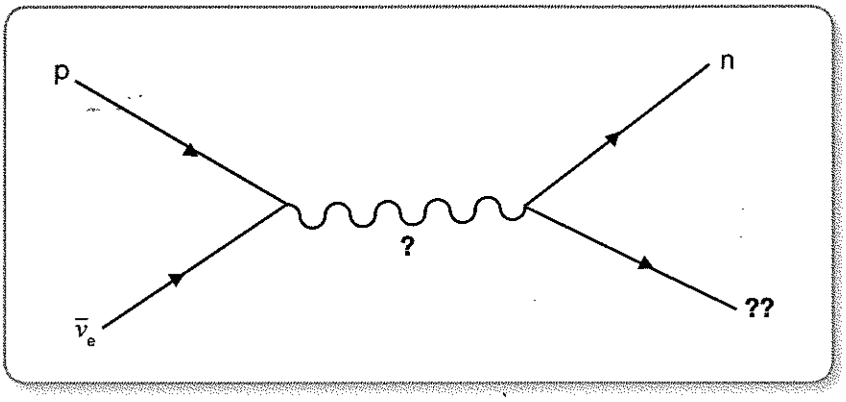


2. Consider the following Feynman diagram.

(a) In the space provided, redraw this interaction along the lines of the second Feynman diagram in Question 1 above.

(b) Use this diagram to identify the boson involved in the interaction.

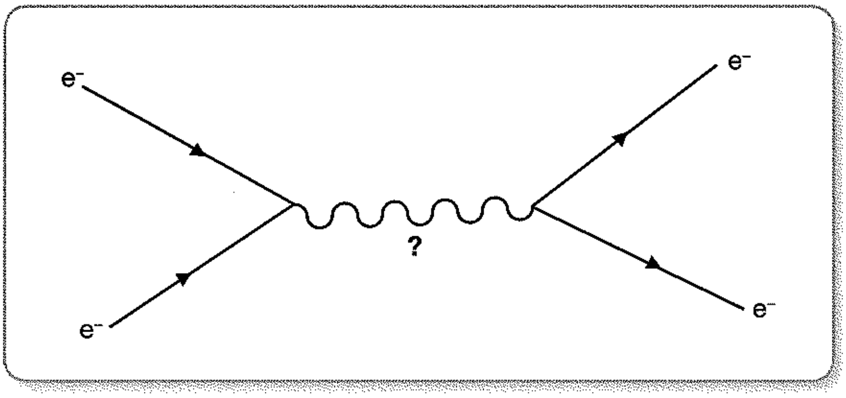
(c) Identify the second product emerging from the second vertex.



3. Consider the following Feynman diagram.

(a) In the space provided, redraw this interaction along the lines of the second Feynman diagram in Question 1 above.

(b) Use this diagram to identify the boson involved in the interaction. Justify your answer.

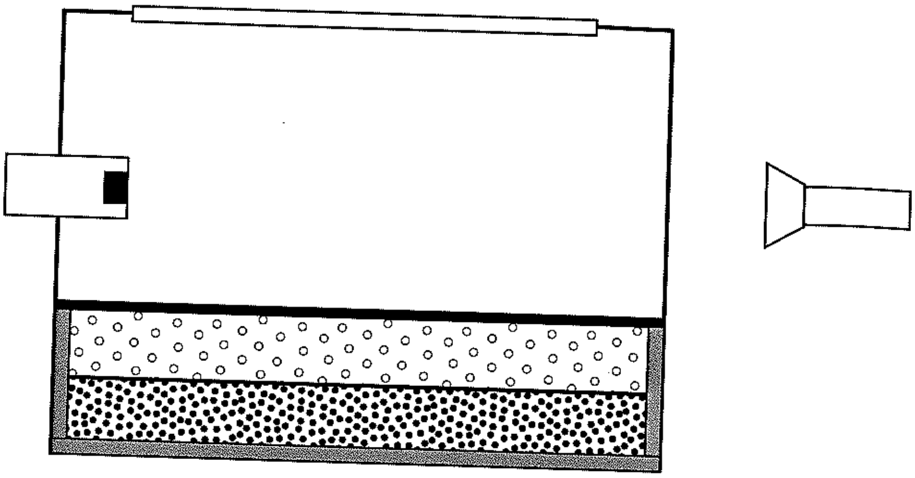


SET 48 Uncovering Matter Particles

1. The diagram below shows a simple cloud chamber.

   (a) Place the following labels on the cloud chamber.

   Radioactive source, Black felt soaked in alcohol, Viewing window, Dry ice, Foam base, Light, Insulation



   (b) What is 'dry ice'?

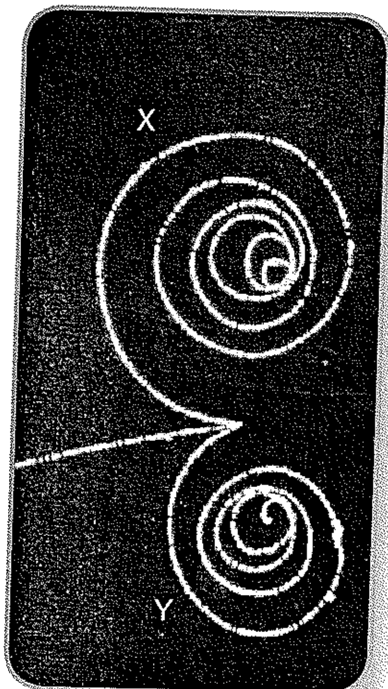
   (c) Why is the dry ice used?

   (d) What is/are the function(s) of the alcohol in this cloud chamber?

   (e) Describe the operation of a simple cloud chamber like the one above.

2. A cloud chamber is set up with a magnetic field directed vertically downwards relative to the motion of the radioactive particles which enter the chamber from the left as shown.

   At the obvious vertex in the diagram an interaction occurs which results in the formation of two particles, X and Y, which spiral inwards as can be seen.



   (a) What can be said about the charges, if any, on each of the two particles X and Y? Justify your answer.

   (b) If the particles were emitted with the same speed and carry charges of equal magnitude, why does Y spiral more tightly than X? Justify your answer.

   (c) Why do both particles spiral more tightly as they move inwards in their spirals?

SET 49 Nuclear Accelerators

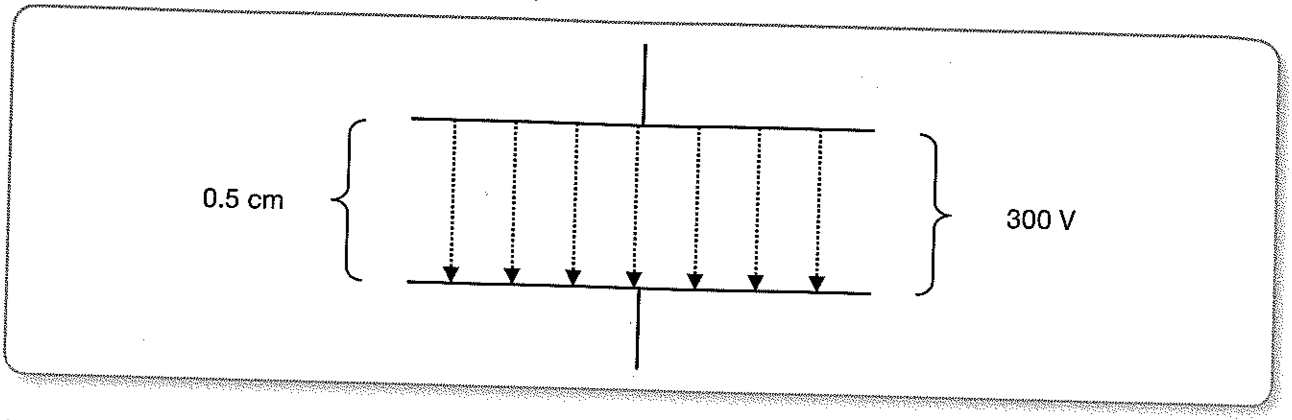
1. Complete the table to summarise advantages and disadvantages of various types of accelerators.

Accelerator	Advantages	Disadvantages
Linear		
Cyclotron		
Synchrotron		

2. The ends of two consecutive tubes in a linear accelerator are 30 mm apart and have a potential difference of 24 000 V across them. A beam of electrons moving at 2×10^4 m s^{-1} travels across the gap between the two tubes. Calculate the following.
   (a) The electric field between the tubes.
   (b) The force on each electron due to the electric field.
   (c) Given the mass of an electron as 9.1×10^{-31} kg, find its acceleration in the linear accelerator.
   (d) Use the formula $W = qV$ to find the work done on each electron by the electric field.
   (e) Find the speed of each electron as it leaves the linear accelerator.

3. A beam of electrons is accelerated by a 2.4 kV electron gun and then passed 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 in the magnetic field.

4. The diagram shows a pair of parallel electric plates. The distance between the plates is 0.5 cm and there is a potential difference of 300 V across them.



(a) Identify the high potential plate. Justify your answer.

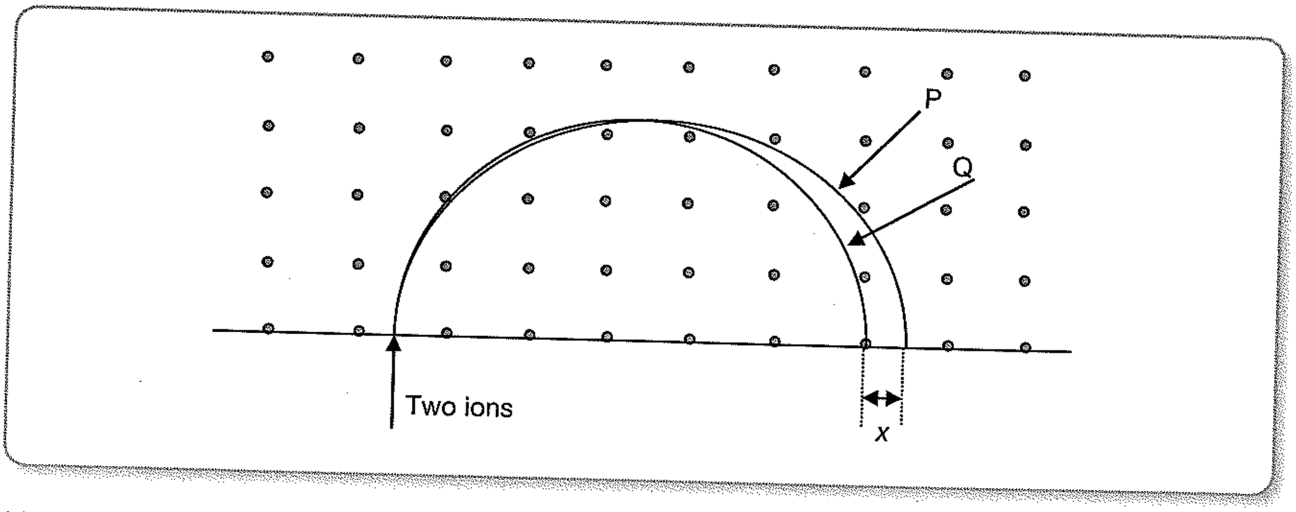
(b) Calculate the electric field between the plates.

(c) An electron enters the space between the plates and exactly halfway between the plates, travelling horizontally at 2.5×10^4 m s^{-1}. Calculate the force it experiences due to the field.

(d) If the mass of an electron is 9.09×10^{-31} kg, calculate its acceleration while it is in this field.

(e) Calculate the increase in the kinetic energy of the electron as it accelerates from its original path to hit the top plate.

5. Two ions, each with a single charge enter the magnetic field of a mass spectrograph at the same point and with the same kinetic energy. The ratio of their masses is 5 : 3, and the lighter particle follows a semicircular path with a radius of 150 mm while it is in the field.



(a) Which ion, P or Q, is the more massive ion? Justify your answer.

(b) Knowing that the kinetic energies of the two ions are equal, and that their masses are in the ratio 5 : 3, calculate the ratio of their velocities as the ions enter the magnetic field.

(c) Use your answer from (b) to find the ratio of the magnetic forces acting on the two ions.

(d) Given that the centripetal forces acting on the ions will be in the same ratio as the magnetic forces, find the radius of the path followed by particle P.

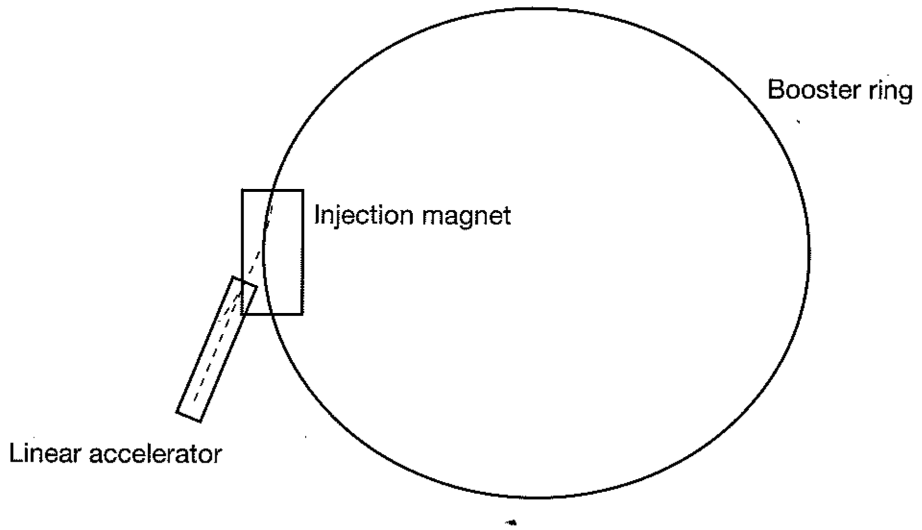
(e) Calculate the distance the ions are apart as they leave the magnetic field (distance x).

(f) Use your calculations to show that the relationship between the masses of ions in a mass spectrograph and their radii of curvature through the magnetic field of the spectrograph is given by the following equation.

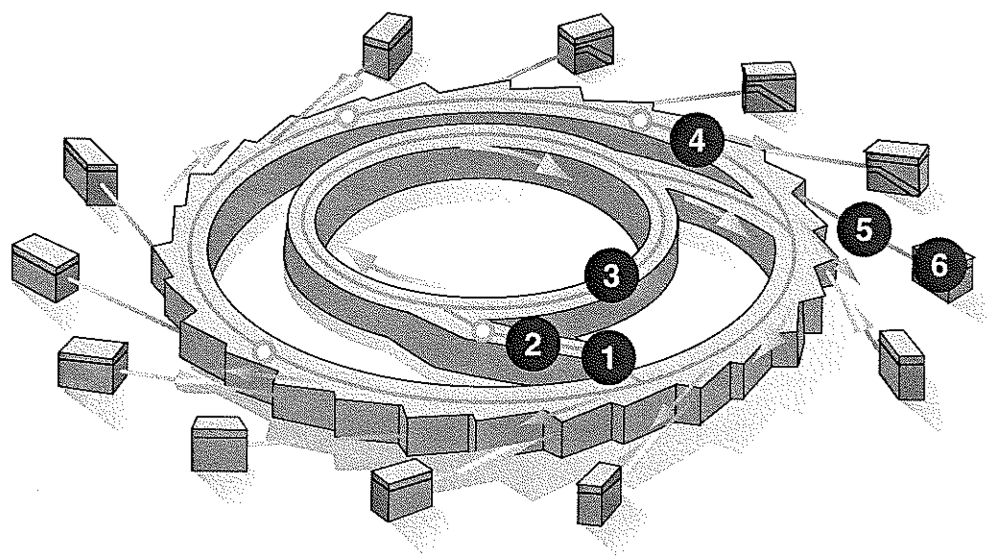
$m_1(r_2)^2 = m_2(r_1)^2$

6. The diagram shows the design of a synchrotron in which pulses of electrons, accelerated by the linear accelerator, entering the booster ring, have their direction of travel adjusted by an injection magnet.

If the strength of the magnetic field applied to electrons by the injection magnet after they leave the linear accelerator is 2.25×10^{-5} T, and their speed is 6.48×10^{7} m s^{-1}, find the radius of curvature of their path through the injection magnet.



7. The diagram shows a schematic of the Australian Synchrotron.



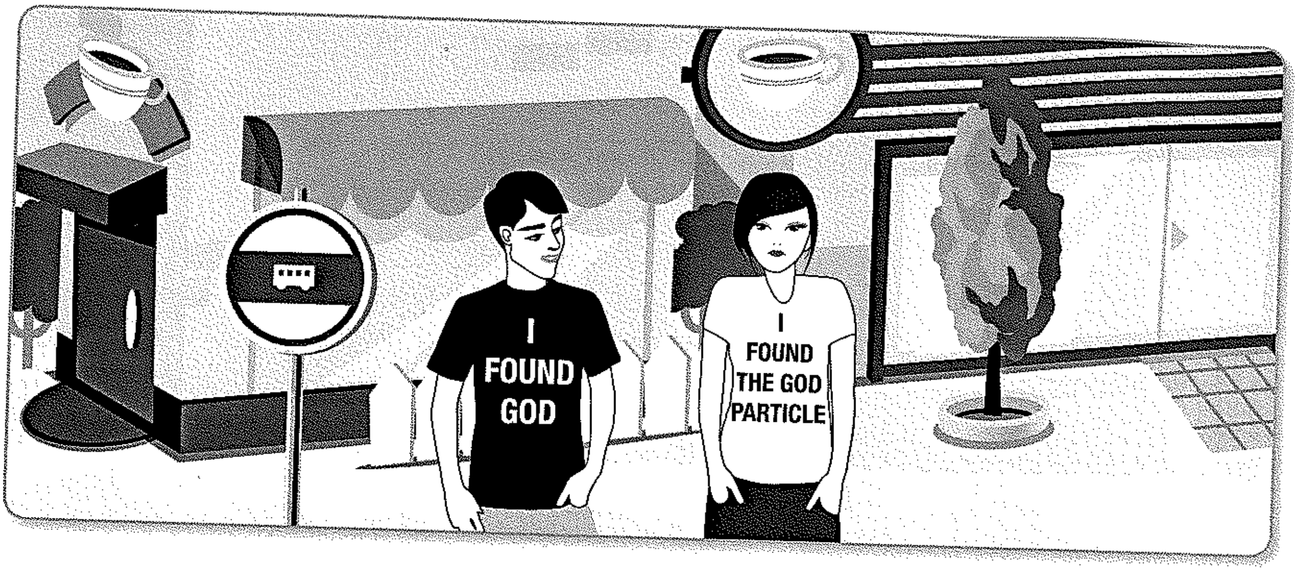
Identify the labelled parts of the synchrotron and state the general purpose of each part. Present your answers in an appropriate table.

SET 50 The Higgs Boson

1. What is the Higgs boson and what is its proposed function in matter?

2. What is the Higgs field as proposed by the standard model, and what is its function in matter?

3. Why was it so difficult to find the Higgs boson?



4. The Higgs boson is often referred to as 'the God particle'.

(a) This nickname is quite misleading. In what way is it misleading?

(b) 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?

5. (a) What was the importance of the discovery of the Higgs boson to the standard model of matter?

(b) In the light of the answer to (a), does this mean that the standard model of matter is the correct model and should maybe be known as a 'law' instead of a 'theory'? Explain your answer.

(c) What finding in 2003 supports the argument that the standard model is not yet complete in its description of matter?

(d) What additional observations made by scientists at CERN may also require a more significant modification to the standard model?

(e) What changes would have to occur in the standard model if this observation was found to be correct?

6. In modelling the way Higgs bosons work it could be likened to the fans meeting their team of football players on the football field after a successful match.

The not so well known or popular players can pass relatively quickly through the crowd, perhaps only stopped by a few autograph or photo-seeking fans. More popular players attract larger groups of fans around them and this slows their movement across the field significantly.

(a) In the analogy described above, what does the football field represent in real life?

(b) What do the football players represent?

(c) What do the groups of fans attracted to the players represent?

(d) What do the new or relatively less popular football players represent?

(e) What do the more popular football players represent?

(f) How does this analogy account for the mass of particles in terms of the standard model?

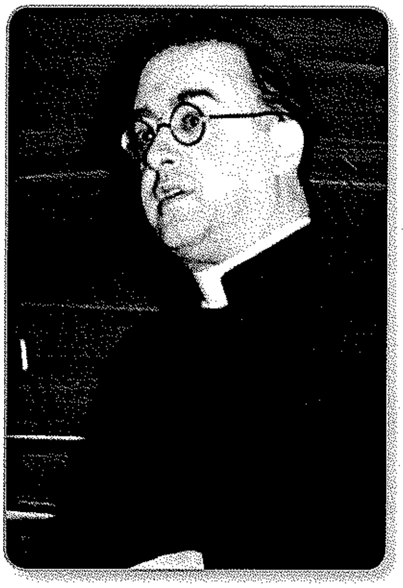
SET 51 Ideas Leading to the Big Bang Theory

1. The scientists pictured on this page all contributed to the development of the Big Bang theory for the origin of the Universe.

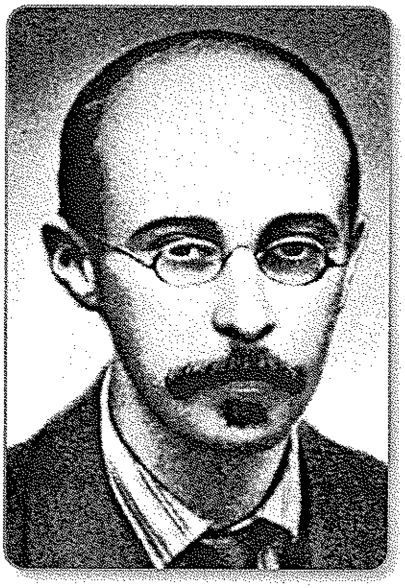
Research information to summarise the contribution of each to the development of the Big Bang theory.

Word process a maximum of two pages to summarise your findings.

2. What technologies not available to earlier astronomers did Slipher and Hubble use in their work?



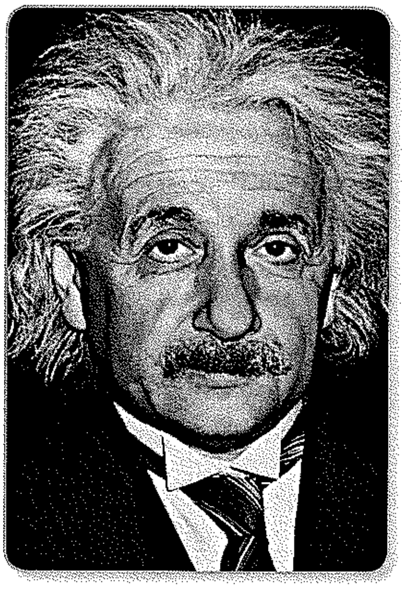
Georges Lemaître (1894-1966).



Alexander Friedmann (1888-1925).

Vesto Slipher (1875-1969).

Edwin Hubble (1889-1953).



Albert Einstein (1879-1955).

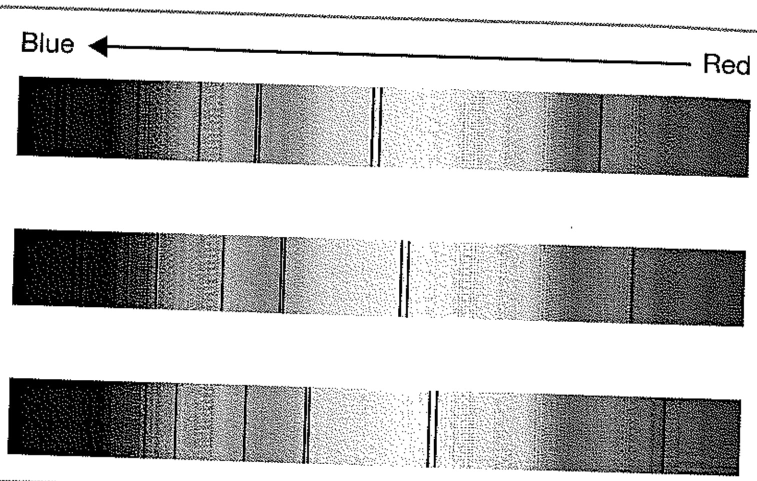
3. (a) What is the optical Doppler effect?

(b) How is the optical Doppler effect explained?

(c) What other Doppler effect(s) are there?

(d) Outline an example of a Doppler effect that you observe quite often.

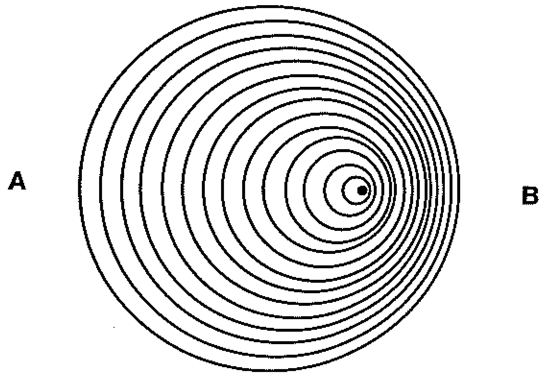
(e) The three spectra below are from a galaxy at rest, a galaxy moving away from us and a galaxy moving towards us. Which is which? Justify your answer.



4. The diagram shows two observers A and B behind and in front of a moving object represented by the black dot.

The moving object is emitting a constant frequency sound which is represented by the circles.

Explain what each of the observers hears relative to the emitted sound.



5. The graph shows the velocities of many galaxies plotted against their distance form Earth.

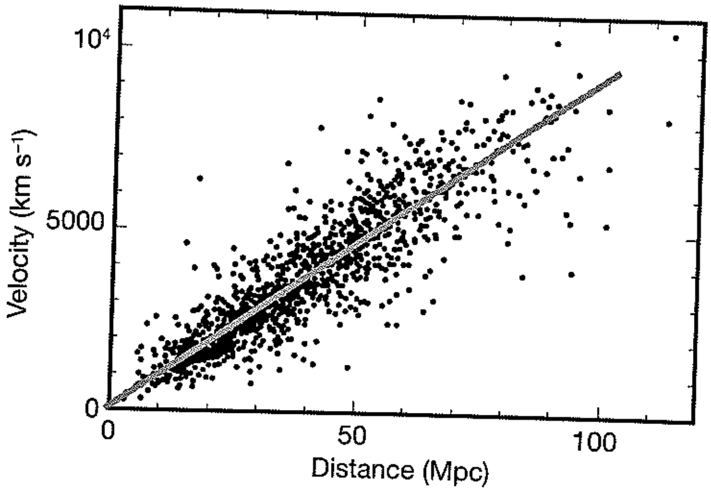
(a) What does the gradient of a graph like this give us?

(b) What do we use this gradient for?

(c) Comment on the reliability of the value we obtain for the gradient.

(d) Comment on the reliability of the value we obtain for the gradient if only a limited number of galaxies was included in the plot data.

(e) Comment on the validity of the use of the gradient for the purpose stated in your answer to (b).

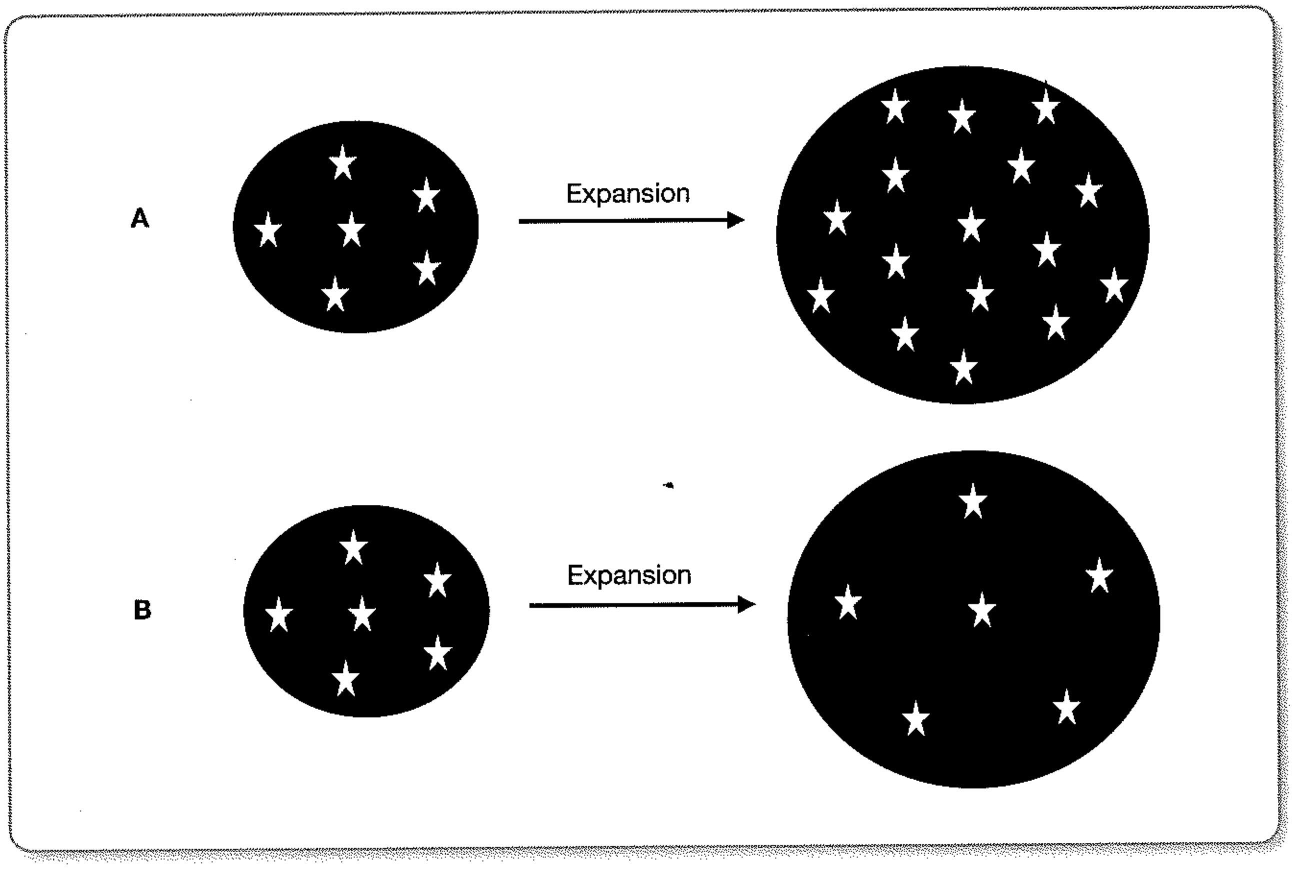


SET 52 The Steady State Theory

1. What is the main idea behind the steady state theory for the beginning of the Universe.

2. How does the steady state theory account for the beginning and expansion of the Universe?

3. Consider the diagrams A and B below. Which diagram represents the steady state theory and which represents the Big Bang theory. Justify your choices.



4. In 1948, when it was first proposed, the steady state theory had one advantage over the Big Bang theory.
   (a) What was this advantage?
   (b) What did this advantage arise?
   (c) Why did scientists later favour the Big Bang theory rather than the steady state theory?

5. Outline some details of each of the following arguments against the steady state theory.
   (a) The ages of galaxies throughout the Universe.
   (b) The development of radio telescopes and the discovery of quasars and radio galaxies.
   (c) The cosmic background radiation.

6. (a) If we look at galaxies far far away, they are found to be much younger than close galaxies. How can this be? Surely, according to the Big Bang theory, all galaxies will be about the same age?
   (b) Does this mean that we can never view another galaxy and see it as it actually is in real time?
   (c) In the 1960s astronomical observations showed that quasars and radio galaxies, the youngest galaxies ever observed, were found only at large distances from Earth and not in closer galaxies. How does each of the two theories account for quasars and radio galaxies?

SET 53 The Big Bang Theory

1. State the main ideas in the Big Bang theory.

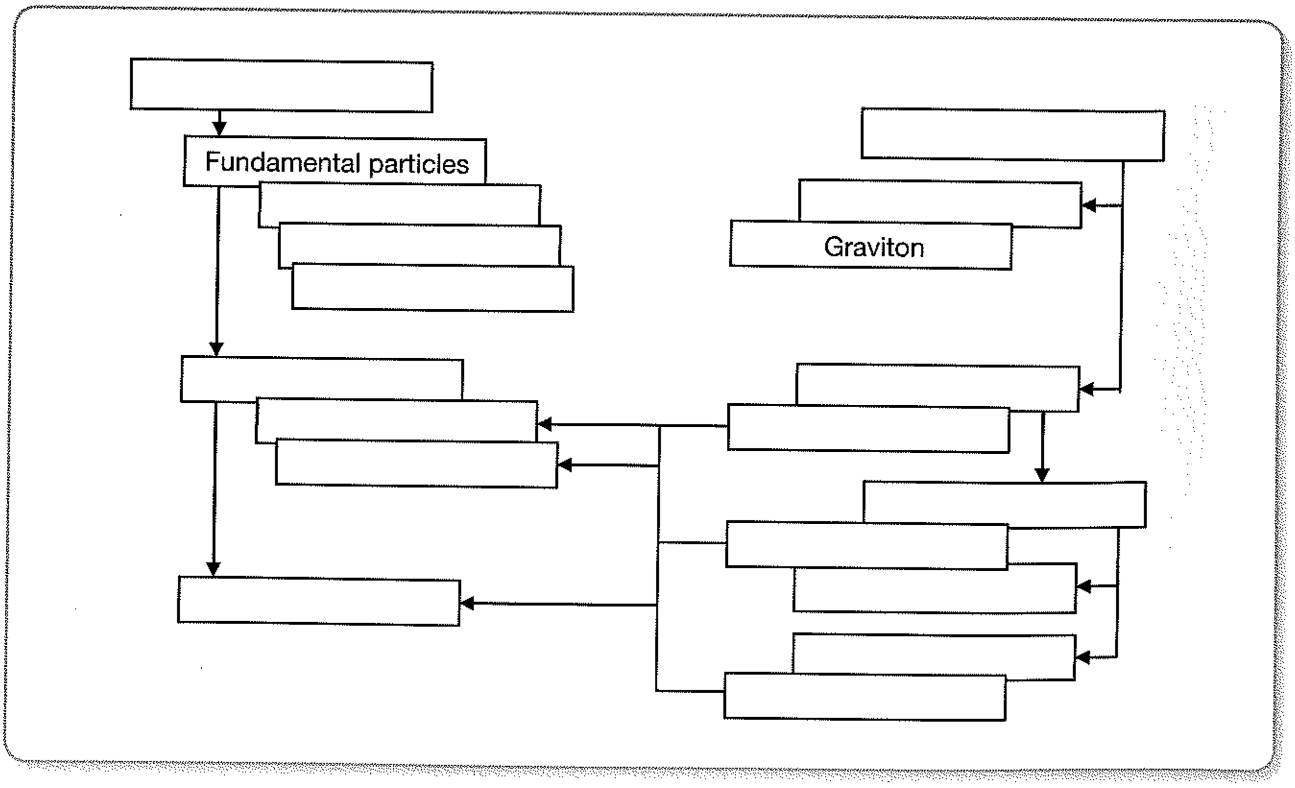
2. Match the sentence halves below to get a brief summary of the evolution of the Universe.

(a) The Big Bang produced
(b) The Universe started at intense heat
(c) The Universe was initially compressed into zero
(d) The temperature of the Big Bang is
(e) Matter as we know it cannot exist at
(f) As the Universe cooled, the
(g) The Universe started as energy, condensing to simple particles first, then to
(h) Accretion of newly formed matter particles
(i) Further accretion of matter within gas clouds

A estimated to have been about at 10^{32} K.
B energy started changing into matter.
C this temperature. Only pure energy existed.
D and has cooling ever since.
E by gravitational forces slowly formed gas clouds.
F more complex particles as it expanded and its temperature fell.
G an enormous amount of energy.
H saw the beginning of stars and eventually galaxies.
I volume and has been expanding since the 'Big Bang'.

3. According to the Big Bang theory, the energy/mass change that occurred following the Big Bang resulted in the formation of hydrogen and helium. The Universe however contains traces of all the other stable elements as well. How is their presence explained?

4. The evolution of particles and the four fundamental forces can be summarised in the diagram below. Complete the diagram.



SET 54 Evidence for the Big Bang

1. (a) Explain the term 'red shift'.
(b) Who discovered galactic red shift? When?
(c) Who applied the concept of the red shift to galaxies in the Universe?
(d) In doing this (see (c)), what relationship was discovered?
(e) What uses do we make of this relationship?
(f) What does the red shift tell us about the Universe?
(g) Explain how the red shift occurs.
(h) How does this provide us with evidence for a Big Bang event?
(i) When would a blue shift occur?

2. (a) What is the measured ratio of hydrogen to helium in the Universe?
(b) Suggest a reason why this ratio might give evidence for a Big Bang event.
(c) What percentage of the Universe is calculated to be composed of hydrogen and helium?
(d) What elements make up the rest?
(e) Were these elements also formed during the Big Bang event? Explain your answer.
(f) What is the explanation astronomers have for the existence of these elements?
(g) The presence of these elements in the spectrum of a star indicates that it is at least a 'second generation' star. Research information to find out what is meant by the term 'second generation star'.

3. (a) Explain how the small number of hot stars in the known Universe provides evidence for a Big Bang event.
(b) Where are most of these hot stars found?
(c) What kind of star are hot blue stars? You may have to research your answer.

4. (a) The discovery of radio galaxies at great distances from us provides evidence for a Big Bang event. Explain how.
(b) There are also much larger numbers of hot blue stars at great distances from us than relatively close to us. Explain how this provides evidence for a Big Bang event.
(c) Are there really many radio galaxies and hot blue stars at great distances from us? Explain your answer.

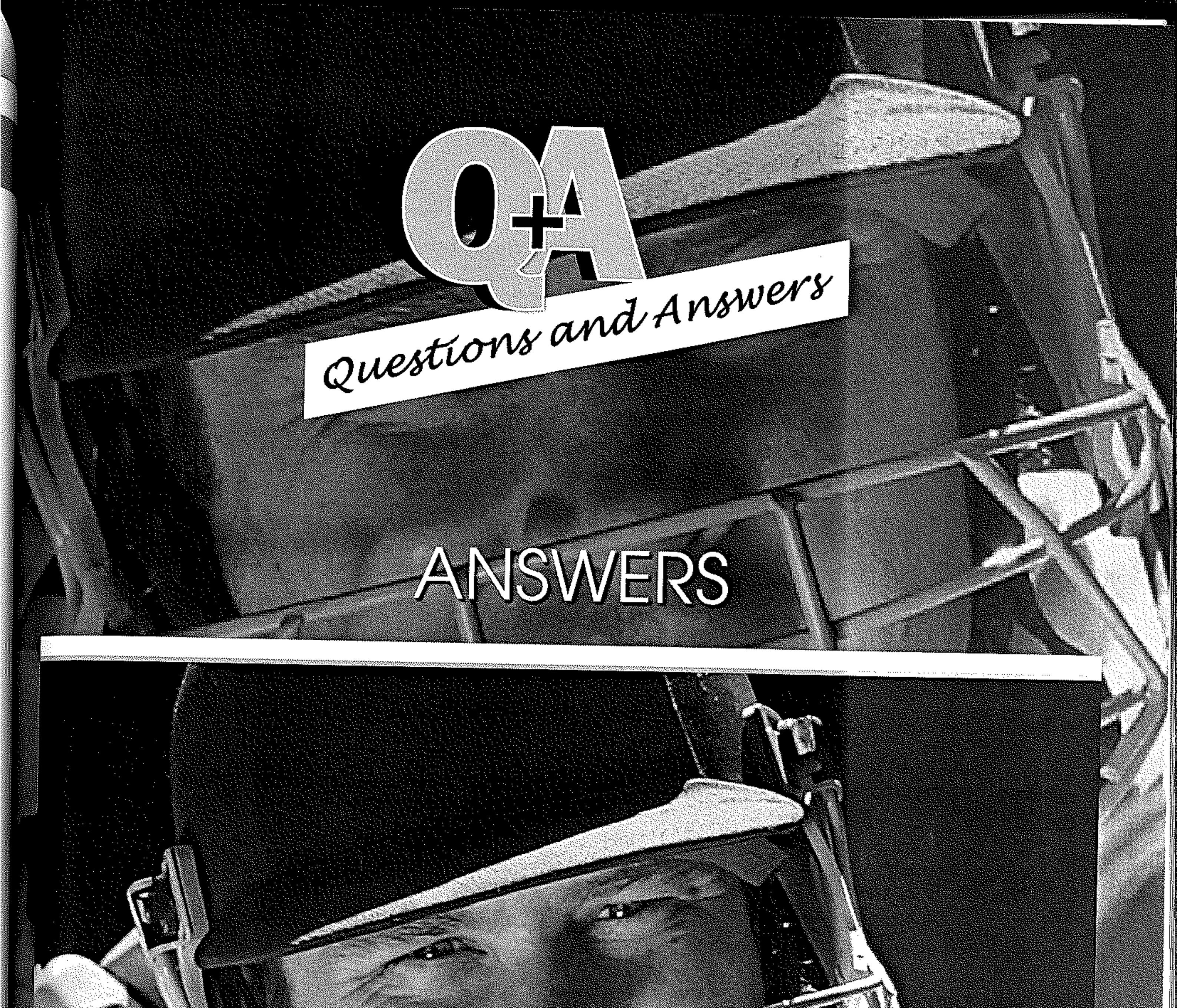
5. (a) Explain how the work of particle physicists is, in a way, working in the opposite direction to the events that are proposed to have occurred after the Big Bang.
(b) How does this provide evidence for a Big Bang?
(c) Clarify the difference between astronomy and cosmology.
(d) How have astronomers/cosmologists collected information that allows them to hypothesise a Big Bang event?

6. (a) What is the cosmic background radiation?
(b) How is this thought to provide evidence for a Big Bang?
(c) Who predicted the cosmic background radiation? When?
(d) How was the cosmic background radiation eventually detected? You may need to research this information.
(e) Explain the relationship between the cosmic background radiation and the temperature of space.
(f) The measurement of the relatively uniform nature of the cosmic background radiation has been a recent discovery. How was this discovered and why is it relatively recent?

Q+A

Questions and Answers

ANSWERS



Set 1 Frames of Reference

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.
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.
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.
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.
5.

	Explanation	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

6. (a) D
   (b) See alternatives A, B and C in Question 6(a).
7. C

Set 2 Galilean Transformations

1. (a) A Galilean transformation is one in which normal mathematics can be applied to determine relative motion – that is, the motion of one object relative to another.
   (b) When we want to compare motion in different frames of reference using only Newtonian physics.
   (c) Galilean transformations cannot be used when relativistic effects have to be considered, that is, when objects are travelling at a significant proportion of the speed of light.
   (d) We use Einstein's relativistic mathematics.
2. (a) 105 m s^{-1} north
   (b) 20 m s^{-1} north
   (c) 105 m s^{-1} south
   (d) 85 m s^{-1} south
   (e) 20 m s^{-1} north
   (f) 85 m s^{-1} north
3. (a) 75 m s^{-1} bearing 307°
   (b) 70 m s^{-1} north
   (c) 75 m s^{-1} bearing 127°
   (d) 65 m s^{-1} bearing 067°
   (e) 70 m s^{-1} south
   (f) 65 m s^{-1} bearing 247°
4. Velocity of A relative to B = –velocity of B relative to A.

5. (a) 0.8 m s^{-1} east
(b) 1.6 m s^{-1} across (at 90° to the river current)
(c) 1.8 m s^{-1}
(d) 30° upstream to straight across
(e) 1.39 m s^{-1}

6. (a) (i) 3.0 m s^{-1} downstream
(ii) 2.0 m s^{-1} upstream
(b) (i) 2.5 m s^{-1} downstream
(ii) 2.5 m s^{-1} upstream

7. (a) 80 km h^{-1} north-west (Note wind directions are always stated as the direction from which they come.)
(b) 250 km h^{-1} bearing 193°
(c) 361 km h^{-1} bearing 013°
(d) Bearing 349.1°
(e) 330 km h^{-1}

8. (a) 11.5° upstream relative to straight across
(b) 3.5 m s^{-1}
(c) 3.43 m s^{-1}
(d) 233.3 s = 3.9 minutes

Set 3 Constancy of the Speed of Light

1. (a) The idea of a frame of reference refers to the environment in which you make measurements.
(b) Your most common frame of reference would be your school laboratory, or your home, or the school playground.

2. Answers will vary, for example: Measurements made without considering the frame of reference in which they are made can be misleading. For example, ancient astronomers considered the Earth to be stationary and that the Sun and the Moon (and the rest of the Universe) revolved about it. This misconception guided the thinking of astronomers for centuries before improved technology enabled later astronomers to discover the true situation.

3. (a) An inertial frame of reference is one which is either stationary or moving with constant velocity, or one which is in a stable orbit around a primary. For example, the Earth in orbit around the Sun is an inertial frame of reference.
A non-inertial frame of reference is one which is accelerating. For example, a car turning a corner, or a plane which is accelerating down the runway.
(b) Without referring to some object known to be stationary outside your frame, you cannot find this out.
(c) This relates to the principle of relativity, which in part states that we cannot determine whether or not an inertial frame of reference is moving at constant speed or is stationary, without referring to a stationary reference object outside the frame of reference. For example, in this case, we may need to refer to a nearby planet (which of course we cannot see from inside the enclosed cabin).

4. (a) Inertia is the property any body has which resists any attempt to change its state of uniform rest or motion.
(b) Whenever an object accelerates, its inertia acts to try to keep it in the same place. We experience this when a plane accelerates down a runway. We 'feel' a force pushing us backwards into our seats. There is no such force. What we actually feel is the reaction force our bodies apply to the back of the seat which is accelerating us forwards.
(c) Inertial forces are felt in non-inertial frames of reference. Because they are accelerating, objects within them will have inertia and therefore be subject to the feeling that a force is acting on them in the opposite direction to the acceleration.
(d) Inertia does not act in inertial frames of reference because no acceleration is involved. They have a centripetal acceleration provided by the value of '*g*' at their altitude – a substantial 7 or 8 m s^{-2}.

5. Both you and the other ship are travelling towards Andromeda, but the other ship is moving faster than you.
You are stationary and the ship is moving past you towards Andromeda.
You are moving backwards and the ship is moving towards Andromeda.
The ship is stationary and you are moving away from Andromeda.
You are both moving away from Andromeda, but you are moving away much faster than the other ship.

6. (a) Craft was no longer an inertial frame of reference. Craft was accelerating in the opposite direction to the angle of hang.
(b) Inertial frame of reference. If the craft was accelerating, inertial forces would be noticeable (the mascot would not hang vertically down). (*Note:* We cannot determine by any experiment if the frame of reference is stationary or moving with constant velocity without referring to some point outside the frame of reference.)
(c) Non-inertial – accelerated motion is detectable because of the inertial forces acting on the mascot and causing it to hang at an angle.

7. (a) Einstein considered himself to be in a train moving at the speed of light, holding a mirror up in front of his face and wondered whether or not he would see his reflection.
(b) He would either see his reflection or he would not.
(c) He concluded that he would see his reflection.
(d) His reasoning was based on his belief that the principle of relativity could not be violated. He reasoned that if he could not see himself, then this would be an experiment that would prove that the train, an inertial frame of reference, was moving with constant velocity faster the speed of light. Because this would violate the principle of relativity, he concluded that he must see his reflection.

8. (a) Thought experiment are not bound by any limitations in technology or conventions of ideas. They can roam wherever they might.
(b) By their nature, thought experiments along the lines of Einstein's could not be tested by actual experiment at that time, so convincing other scientists that the experiments and conclusions are valid presents a problem.
(c) The technology to carry out actual experiments along the lines of his thought experiments did not exist (until some 50 years later).
(d) They definitely have a place. They stimulate other scientists to either believe and therefore work to gain evidence or improve their conclusions, or to disbelieve and work to disprove them. Both courses of action often result in the development of further new ideas and advances in scientific thinking.

9. (a) 1. The laws of physics are the same for all inertial observers. (Note that this is sometimes expressed as: All motion is relative and the principle of relativity holds in all situations.)
2. All inertial observers will measure the same value for the speed of light irrespective of their velocity relative to the source. (Note that this is often expressed as: The speed of light is constant regardless of the observer's frame of reference.)
(b) The ideas expressed in the first postulate had been around since the time of Newton, and simply reiterated that idea. It did not cause any change in scientific thinking. However, the second postulate – the consistency of the speed of light was to cause major changes. It redefined the standards of measurement and led to the development of special relativity. It also led to the discarding of the aether model for the transmission of light.

10. (a) Infinite.
(b) c

11. (a) c
(b) c
(c) c
(d) c
(e) c
(f) c

12. (a) c
(b) c
(c) c
(d) c
(e) c
(f) c

Set 4 Galilean and Relativistic Transformations

1. A Gallilean transformation is one in which normal mathematics can be applied in order to determine the relative motion. It compares motion in different frames of reference using only Newtonian physics and ignores relativistic effects.

2. Galilean transformations hold at low speeds where relativistic effects can be ignored. If objects are moving at significant proportions of the speed of light then relativistic effects must be considered, so a simple Galilean transformation would be invalid.

3. (a) Galilean kinematics indicates that the speed of Y relative to observer is = original speed of pion + speed of Y after decay = 1.95 c.
(b) Galilean kinematics indicates that the speed of X relative to observer is = original speed of pion – speed of X after decay (it is moving in the opposite direction) = 0.05 c.
(c) c
(d) c

4. (a) $c - v$
(b) c

5. (a) 1.5 c
(b) 0.96 c
(c) 2 c
(d) c

6. (a) 1.6 c
(b) 0.976 c

7. (a) From $v = \dfrac{(u-v)}{\left(1-\dfrac{uv}{c^2}\right)} = \dfrac{(1-0.6)}{\left(1-\dfrac{1\times 0.6}{1^2}\right)} = \dfrac{0.4}{0.4} = 1 = c$
(b) From $v = \dfrac{(u+v)}{\left(1+\dfrac{uv}{c^2}\right)} = \dfrac{(1+0.4)}{\left(1+\dfrac{1\times 0.4}{1^2}\right)} = \dfrac{1.4}{1.4} = 1 = c$
(c) The speed of electromagnetic radiation is constant regardless of the frame of reference of the observer.

8. (a) From $v = \dfrac{(u-v)}{\left(1-\dfrac{uv}{c^2}\right)} = \dfrac{(0.7-0.4)}{\left(1-\dfrac{0.7\times 0.4}{1^2}\right)} = 0.42\ c$
(b) From (a), speed of X relative to Y will 0.42 c in the opposite direction.

9. (a) 1.9 c
(b) 0.999 c

10. (a) 0.5 c towards Y
(b) 0.5 c towards X
(c) 0.86 c towards Z
(d) 0.86 c towards X
(e) 0.64 c towards Z
(f) 0.64 c towards Y
(g) c
(h) c
(i) c

Set 5 Consequences of Einstein's Postulates

1. The speed of light in a vacuum is an absolute constant.
All inertial frames are equivalent.

2. (a) Standard units of measure are measures that are very accurately known.
(b) A set of standards is needed so that everyone reports measurements the same way. This means the reports will be understood throughout the world.
(c) Standard International Units or Système Internationale or International System of Units.
(d) So that people throughout the world make measurements and report measurements in the same 'language'. It makes measurements throughout the world understood by everyone.
(e) The standards changed as technology improved and more accurate ways were developed to define the standards.
(f) Standards used to be based on the measurement of length, mass and time (the three fundamental quantities on which all other units are based). With special relativity, these could not be considered constant as they all depended on the relative velocity of the person making the measurement.
(g) The standards were changed to be defined using the speed of light, the only constant quantity in the Universe, as the basis for definition.

3. (a) A frame of reference is the environment in which we make measurements.
(b) A rest frame is a frame of reference which is stationary relative to the object we are considering.
(c) The room you are sitting in at the moment is your current rest frame. It is at rest relative to you.
(d) In Newton's physics measurements are compared on the basis that they can all be referred to a frame of reference that is at rest. This is how the motion of individual objects is measured and stated (for example, relative to the ground – assumed to be at rest).
(e) An absolute rest frame is a frame of reference which is at absolute rest. It is stationary with respect to everything in the Universe.
(f) While the room is at rest relative to you, it is moving with the rotation of the Earth on its axis, and with the Earth's orbital motion around the Sun, and with the rotating motion of the Milky Way galaxy, and with the translational motion of the galaxy as it moves with the expansion of the Universe (same answer will apply regardless of the frame you choose).
(g) This is not a simple concept. According to Einstein, space and time cannot be separated, but exist jointly as spacetime. In spacetime there is no absolute rest frame because everything in the Universe is moving relative to all other things in the Universe. One frame of reference may be at rest relative to another frame, but it will always be moving relative to other frames.

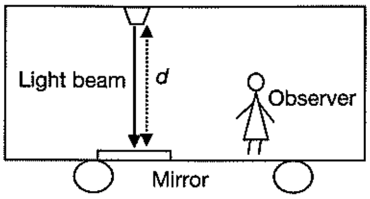
4. (a) Einstein is referring to the fact that because of the consistency of the speed of light, there is not need to invent an aether as a medium to propagate light.
(b) If light was carried by a stationary medium, then the velocity of light would not be constant to all observers, because the observer's motion relative to the aether would affect the relative velocity of the medium to the observer, and therefore the velocity of light relative to the observer.

5. Any four of:
(a) Mass, length and time can no longer be considered to be fundamental quantities, they must be considered as relative quantities which depend on the relative motion of the observer, or stated another way:
- Time measured by observers in different frames of reference may not be the same (time dilation).
- Length measured by observers in different frames of reference may not be the same (length contraction).
- Mass measured by observers in different frames of reference may not be the same (mass dilation).

(b) Events considered as occurring at the same time in one frame of reference, may not be considered to be occurring at the same time in a different frame of reference.
(c) Relative velocities for objects moving at relativistic speeds cannot be determined by simple Galilean transformations.
(d) Light, being constant speed, is not carried by an aether, so there is no need to propose that an aether exists.
(e) Space and time can not be considered as independent quantities. Rather we need to consider a new concept, that of spacetime to define an object's position in the Universe (this idea is not covered in this course).

Set 6 Time Dilation

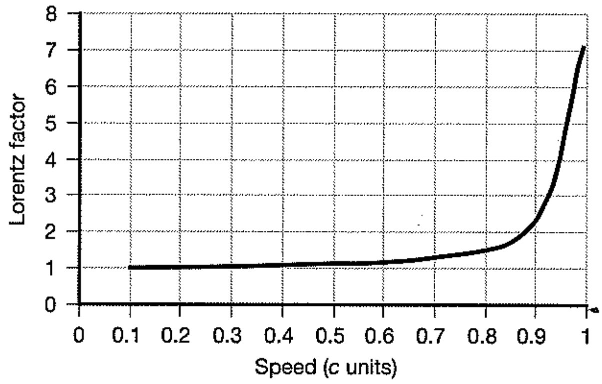
1. A light clock is a device in which time is measured by dividing the distance light travels from a source to a mirror where it is reflected and then travels back to the source by the speed of light. In other words, $t = \frac{d}{c}$. This time, if measured by an observer in the same frame of reference as the clock is known as proper time.



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

3. (a)

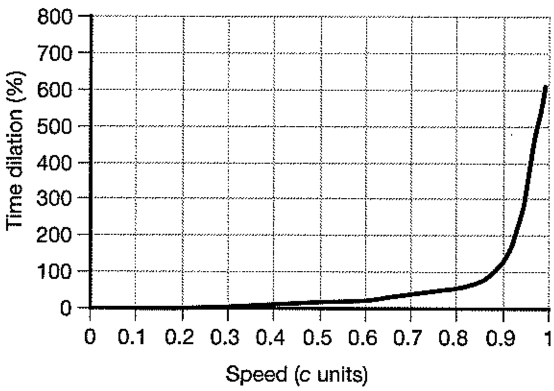


(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 c.

4.

Time on spaceship (s)	Speed of ship	Length of 1 second on spaceship as perceived by observer on Earth	Time dilation effect (%)
1	0.1 c	1.005	0.5
1	0.3 c	1.048	4.8
1	0.5 c	1.155	15.5
1	0.7 c	1.400	40.0
1	0.9 c	2.294	129.4
1	0.99 c	7.089	608.9

5. (a)



(b) At low light speeds, time dilation effect is small, rising exponentially after speeds greater than 0.9 c.

6. Speed of the meson is 0.99 c.

7. (a) 11.55 hours

(b) 8.7 hours

8. 0.503 s

9. 4.9 s
10. 5.46 s
11. 0.94 c
12. (a) 7.79 hours
    (b) 8.21 hours
13. (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}
14. (a) Time recorded on Earth = (4.5 ÷ 0.9) = 5 years
    (b) Astronauts see this as = 2.18 years.
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 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.
16. (a) 0.92 km
    (b) 2.2×10^{-5} s
    (c) 6.5 km

Set 7 Length Contraction

1. Proper length is the length measured by an observer at rest to the object.
2. (a) 1.5 m
   (b) $L = \gamma L_o$
   (c) L will be shorter because the desk is moving relative to Jenny, so length contraction will occur for her.
3. (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.
4. (a) 116 189.5 km
   (b) 96.82 m
5 38 m (speed is too slow for a significant relativistic effect).
6. (a) 250 km
   (b) 250 km
7. (a) 0.66 c
   (b) 0.87 c
8. 0.53 c
9. 124.9 m
10. 293.6 m
11. 137.5 m
12. (a) 8.64×10^8 km
    (b) 1.44×10^9 km
    (c) 1 hour
    (d) 1.67 hours
    (e) 167 m
    (f) 100 m

Set 8 Relativistic Mass

1. (a) 9.16×10^{-31} kg
   (b) 2.92×10^{-30} kg
   (c) 0.806 c

2. (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 $v = 4.2 \times 10^8$ m s^{-1}

(b) This velocity is impossible because it exceeds the speed of light.

3. (a) Negligible (don't even bother working it out).

(b) Negligible (ditto).

(c) 34.2%

4. (a) 2.3×10^{-14} J

(b) 3.49×10^{-14} J

5. 0.999885 c (do not round to 1.0 c, as this would make the mass of the electron infinite)

6. (a) 0.745 c

(b) 1×10^{-7}%

7. (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

$= \frac{1}{2} \times 1.14 \times 10^{-30} \times (0.8 \times 3 \times 10^8)^2 - \frac{1}{2} \times 9.94 \times 10^{-31} \times (0.4 \times 3 \times 10^8)^2$

$= 4.4 \times 10^{-14} - 7.2 \times 10^{-15} = 3.7 \times 10^{-14}$ 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.

8. (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

9. (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

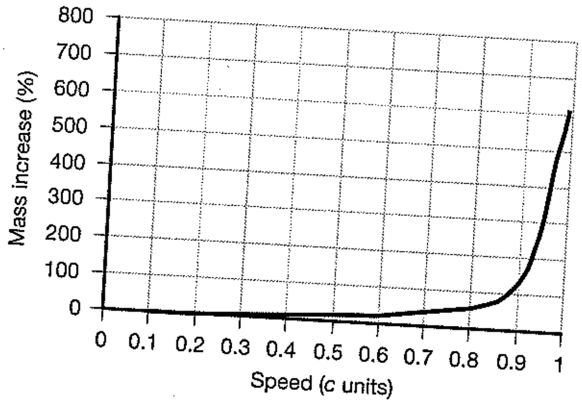
Difference = 1.0602×10^{-10} J

(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.

Set 9 Some Combined Relativity Questions

1. (a) T observes length contraction (and time dilation occurs). Since the train is moving to the right light from the bolt in front has less distance to travel than from the rear bolt.
   (b) The front strike.
   (c) Slightly less than the length of the train carriage.
   (d) Equal to the length of the train.
   (e) Equal to the distance between them as they hit.
   (f) Slightly less than the distance P observes.
2. (a) From $\gamma = \frac{1}{\sqrt{(1-0.95^2)}} = \frac{1}{\sqrt{(1-0.9025)}} = 3.2$
   (b) About 31.2 m
   (c) 0.11 μs
   (d) 0.35 μs
   (e) 9.11×10^{-31} kg
   (f) 2.92×10^{-30} kg
   (g)



3. (a) 4.42 years
   (b) 1.38 years
   (c) 8.84 years
   (d) 2.76 years
4. (a) The astronaut would notice no changes. All would be normal because he is at rest relative to those events.
   (b) His body would be thinner in the direction of travel (length contraction effect), his mass would have increased (relativistic mass increase), and his pulse rate would appear to be slower (time dilation) because of his movement relative to the Earth observers.
5. (a) 4.94 years
   (b) 4.2 light years
   (c) 2.60 years
   (d) 2.21 light years
   (e) Because of their speed, the distance to Alpha Centauri as perceived by the astronauts will be length contracted to 2.21 light years. So, after travelling for 2.60 years their time, they will be at Alpha Centauri.
6. (a) 0.48 *c*
   (b) 17.5 years
   (c) Because they are in motion relative to Xenos, the distance they travel will be length contracted to 8.42 light years, which means they will cover the distance in less time ($8.42 \div 0.48 = 17.5$).
7. (a) The Earth observer will measure the period to be shorter because he is not at rest relative to the ship.
   (b) Neither observer would get this result because the gravitational field strength at the position of the spaceship will be less than that on the surface of Earth. '*g*' out in space is likely to be zero and the pendulum will just hang at its release position and not swing at all.
   (c) They both would. Again, because the gravitational field strength at the position of the spacecraft will be less than that on the surface of Earth.
8. (a) The Earth observer would observe time to be passing more slowly on the spaceship compared to Earth.
   (b) The doctor's logic is flawed. Because the patients are at rest relative to the spaceship, time is passing normally for them, and all body functions will be normal. The disease will progress at the same rate for the patients regardless of the time dilation effect observed from Earth.

Set 10 Relativistic Momentum

1. (a)

Speed (c)	Classical momentum ($\times 10^{-22}$)	Relativistic momentum ($\times 10^{-22}$)	Relativistic momentum compared to classical momentum (γ)
0.10	0.273	0.276	1.011
0.25	0.683	0.706	1.034
0.50	1.36	1.57	1.154
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	2.732	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.

2. (a) Particle A 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 = $\gamma m_o.v = 1.155 \times 2 \times 0.5 = 1.155$ units

Relativistic momentum of B = $\gamma m_o.v = 1.034 \times 4 \times 0.25 = 1.034$ units

(c) Relativistic momentum of A = $\gamma m_o.v = 1.667 \times 40 \times 0.8 = 53.34$ units

Relativistic momentum of B = $\gamma m_o.v = 1.091 \times 80 \times 0.4 = 34.91$ units

3. 0.866 *c*

4. (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.

5. 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.

Set 11 Equivalence of Mass and Energy

1. (a) $E = mc^2$

(b) The mass in kg of an object has a certain value in joules of energy.

2. (a) The mass of an object when it is at rest.

(b) Mass increases at relativistic speeds.

3. (a) Energy possessed by a mass at rest (= mc^2).

(b) It can't be totally observed, but some is released during nuclear reactions.

4. (a) 1.503×10^{-10} J

(b) 9.0×10^{13} J

(c) 1.11×10^{-17} kg

(d) 1.11×10^{-17} kg

5. (a) 9.0×10^{19} J

(b) 9.0×10^{19} J

(c) 9.0×10^{19} J

6. (a) 125 J

(b) 9.0×10^{17} J

(c) 9.0×10^{17} J + 125 J (which can be neglected)

7. 2.25×10^{17} J

8. They would all release the same amount of energy (= 9×10^{16} J) because we use the equation $E = mc^2$ to find this, and for each element, m = 1 kg.

9. (a) Mass defect is the difference between the mass of a nucleus and the total mass of its component nucleons.

(b) The larger the nucleus, the larger the mass defect because more energy is needed to bind the nucleons together.

(c) The mass of the nucleus is less than the mass of the proton plus the mass of the neutron. The binding energy does not contribute to the mass of a nucleus – this is in fact why there is a mass defect – some mass has been converted into the energy which holds the atom together.

(d) Binding energy.

(e) Product nuclei have a lower binding energy per nucleon than reactant nuclei.

(f) The binding energy per nucleon for a nucleus is simply the binding energy of that nucleus divided by the total number of nucleons (protons + neutrons).

(g) Binding energy per nucleon gives us an immediate indication of the stability of the nucleus. The higher the binding energy per nucleon, the more stable the nucleus is. The total binding energy of a nucleus might be small or large, but without knowing the number of nucleons in each nucleus, that information is not as useful.

(h) The higher the binding energy per nucleon, the more energy needed to 'take apart' that nucleus. Therefore nucleus X is more stable than nucleus Y.

10. (a) 2.78×10^{5} J

(b) 3.08×10^{-12} kg

(c) 8.9×10^{15} atoms

(d) 1.35×10^{15} J

(e) 4.32×10^{26} atoms

11. Total binding energy = $7.977 \times 16 = 127.63$ MeV

Which is equivalent to ($\times 1.6 \times 10^{-19} \times 10^{6}$) = 2.042×10^{-11} J

Which from $E = mc^2$, is equivalent to 2.269×10^{-28} kg = 0.1366 amu

12. (a) 0.208885 amu

(b) 3.47×10^{-28} kg

(c) 3.12×10^{-11} J

(d) 4.63×10^{-18} kg

(e) 9×10^{16} J

(f) 1.33×10^{7} tonnes

(g) 2.16×10^{20} atoms

(h) 3.6×10^{-4} moles = 8.43×10^{-5} kg

(i) 2.37 tonnes

(j) 2.27×10^{-4} kg

13. The principle of mass-energy equivalence.

14. 2.28×10^{-13} J = 1.43 MeV

15. 1.12×10^{-12} J = 7.0 MeV

16. 4.5×10^{14} J = 2.8×10^{27} MeV

17. 2.34×10^{15} J = 1.46×10^{28} MeV

18. Mass defect = 0.001212 amu × 931.494 = 1.129 Mev ÷ 2 = 0.564 MeV per nucleon

Set 12 Mass-Energy Relationship and Nuclear Energy

1. (a) A = mass number = sum of number of protons and neutrons

Z = atomic number = number of protons = position on periodic table

X = chemical symbol for the element

(b) Z

(c) Z

(d) $A - Z$

(e) A would be different; the rest would be the same.

(f) Isotopes are atoms of elements which have the same numbers of protons but differing numbers of neutrons.

2.

$^{235}_{92}U$	
A	235
Z	92
Number of electrons	92
Number of protons	92
Number of neutrons	143

$^{238}_{92}U$	
A	238
Z	92
Number of electrons	92
Number of protons	92
Number of neutrons	146

$^{138}_{55}Cs$	
A	138
Z	55
Number of electrons	55
Number of protons	55
Number of neutrons	83

3. (a) The transmutation of a parent element into a daughter element by emission of radiation.

(b) A daughter element and energy.

(c) Alpha and beta particles and gamma radiation.

(d) A helium nucleus.

(e) $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}X + ^{4}_{2}He$

(f) An electron.

(g) ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}X + {}^{0}_{-1}e + {}^{0}_{0}\overline{v}$ (Remember from year 11 work that beta decay is always accompanied by an antineutrino.

(h) 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.

(i) Nuclear fission involves a larger nucleus splitting to form two (or more) smaller daughter nuclei.

(j) Spontaneous and artificial (human induced).

(k) Nuclear radiation and energy.

(l) By bombarding a relatively unstable nucleus with high speed particles (such as neutrons).

(m) Nuclear fusion involves the fusion (joining together) of two smaller nuclei to form a larger nucleus.

(n) Energy.

(o) $E = mc^2$ E = energy released
m = mass defect in the nuclear reaction
c = speed of light = 3×10^8 m s^{-1}

4. (a) Mass defect = 5.195542 amu (= 8.6274×10^{-27} kg)
Energy released = 5.195542 × 931.5 = 4839.65 MeV (= $mc^2 = 7.743 \times 10^{-10}$ J)

(b) Mass defect = 0.1860 amu (= 3.089×10^{-28} kg)
Energy released = 0.1860 × 931.5 = 173.259 J

(c) Mass defect = 6.0024×10^{-3} amu (= 9.97×10^{-3} kg)
Energy released = 5.59 MeV (= $mc^2 = 8.94 \times 10^{-13}$ J)

(d) Mass defect = 0.018882 amu (= 3.135×10^{-29} kg)
Energy released = 17.59 MeV (= $mc^2 = 2.814 \times 10^{-12}$ J)

(e) (i) Y = Po-84
(ii) Mass defect = 6.002×10^{-3} amu (= 9.9665×10^{-30} kg)
Energy released = 5.591 MeV (= $mc^2 = 8.946 \times 10^{-13}$ J)

(f) (i) X = Pa-91
(ii) Mass defect = -2.566×10^{-4} amu (= -4.2609×10^{-31} kg)
Energy released = −0.239 MeV (= $mc^2 = -3.824 \times 10^{-14}$ J)

(g) Mass defect = 0.01071 amu (= 1.7788×10^{-29} kg)
Energy released = 9.975 MeV (= $mc^2 = 1.596 \times 10^{-12}$ J)

(h) The negative value indicates that there is a mass/energy gain in the reaction rather than a mass defect and energy release. This reaction will not occur unless this energy is added to the system, so the decay is not a spontaneous decay. It would have to be initiated in a reactor.

5. (a) 3.489×10^{-3} amu

(b) 2.1041×10^{-3} amu

(c) 2.4945×10^{-3} amu

(d) 1.3097×10^{-2} amu

(e) 6.1836×10^{-3} amu

(f) 2.744×10^{-30} kg = 1.6520×10^{-3} amu

(g) 6.367×10^{-30} kg = 3.8330×10^{-3} amu

(h) 4.200×10^{-30} kg = 2.5293×10^{-3} amu

(i) 9.922×10^{-29} kg = 5.9735×10^{-2} amu

(j) 8.378×10^{-29} kg = 5.0452×10^{-2} amu

Set 13 Ring Laser Gyroscopes

1. (a) Gyroscopes are devices used in planes, helicopters, boats and spacecraft to indicate whether or not the craft is in level flight or movement.

(b) Mechanical gyroscopes work on the basis of the inertia of a freely moving 'gimbal' which will tend to maintain its relative position as the craft pitches or rolls about it.

(c) They work on the basis of laser beam interference rather than mechanical inertia to determine, e.g. angle of pitch, roll or yaw. Ring laser gyroscopes have no mechanical moving parts. They are much more accurate than mechanical gyroscopes.

(d) When the device rotates, rocks or tumbles, there will be a minute difference in the path lengths travelled by the two beams. This will result in a net phase difference in the path lengths of the two laser beams. As a result, there will be a destructive interference pattern formed at the detector. This is known as the Sagnac effect.

(e) The fact that any rolling motion of the craft carrying the RLG will result in the two laser beams being out of phase when they meet at the detector, and so forming an interference pattern.

(f) It is the extent of the Sagnac effect (i.e. the interference pattern formed) that is analysed to determine the pitch, roll, yaw of the craft so it can be corrected automatically.

(g) They are highly accurate, have no moving parts, are compact and lightweight, and do not resist changes to their orientation.

(h) RLGs are commonly used in aircraft for accurate navigation and have military applications in helicopters, ships, submarines and missiles.

(i) They are much more sensitive and accurate than other forms of gyroscopes.

2. (a) A ring laser gyroscope consists of two laser beams travelling in opposite directions.

(b) The two laser beams each reflect off a mirror to a detector.

(c) In the absence of rotation or movement, the path lengths of the two laser beams will be the same.

(d) If the laser beam paths are the same length, the detector will show total constructive interference of the two beams.

(e) If the apparatus rotates, rocks or tumbles, there will be a minute difference in the path lengths travelled by the two beams.

(f) This will result in a net phase difference in the path lengths of the two laser beams.

(g) As a result, there will be a destructive interference pattern formed at the detector.

(h) This is known as the Sagnac effect.

(i) The signal from the output sensor will vary in amplitude depending on the degree of interference.

(j) So the amplitude of the signal gives a measure of the rocking motion of the vehicle concerned.

(k) A computer will analyse the output signal and convert it to an orientation figure for pilots to read.

3. (a) Ring laser gyroscopes, while more accurate than mechanical gyroscopes, suffer from an effect known as 'lock-in' if the movement of the (say) spacecraft, is very slight. When the ring laser is hardly rotating, the frequencies of the two laser modes become almost identical. In this case, crosstalk between the beams results in a standing wave and the beam frequencies lock to each other rather than responding to gradual rotation.

(b) This problem can be overcome by rotating the ring laser clockwise and anticlockwise about its axis using a spring driven at its resonance frequency by a small motor.

(c) This process is known as forced dithering.

Set 14 Medical Uses of Radioisotopes

1. Radioisotopes are radioactive isotopes of elements. As the atoms in each isotope have the same number of protons, the atoms, and therefore the isotopes, are of the same element. Having different numbers of neutrons, they will have different masses.

2. Both have 8 protons and 8 electrons, O-16 has 8 neutrons, O-18 has 10 neutrons.

3. Diagnostic – finding out what is wrong.

Therapeutic – treating the malady.

4. Alpha and beta have very limited penetration powers.

5. Close to Lucas Heights nuclear facility, so short half-life radioisotopes can be delivered to hospitals in the immediate vicinity. (With modern flight times, hospitals within 2 or 3 hour flight time may still find some radiosotopes viable.)

6. Radiotherapy involves the use of long half-life radioisotopes, chemotherapy uses short half-life radioisotopes.

7. Patients – improved, longer life span, cure or at least remission or slowing down of effects of malignant diseases, some detrimental effects during treatment (hair loss, vomiting, weakness), better diagnosis from doctors so better, more effective treatment of problems.

Hospitals – only those close to source can have access to short half-life radioisotopes so services limited in isolated areas; expensive, so pressures on government funding, health societies, patients not covered.

8. Enormous diagnostic advantages – some radioisotopes tend to collect in specific tissue and help diagnosis; computer imaging allows three-dimensional image to be built up.

9. Either by ingestion if the radioisotopes collect in specific organs (iodine in thyroid, strontium-90 in bones) or externally by focusing a thin beam of particles onto the tissue to be treated – energy of particles will determine depth of penetration although tissue passed through will also be affected (hence rotation of source or body).

10. (a) Answers will vary for example:
Nickel-60, which is a beta and gamma emitter, produces gamma rays, which can be used to treat cancer by irradiating the affected areas of the body. Has a suitable half-life for the process, being long enough to have a reasonable lifetime in the equipment (about 5 years), but short enough to emit a reasonable intensity of radiation.

(b) Has very long half-life and would damage tissue if in body for too long. Would kill cancer cells along with other cells.

11. The path of a tracer through an organism or pipe can be 'traced' or followed. For example, tracers can be used in the circulatory system to detect the positions of blockages.

12. Extremely advantageous for both doctors (help in diagnosing maladies) and patients (cure, remission).

13. Valuable in diagnosing and treating disease, which leads to healthier people with longer lives and longer working lives, happier families, less impact on health societies or government medical benefits as patients can return to productive lifestyle.

14. B

15. A

16. D

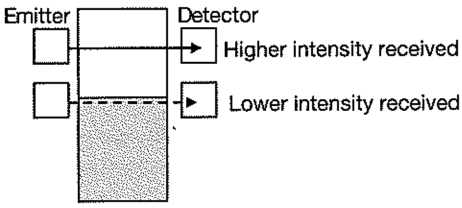
17. D

Set 15 Industrial Uses of Radioisotopes

1. Their half-life, their ionising or penetrating power, and the type of radiation they produce.

2. (a) Beta particles – alpha stopped by paper, gamma too energetic to be affected significantly by paper.
   (b) Gamma radiation emitter – alpha and beta particles would be stopped by metal. Only gamma could penetrate.
   (c) Gamma, because of its very high penetrating power would be the most dangerous to human and the source and emitted radiations would have to be enclosed so that the people were shielded from them. While alpha particles are a safety hazard (mainly because of their high ionising power) their penetrating power is low and they can be easily screened.

3. (a) Radiations emitted by a source would travel through the empty part of the container with greater intensity than the part of the container containing the liquid or grain. The level can be detected by the sudden drop-off in the intensity received on the other side of the container.
   (b) A gamma emitter would be needed as only gamma rays have the penetrating power to reach the detector.



4. (a) No. For example, an alpha emitter would be no use to gauge the thickness of metal sheeting because the alpha particles would not penetrate the metal. It is also important to use radiation that is appropriate but also presents the least danger to workers, so gamma emitters would be used only if they had to be.
   (b) Gamma rays would not be stropped by the paper, so they would not be suitable to use to measure differences in its thickness. Their penetrating power is too high.

5. (a) A radioactive tracer is an isotope introduced into a system (industrial or biological) to study the pathway of materials through that system.
   (b) To be able to be traced, e.g. through an organism, chemical pathway or pipeline.
   (c) Radioisotopes are useful as tracers because their presence (or absence) can be detected without having to do chemical tests or to have actual visual observation of the pathway (as in an underground pipe or aquifer). The intensity of the radiation can be measured easily at any point along the pathway.
   (d) Isotopic gold (Au-198) used in sewers and pipelines.
   (e) Most applications in industry require radiation which has high penetrating power.
   (f) Alpha and beta particles would probably be stopped by the material examined and therefore not give reliable readings.

6. (a) Americium-241, an alpha emitter, has a half-life of 432 years, so it will remain active far beyond the life of the detector. Alpha particles have high ionisation, so sufficient air particles will be ionised for the current to flow, and they have low penetrative power (will be stopped by a few centimetres of air), meaning they will be stopped by the plastic of the smoke detector or the air.
   (b) About one per cent of the emitted radioactive energy of Am-241 is gamma radiation, which could be considered a health hazard.
   (c) The isotope is used because it is inexpensive, easy to obtain and the amount of elemental americium-241 is small enough to be exempt from the regulations applied to larger sources. It provides sufficient ion current to detect smoke, while producing a very low level of radiation outside the device.

7. (a) Gamma radiation is the only one with enough penetrating power to go through the pipe and the ground to reach the detector.
   (b) If a gamma emitting tracer is used, then gamma rays will penetrate the pipe itself and through the ground.
   (c) The radiation intensity will be greater at the position of the leak.

8. Cost effectiveness in tracing leaks; quality control in manufacturing items means better safety, so fewer injuries to people because things like planes, bridges, buildings will be more reliable; cheaper items because of increased reliability so people will have more money to spend on other things.

9. A

10. (a) D
    (b) 3.32 seconds

11. B

12. C

13. C

14. C

15. A

16. The radioactive source produces alpha particles which ionise the air and cause a current flow between the terminals. When smoke enters the detector the current flow reduces and this prompts the electronics to ring the alarm and provide warning of a possible problem.

Set 16 Agricultural Uses of Radioisotopes

1. They are all isotopes of elements in carbohydrates and proteins – the essential compounds in living organisms and so will be integrated easily into the chemicals within the living organisms.
2. (a) A special batch of pesticide would need to be manufactured using a radioactive isotope as one of the elements in the compound. Its ingestion or absorbtion into animals and plants will follow if that occurs and its path through the organisms can be traced.
   (b) We can determine if pesticides end up in the food product, fish or other animals we eat as well as judging its effectiveness in solving the problem of the particular pests involved.
   (c) If a chemical compound is 'tagged', a radioactive isotope is used in its manufacture, so radioactive atoms are incorporated into the molecule of the chemical.
3. (a) Helps scientists determine effectiveness of fertilisers; trace the path of chemicals through the food chain and so be able to change strategies if end products are likely to be adversely affected; detect disease in animals and dietary preferences of animals.
   (b) Some residue radioactive material may end up in foodstuffs; may damage the plants and animals it travels through; may cause detrimental genetic modification in those plants and animals and in humans who ingest them; may cause illness or longer-term side effects of radiation poisoning if overused.
4. (a) Economically it makes sense as food products have a longer shelf life and harmful organisms we may ingest with the food have been eliminated.
   (b) For – better taste, more disease resistant, longer shelf life, bigger, more colourful, grow faster, better adapted to weather changes, temperatures.

   Against – may be harmful to humans, may have undetected long-term effects. Even if not harmful, many people worry that the radiation will cause genetic modifications within the food which may affect humans or that there may be residual radiation which could be harmful to humans.
   (c) Gamma radiation is required – the side effects of this on humans, particularly as most viral infections are spread throughout the body, would probably be fatal.
5. (a) Biological control involves using one biological organism or component of life to control the growth or reproduction of another.
   (b) Radioisotopes are used to sterilise laboratory insects which, when released into the wild, will mate ineffectively with others and so help control the population of that insect.
   (c) There are no residual chemicals in the soil, plants or animals if radioisotope control is used – therefore no possibility of harmful effects to people or other animals or plants. It would seem to be the preferable alternative to using pesticides which can remain in a food chain for years.
   (d) The insects will indulge in a limited number of copulations during their life cycle and if a number of these are with a sterilised partner, then no offspring will result and the population will therefore be reduced by this potential number.
   (e) Unless new generations of sterilised insects are released, when the current generation dies, the remaining insects will be fertile and the pest population will increase again.
   (f) As long as the numbers of pest insects are reduced sufficiently in the sterilising program, traditional methods of controlling their numbers will have more effect in subsequent generations, so long-term control can be effected.
6. C
7. A
8. A
9. (a) B
   (b) Calcium is not a natural constituent of plant cells.

Set 17 The Nuclear Problem

1. The statement has been designed to have a check value in the mention of the very large figure in very short times to emphasise that background radiation should therefore be considered relatively harmless. It has most probably been written by a proponent of nuclear energy and while designed to allay fears connecting cancers with radiation, it is slightly invalid in that it does not consider the additional radiation produced by nuclear reactors or state their contribution to any increase in background radiation.
2. (a) Answers may vary, for example:
   The disposal of nuclear waste products.
   The possibility of nuclear accidents.
   The danger to human health from nuclear accidents and waste.
   The possibility of genetic modifications as the result of exposure to increased background radiation.
   The effects of radiation in food chains when biological control strategies involve radioisotopes.
   (b) Answers may vary, for example:
   The use of radioisotopes to diagnose medical conditions.
   The use of radioisotopes to treat medical conditions.
   The cost savings in discovering leaks in underground pipes.
   The use of radioisotopes in biological control of pests.
   The research value in using radioisotopes as tracers in many branches of science and industry.

3. (a) The data makes the relative danger to humans of background radiation seem negligible.

(b) Not necessarily until we know the validity of the source of the data, and have checked other, similar research studies to see if the data is reliable.

(c) If correct, then the mimimal risk should be a major factor in making decisions as to use nuclear energy or not, but at the same time, it does not take into account the massive danger to people should there be a reactor meltdown. People may consider that risk far outweighs the minimal risk from radioactive wastes.

4. (a) (i) While the data suggests the risk is minimal, human error, as seemed to be the cause in Chernobyl, is unpredictable, so perhaps the figure should be taken as unreliable. Besides, the data does not refer to 20 000 years as an absolute time, but as equivalent operational hours.

(ii) Again, the data suggests this, as well as suggesting the direct consequences to human life would be minimal. It does not mention long-term effects of radiation released into the air which may be considerable. Also, nuclear power has not been with us for very long, so extrapolating to 20 000 years of operation time may be a little premature. Perhaps longer time studies would make the data more reliable.

(iii) Incorrect. The data estimates 1 in every 100 000 meltdowns involving 50 000 deaths.

(iv) The data certainly says that pollution causes many more deaths than nuclear energy production, and equates nuclear meltdowns as 25 per year which is extremely unlikely to happen. So this statement could be accepted on the basis of this data.

(v) This is an estimate based presumably on the number of meltdown accidents there have been so far – very very few. On such little data, the figure is probably unreliable.

(b) Proponents of nuclear power would produce data like this in order to allay public fears about its danger. However, it is also possible that an independent scientific group with no bias could be commissioned by governments to conduct similar studies. In this case, one would accept the data as more reliable.

(c) Only if the research has been done by an independent, unbiased organisation with no actual interest in the process apart from doing reliable research.

5. (a) Not necessarily. Additional deaths are not necessarily due to genetic defect. One would assume they are deaths due to radiation induced cancers. However, knowledge would suggest that 'zero' genetic diseases is an optimistic statement given the intensity of the two atom bombs, and may require better research.

(b) Absolutely not. There is sufficient evidence to support the idea that nuclear radiations actually do cause genetic diseases or mutations.

6. (a) The figures indicate that high level waste is more dangerous, causing one death per 50 years of operation as compared to one per 1000 years for low level waste.

(b) Deep burial would seem to be safer as the waste is carefully contained and monitored in controlled environments. Low level burial containers are subject to corrosion by soil chemicals and water and are likely to corrode and release the radioactive material over time.

7. (a) High level waste (HLW) is produced by nuclear reactors. It contains fission products and highly radioactive transuranic elements generated in the reactor core. High level radioactive waste contains radioactive isotopes with high levels of radiation and long half-lives.

Low level waste (LLW) is generated from hospitals and industry, as well as the nuclear fuel cycle. Low level wastes include paper, rags, tools, clothing, filters, and other materials which contain small amounts of mostly short-lived radioactivity.

(b) Storage of HLW in deep geological storage areas (at least several hundred to at least a thousand metres) is considered the most appropriate strategy.

Some high-activity LLW requires shielding during handling and transport but most LLW is suitable for shallow land burial, ocean depth disposal, incineration or storage in 200 L drums at ANSTO. Isolation of LLW, depending on the radionuclides, could be several hundred years.

(c) Answers will vary, for example:

Burial should be far away from inhabited areas.

Region should be dry and have zero ground water circulation if possible.

Containers need to be as corrosion proof as possible.

(d) Answers will vary, for example:

Area needs to be geologically stable.

Stored material needs to be monitored for container stability.

Should also be in isolated area, e.g. the outback.

(e) This would be an ideal solution if we could guarantee that there would never be a rocket explosion during take-off as this would distribute the waste into the atmosphere and cause widespread increases in airborne radioactivity. The consequences could be disastrous.

8. Disposing of nuclear waste by burying it and forgetting all about it is just like locking things away unseen in a cupboard. It is future generations which will have to cope with the shortcomings of these disposal strategies.

9. (a) 10^{12} watts

(b) 317 ($10^{12} \div 100 \div 365 \div 24 \div 3600$)

(c) This data suggests that the danger from nuclear energy is negligible compared to coal, and to a lesser extent, oil, and much less than the other fuels shown.

Set 18 Development of Relativity

1632 Galileo Galilei – Was the first scientist to propose a principle of relativity. He stated that constant linear motion only had meaning if it was measured relative to something else. Long before Einstein, Galileo proposed that there was no absolute reference frame

1687 Sir Isaac Newton – In his classical physics, time was the same for everything, but light was composed of particles. All other known waves required a medium for their propagation, so light must also. This medium was the 'luminiferous aether.'

1804 Thomas Young – Young's experiments with light caused him to propose, in opposition to the famous Newton, that light is composed of waves and propagates as a transverse wave motion.

1810 François Arago – Realised that differences in the refractive index of a substance predicted by the particle theory of light would provide a useful method for measuring the velocity of light.

1818 Augustin-Jean Fresnel – Realised that even if light was transmitted as waves rather than particles, then the refractive index of the glass-air interface should vary because of the movement of the glass through the aether. Fresnel proposed that the glass prism would carry some of the aether along with it. He proposed that the velocity of light in a prism would need to be adjusted by an amount of 'drag' caused by the presence of the aether in the glass.

1845 George Stokes – Proposed that the aether is completely entrained within or in the vicinity of matter. He argued that the aether is condensed and completely dragged within a medium and expands when it leaves the medium. This compression and expansion changes the speed of the aether, and therefore changes the speed of light which is carried by the aether within the matter.

1851 Hippolyte Fizeau – Conducted an experiment to measure the relative speeds of light in moving water. He expected that the speed of the light in the moving water would be a simple sum of its speed through the water plus the speed of the water. Fizeau detected what he interpreted as a dragging effect, but its magnitude was far lower than expected. He interpreted his results as supporting the partial aether-drag hypothesis of Fresnel.

1873 James Clerk Maxwell – Maxwell connected the known facts that changes in magnetic fields cause changes in electric fields and vice versa, and predicted that these electric and magnetic waves travelled as an electromagnetic radiation, not as a transverse matter wave and proposed that light was also an electromagnetic radiation.

He used this idea to develop a theory of electromagnetism by deriving a set of equations to explain electricity and magnetism. These are known as Maxwell's equations.

The equations predicted the speed of these electromagnetic waves to be a constant 3×10^8 m s^{-1} which was known to be the speed of light – that is, it did not depend on the speed of the source of the light. However, while Maxwell's theory was able to describe the motion of moving bodies mathematically, his ideas were not widely accepted because he was not able to provide an acceptable physical description of the aether.

1881 JJ Thomson – While working on the nature of electrical discharges in vacuum tubes he observed that charged bodies are harder to set in motion than uncharged bodies. Thomson proposed that the mass of a moving object increases with speed, the first proposal of relativistic mass increase.

1881 Albert Michelson – Tried to measure the relative motion of the Earth to the aether, as predicted by Fresnel's partial aether drag theory. He could not determine any relative motion so he interpreted the result as a confirmation of the complete aether drag theory proposed by Stokes.

1886 Hendrik Lorentz – Demonstrated that Michelson's calculations were incorrect. Lorentz showed that Michelson had overestimated the accuracy of his measurements and proposed that this made Michelson's results inconclusive. Lorentz supported the partial drag theory of Fresnel's.

1886 Michelson-Morley – Repeated the Fizeau experiment to confirm Fresnel's results. This changed Michelson's opinion and he now considered Fresnel's partial drag theory of the aether was the correct one.

1887 Michelson-Morley – To confirm Fresnel's partial drag theory, Michelson and Morley conducted experiments to prove the existence of the aether. Their null result in fact supported Stokes' complete drag theory.

1887 Heinrich Hertz – Discovered what we now know as radio waves. These were the first electromagnetic waves to be discovered (apart from light) and this discovery provided support for Maxwell's theory.

1889 George FitzGerald – Published the first known paper about a relativistic effect, claiming that the Michelson-Morley experiment could be explained by introducing a length contraction in the direction of the movement.

1892 Lorentz – Proposed length contraction independently from Fitzgerald in order to explain the Michelson-Morley experiment. In this year Lorentz also proposed that the aether was stationary and that it was not dragged by matter moving through it, thus supporting the idea that the speed of light in a particular medium was constant and independent of the observer.

1893 JJ Thomson – Proposed that objects would not be able to go faster than the speed of light because as their mass increased the amount of energy required to accelerate them would increase to an impossible amount.

1895 Lorentz – Published a draft version of what was to become known as the Lorentz transformations, in which he proposed that electrical and optical phenomena in a moving system were independent of the motion of the system provided the speeds were relatively low. In other words, the term $\frac{v^2}{c^2}$, included in his equations, was small enough to be neglected and therefore when the velocities involved are much less than the speed of light, the Galilean transformations can be used to approximate the results.

With regard to fast moving objects within an aether, Lorentz proposed that since electromagnetic forces travelling at the speed of light within an object hold an object's atoms together (part of Maxwell's ideas), high speed motion would rearrange these forces, changing the object's shape and causing a shortening (known as Lorentz-Fitzgerald contraction), and proposing a shortening by a factor of $\sqrt{\left(1-\frac{v^2}{c^2}\right)}$ that is $L_v = L_o\sqrt{\left(1-\frac{v^2}{c^2}\right)}$ – the same equation later used by Einstein.

He also proposed that there would be a similar mathematical difference in the way they perceived time (time dilation) and that fast moving objects would not necessarily see events occurring at the same time as stationary or other moving objects (early version of the principle of simultaneity).

1898 Henri Poincaré – Explained that astronomers, in determining the speed of light, simply assume that light has a constant speed and that this speed is the same in all directions.

1899 Lorentz – Presented a second version of his Lorentz transformations. The reworked mathematics still indicated a time dilation and a mass increase for moving systems.

1900 Poincaré – Proposed that electromagnetic energy behaves like an imaginary fluid with mass density given by $m = \frac{E}{c^2}$ (rearranging to form $E = mc^2$). He also argued that experiments like the 1897 Michelson-Morley experiment show the impossibility of detecting the absolute motion of matter, that is, the relative motion of matter is relative to the aether. He called this the 'principle of relative motion'.

He supported Lorentz's idea that time measured by different observers isn't necessarily the same, arguing that observers don't necessarily realise this because they are unaware of their motion relative to the objects or events they are observing.

1900 Joseph Larmor – Reworked and published Lorentz's 1895 transformations and stated them in an algebraic form very similar to the ones we see today. In this work he also predicted length contraction and showed that some sort of time dilation would occur for orbitting electrons.

1902 Poincaré – Proposed that although most of the measurements we make assume that there is an absolute space and time (that is a frame of reference that was absolutely motionless relative to all other frames of reference), this, in fact, did not exist.

1902 Walter Kaufmann – Was the first to show experimentally that the ratio of e/m for electrons depended on the speed of the electrons. This was the first experimental proof of the idea of relativistic mass increase.

1903 Wilhelm Wien – Recognised an important consequence of Kaufmann's proof of the velocity dependence of mass. He argued that speeds in excess of the speed of light were impossible, because reaching them would require an infinite amount of energy.

1904 Lorentz – Attempted to develop a theory for electrodynamics which explained all the known aether drag experiments. He tried to prove the applicability of the Lorentz transformations for all electromagnetic forces as well as for non-electrical forces. Although he did not succeed completely, possibly because he still held a belief in the existence of the aether, his work did support the idea that mass was due to electromagnetic forces. The question arose as to whether the electromagnetic theory or the principle of relative motion was correct.

1904 Poincaré – Drew some conclusions from Lorentz's theory and defined the following principle: 'The Principle of Relativity, according to which the laws of physical phenomena must be the same for a stationary observer as for one carried along in a uniform motion of translation, so that we have no means, and can have none, of determining whether or not we are being carried along in such a motion.'

He also proposed that no velocity, regardless of its frame of reference, can surpass that of light as measured by any observer.

With these statements, Poincaré came very close to special relativity which, in part, states that an observer in a non-inertial frame of reference can do no experiment to determine his state of uniform motion without reference to some known object outside the frame of reference.

1905 Poincaré – Published a summary of a paper which filled the existing gaps of Lorentz's work and corrected Lorentz's formulas for the transformations relating to relativistic velocity additions. On 5 June, Poincaré finished an article in which he stated that there seems to be a general law of nature, that it is impossible to demonstrate absolute motion.

He proposed the existence of a non-electrical binding force to explain the stability of the electrons and to explain length contraction. He also modified the Lorentz equations to develop a wave model for gravitational forces and introduced the idea of four-dimensional space.

Later in 1905 Poincaré (independently of Einstein) finished a substantially extended work of his June paper (the so-called 'Palermo paper', received 23 July, printed 14 December, published January 1906). He spoke, among many other things, of 'the postulates of relativity'.

Most historians of science argue that Poincaré did not invent what is now called special relativity, although it is admitted that he anticipated much of Einstein's methods and terminology.

1905 Albert Einstein – Einstein built on the ideas and mathematics of those before him, but instead of trying to incorporate the aether into the work, he ignored it completely. This meant that the mathematics which was unable to explain developing ideas when the aether was included, suddenly made much more sense and held together more coherently.

On 30 June, Einstein finished work on his famous article *On the Electrodynamics of Moving Bodies,* where he formulated the two postulates of special relativity:

- 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.

Einstein showed that when a material body lost energy (either 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: $E = mc^2$.

In September 1905, Albert Einstein published the paper which we now know as *special relativity* and which applied to all inertia frames of reference. Einstein's paper includes a fundamental new definition of space and time (all time and space coordinates in all reference frames are equal, so there is no 'true' or 'apparent' time) and the abolition of the aether.

Einstein stated that Lorentz's theory of 1895, the Maxwell-Lorentz electrodynamics, and also the Fizeau experiment had considerable influence on his thinking but he denied any influence from the Michelson-Morley experiment. This experiment had been an influential turning point in scientific thinking about the aether for many scientists.

The null result in the Michelson-Morley experiment actually provides experimental proof (in retrospect) for Einstein's second postulate – the consistency of the speed of light regardless of the frame of reference of the observer.

Set 19 Atomic Spectra

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.

(c) The isolated coloured lines in the emission spectrum will be the same frequencies as the black lines in the absorption spectrum.

(d) The spectrum formed from light from the Sun.

(e) 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 reflecting 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 the spectrometer.

(f) 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.

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.

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.

2. (a) Top is continuous, middle is emission and bottom is absorption.

(b) Continuous – radiation emitted from the hot object includes all frequencies (the Sun or a light globe).

Emission – formed by radiation emitted from a hot object which is a pure element (hydrogen) or which contains a limited number of elements such that a continuous spectrum does not result.

Absorption – formed when specific frequencies are absorbed by the matter a white light beam passes through, thus deleting those frequencies from the continuous spectrum.

(c) Short wavelength end is the left hand end (the blue/violet end).

(d) High frequency end is also the blue/violet end.

(e) Blue/violet end.

3. (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.

4. (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.

5. (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.

Set 20 Max Planck – The Beginning of Quantum Theory

1. (a) Why was the emitted radiation curve the same general shape for all substances?

Why was the range of radiation emitted by a hot object limited?

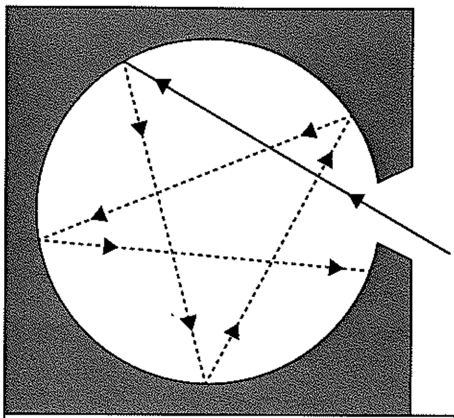
Why did the wavelength of emitted radiation with the greatest intensity (λ_{max}) indicate the temperature of the hot object?

(b) A cavity radiator is simply a hollowed out, hot object with an opening to allow radiation to exit and be observed by an external detector.

(c) A black body radiator is a perfect absorber and emitter of radiation.

(d) The radiation emitted can be analysed without interference from radiation for outside sources – the cavity radiator acts as an experimental control.

(e) The radiation detected inside the cavity can only be radiation absorbed and transmitted through the body of the object to the cavity. So whatever frequencies are absorbed are hypothesised to be re-emitted into the cavity.



Cavity radiator. Energy emitted can be accurately detected through the opening.

2. (a) Planck's idea had the atoms in the black body absorbing heat energy and starting to oscillate back and forth. This oscillation causes the atoms to emit electromagnetic radiation with a frequency that was related to their frequency of oscillation.

(b) Planck proposed that only specific frequency oscillations of atoms was possible as defined by his equation $E = hf$.

He stated that atoms 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 and that 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.

(c) This concept combines the idea of temperature being a measure of the average kinetic energy of the particles of matter with Planck's idea of oscillating atoms. The Planck curve for emitted radiation approaches (at lower temperatures) a normal distribution curve, with the peak frequency being the average and also indicating the greatest number of atoms oscillating at this frequency. As such, it will indicate the average surface temperature of the hot object.

(d) In matter waves, the energy carried is proportional to the amplitude of the wave, whereas in electromagnetic waves it is proportional to the frequency of the wave.

(e) A quantum of energy is simply a very specific amount of energy, often referred to as a 'packet' of energy rather than a quantum.

3. (a) One electron volt is equal to the work done when an electron moves through a potential difference of 1 volt.

(b) 1.6×10^{-19} joules.

(c) Because the amount of energy absorbed and emitted when electrons change quantum levels is so small, the unit we use when we deal with quanta of energy is the electron volt (eV) rather than the joule. The numbers are easier.

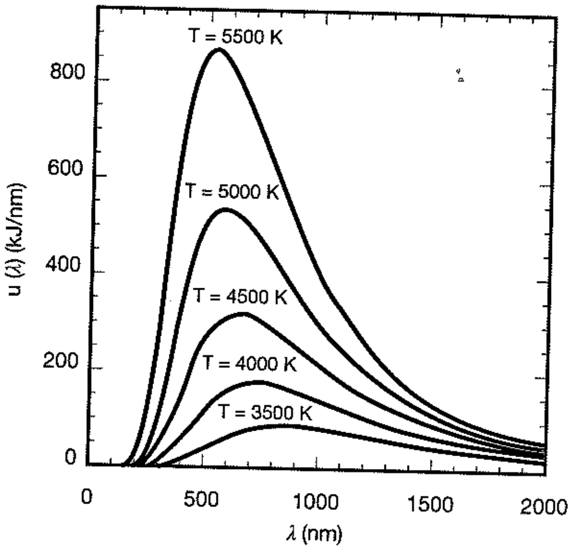
4. D
5. D
6. C
7. D
8. D
9. A
10. C
11. B (While this is a correct formula, it is not an observation.)
12. C
13. A

Set 21 Wien's Displacement Law

1. (a) Wien's displacement law states that the wavelength distribution of thermal radiation from a black body at any temperature has essentially the same shape as the distribution at any other temperature, except that each wavelength is displaced on the graph towards higher frequencies at higher temperatures, or

There is an inverse relationship between the wavelength of the peak of the emission of a black body and its temperature when expressed as a function of wavelength.

(b)



(c) The graphs are typical Planck black body graphs as they are the graphs that Wien was interpreting and quantifying in the mathematical relationship he developed.

(d) The inclusion of the word 'displacement' emphasises the main concept – that the emitted radiation curve is displaced as a whole towards higher frequencies the hotter the object is.

2. Answers will vary, for example:

- We see the Sun because its peak radiation is about 502 nm which corresponds to a surface temperature of about 5778 K and this wavelength is approximately in the middle of the part of the spectrum visible to our eyes.
- The temperature of the filament in a light bulb is typically around 3000 K which means the peak radiation they emit has a frequency in the yellow range of the visible spectrum.
- The body temperature of most warm blooded animals is around 300 K which means the peak radiation they emit is in the infra-red range which is why we can use infra-red cameras and detectors to spy on people.

3. (a) About 1800 nm

(b) About 1.063×10^{-6} nm

(c) About 1208 nm which is in the infra-red range. It appears red to the eye as it puts out more light in the red end of the spectrum than in the blue/violet end.

4. (a) 231.8 nm

(b) This is in the ultraviolet region, so star will appear bluish white in reality as it has more intensity at the violet end than in the red.

(c) 96.6 nm

(d) This is well into the ultraviolet region, so star will appear bluish white.

(e) 305 nm

(f) This is in the ultraviolet region, but it produces a balance of red and blue light so it appears white.

(g) 966 nm

(h) This is an infra-red wavelength but its red output exceeds its blue so it appears red.

5. (a) 9.89 μm or 9890 nm

(b) 3×10^{13} Hz

(c) Deep in the IR band, invisible to the eye but felt as weak heat if you held the lizard since it's only 20°C.

(d) If the lizards are at the ambient temperature then they would be the same temperature as everything around them, and therefore would not stand out in any electromagnetic radiation detector. Perhaps we could use a motion detector.

Set 22 Energy from the Sun

1. (a) The total energy radiated per unit surface area of a black body across all wavelengths per unit time, E^*, is directly proportional to the fourth power of the black body's temperature T.

(b) $E^* = \sigma T^4$

Where E^* = total energy radiated per unit surface area

T = temperature of the hot object in kelvins

$\sigma = 5.67 \times 10^{-8}$ J s^{-1}m^{-2} K^{-4} = Stefan's constant

2. (a) Surface area = $4 \times \pi \times (6.9 \times 10^8)^2 = 5.983 \times 10^{18}$ m^2

(b) Total energy output = 5.983×10^{18} m^2 $\times 6.41 \times 10^7 = 3.835 \times 10^{26}$ W

(c) Its luminosity.

(d) The Stefan's law equation, $E^* = \sigma T^4$, is the energy per square metre of surface area, and given the luminosity is the total energy emitted, it becomes:

Area of sphere is $4\pi r^2$ so $L = 4\pi r^2 \sigma T^4 = A \sigma T^4$

(e) $L = A \sigma T^4 = 3.835 \times 10^{26}$ W $= 5.983 \times 10^{18}$ m^2 $\times 5.67 \times 10^{-8}$ J s^{-1}m^{-2} K^{-4} $\times T^4$

From which $T = 5799$ K

(f) Theory gives the Sun's surface temperature as 5778 K, so the figure obtained is 21 K different = $\left(\frac{21}{5778}\right) \times 100 = 0.36\%$ error.

(g) Data used, especially radius and therefore surface area, and even Stefan's constant have been rounded off, so the error is most likely due to rounding off errors.

3. (a) Surface area of sphere at distance of 150 000 000 km = $4\pi r^2 = 2.83 \times 10^{23}$ m^2

(b) Area = $\frac{(4\pi r^2)}{2} = 2.89 \times 10^{14}$ m^2 (note we divide by the 2 because half the Earth's surface faces away from the Sun)

(c) Fraction = $\frac{2.89 \times 10^{14}}{2.83 \times 10^{23}} = 1.02 \times 10^{-9}$

(d) Solar energy falling on Earth = $1.02 \times 10^{-9} \times 3.835 \times 10^{26}$ W $= 3.916 \times 10^{17}$ W

(e) Energy per square metre = solar constant = 1355 W

4. From $I_1 d_1^2 = I_2 d_2^2$, we get

$6.41 \times 10^7 \times (6.9 \times 10^8)^2 = I_2 \times (150\ 000\ 000\ 000 + 6.9 \times 10^8)^2$

Therefore $I_2 = 1354$ W

5. (a) In our calculations (without actually stating it as an assumption) we have assumed that the solar radiation is incident on Earth at 90° to the surface, and this will only happen for that part of the Earth's surface closest to the Sun.

(b) The average intensity would be less (actually, the average value is only 50% of the calculated value) because for any radiation incident less than 90° to the surface, some radiation will be reflected rather than absorbed.

(c) Efficiencies of the panels should be calculated for the position of the installation on Earth and more panels used to adjust for the lower intensity incident radiation.

Set 23 The Earth's Energy Balance

1. (a) The Earth's energy balance refers to the amount of energy received from the Sun minus the energy reflected and emitted from the Earth.

(b) Climate change is thought to be due to the increasing global temperature which in turn is thought to be due to the greenhouse effect, and this is due to the pollution of the atmosphere by the burning of fossil fuels.

(c) Answers will vary, for example:

- One of the major problems is in the limitations of the models scientists use to predict the changes and their impacts because there are so many variables that need to be considered and many of these are themselves unpredictable.
- Different measures using different instruments in the past have given different results.
- The predictions made years ago have not matched the actual changes, and this weakens our belief in future predictions.
- There are also uncertainties about the effect of temperature rise on the rate of melting of glaciers and ice caps. Again, the actual retreat of many glaciers has been more rapid than models have simulated.

2. (a) This diagram shows 51% of the incident energy being absorbed by the Earth, but none of this is shown as being re-emitted. It also does not show any energy effects of the greenhouse effect. On this diagram, the temperature of the surface of Earth would be extremely hot and rising rapidly.

(b) The second diagram corrects the problems in the first diagram. Although the figures are in different units and differ slightly in percentages, and the combination of the greenhouse effect with surface radiation is a little confusing, the figures in this diagram actually balance.

(c) Energy input = 168 (solar) + 324 (greenhouse) = 492 units

Energy output = 24 (thermal) + 78 (evapotranspiration) + 350 (surface radiation) + 40 (atmospheric window) = 492 units

(d) Energy input = 67 (solar) + 24 (thermals) + 78 (evapotranspiration) + 350 (surface radiation) = 519 units

Energy output = 165 (emitted by atmosphere to space) + 30 (clouds to space) + 324 (to surface) = 519 units

(e) Energy in = 342 (solar) = 342 units

Energy out = 107 (reflected) + 235 (from atmosphere and surface) = 342 units

(f) It isn't. This is a diagram to show the energy balance and it is obviously assuming that all energy transfers are in balance.

3. (a) The greenhouse effect refers to the reflection of heat energy emitted from the Earth's surface back towards the Earth's surface instead of escaping into space.
(b) Thought to be the greenhouse gases emitted from the burning of fossil fuels (oxides of carbon, nitrogen and sulfur) and methane produced by animal flatulence and decomposition of plant matter.
(c) Underwater volcanoes, bushfires, surface volcanoes.
(d) The data in the graph would seem to support the idea that current global warming is part of a natural cycle if the rapid increase in carbon dioxide concentrations since 1950 are ignored. It is the rapid, unnatural increase since then that is the problem.
(e) Mary's statement is correct, especially with food crop plants which would thrive in a higher carbon dioxide environment.
John's statement is also correct. More carbon dioxide means higher atmospheric temperature which means higher evaporation rates from both soil and plants (transpiration), and this would affect the ability of plants to survive normally.

4. (a) Phytoplankton of microscopic plant material living in the surface layers of the oceans.
(b) They provide the base for the food chain of ocean life and they play a major role in atmospheric carbon dioxide to oxygen conversion.
(c) The ocean waters will become more acidic.
(d) The viability of the phytoplankton will be decreased.
(e) They may reproduce more rapidly, or they may die back if the water temperature exceeds the maximum they can survive and reproduce.
(f) If phytoplankton increase, ocean life would increase accordingly, and vice versa. The carry on effects of these to human food supplies will follow the same trend.

5. (a) The correlation is extremely high. All three sets of data follow the same trend patterns almost exactly. There is no doubt on this data that the three variables are intimately connected – until 1950.
(b) There is obviously an unnatural, extraneous variable affecting the carbon dioxide concentrations since 1950, so the correlation is lost between the carbon dioxide graph and the other two after this time. In addition, the non-observed rise in global temperature and sea level during this time suggest the carbon dioxide increase has had little effect.
(c) Given the lack of correlation between the carbon dioxide and the other two variables since 1950, this data would tend to support the opponents of global warming (at least as being caused by the increase in carbon dioxide).
(d) The values of the variables in 1950.
(e) The melting and refreezing of the ice caps due to the changes in global temperature, seemingly also or in turn due to changing carbon dioxide levels in the air.
(f) There is no doubt that it is closely related to carbon dioxide concentrations in the air, although again, the levels since 1950 call the correlation since then into some question.

6. This is a complicated question and the answer is affected by many variables. For example:
- The accuracy of climate change measurements has been questioned mainly because of the limitations of the models scientists use to predict the changes and their impacts.
- There are problems predicting how rapidly global temperature will increase in the future, and by how much, partly because we do not know what the rate of greenhouse gas emissions will be.
- Rising temperatures play a key role in all factors that contribute to sea-level rise and climate change, so uncertainty in its prediction means uncertainty in the models predicting the future changes.
- In addition, different measures using different instruments in the past have given different results. The predictions made years ago have not matched the actual changes, and this weakens our belief in future predictions.
- There are also uncertainties about the effect of temperature rise on the rate of melting of glaciers and ice caps. Again, the actual retreat of many glaciers has been more rapid than models have simulated. It is not yet known if this is a fault in the modelling or due to changing environmental conditions since the modelling programs were developed.
- In other areas, the cost of implement emission reduction technologies is high and both governments and businesses are unwilling to commit to those costs, even if they could be convinced that the problem was serious enough to act now.
- The general population is unlikely to be seriously active against global warming unless it impacts directly on their lives in a noticeable way. It isn't at present, so they have no stimulus to force governments to act.

Set 24 The Rutherford Atom

1. (a) Rutherford's planetary model had negative electrons orbiting around a small nucleus which contained most of the mass of the atom. He proposed that the nucleus was dense, small, and carried a positive charge.
(b) Observations made from his alpha particle experiment.
(c) The model was the 'plum pudding' model where positive and negative charge was distributed evenly throughout the atom like the plums in a pudding. It was proposed by JJ Thomson.
(d) A
(e) It did not explain spectral lines. And since electrons emit EMR due to a_c they would spiral into the nucleus in a hundred millionth of a second.
(f) Scientific 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.

2. (a) Helium nuclei.

(b) ^4_2He

(c) Its nuclei are heavy and it can be beaten into very thin sheets. 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.

(d) Alpha particles were relatively massive and charged and therefore could be accelerated if necessary, and had enough momentum to penetrate the thin gold sheet and to have observable effects when they collided with gold nuclei.

(e) V = electrons orbiting gold nucleus

W = alpha particle deflected by passing close to gold nucleus

X = gold nucleus

Y = undeflected alpha particle

Z = alpha particle reflected back after electrostatic rebound with gold nucleus

(f) Most of the atom was empty space.

(g) Reference material is unreliable here. Some say Rutherford allocated a positive charge to the nucleus, others say that he left it undecided.

(h) Alpha particles passing close to a nucleus could have been deflected due to repulsion from a positively charged nucleus or attraction due to a negatively charged nucleus.

(i) Most alpha particles passed through the gold foil undeflected.

(j) It suggested that an electric field existed within the gold foil – perhaps associated with its atoms. This suggests that some component within the atom would carry an electric charge.

(k) There is no reason why Rutherford should have connected quantum theory with atomic structure in 1911 because no one else had either. Planck's theory was about the origin of electromagnetic radiation, not atomic structure and there was no reason at the time to connect these different areas of study (although both Einstein and Bohr did a few years later).

(l) Rutherford's simple model became the basis for modifications by Bohr and other physicists in the next few decades. It was the first modern model with a nucleus and orbiting electrons. Of significant importance were the calculations of the relative sizes of the atom compared to the atom as a whole. Although it did not explain atomic spectra, it was the foundation on which Bohr developed his allowable orbits model and led to the eventual development of equations (Balmer got his equation in the 1890s and Rydberg in the few years to follow).

(m) An accelerating charged particle emits electromagnetic radiation. Travelling in a circular orbit, electrons should be emitting radiation, and should spiral into the nucleus. Atoms should be unstable based on Rutherford's model.

Rutherford's model was also unable to explain the spectral lines emitted by hot gases, and in fact, made no attempt to do so.

Set 25 The Bohr Atom

1. (a) Bohr examined evidence collected by other scientists and recognised the connection between Balmer's equation (developed to explain the spectrum of hydrogen), Planck's quanta and Einstein's idea that quanta applied to all electromagnetic radiations.

He combined their ideas and predicted that Planck's oscillators were electrons, that quanta were involved with electrons transferring from one energy level to another, and that it was these quanta which determined spectra.

(b) In Bohr's model of the atom, electrons in an atom exist in stable, circular orbits and did not emit radiation as would be expected on moving charges in classical physics. Electrons absorbed or emitted specific quanta of energy when they move from one stable energy level to another.

(c) The movement of electrons from a higher energy level to a lower energy level emitted the radiation which produced spectral lines.

2.

	Energy (J)	Energy (eV)	Wavelength (m)	Frequency (Hz)
(a)	2.56×10^{-17}	160	7.76×10^{-9}	3.87×10^{16}
(b)	1.6×10^{-18}	10.0	1.24×10^{-7}	2.42×10^{15}
(c)	2.56×10^{-19}	1.6	7.76×10^{-7}	3.87×10^{14}
(d)	4×10^{-12}	2.5×10^{7}	4.97×10^{-14}	6.04×10^{21}
(e)	5×10^{-18}	31.25	3.98×10^{-8}	7.54×10^{15}
(f)	9×10^{-16}	5625	2.21×10^{-10}	1.36×10^{18}
(g)	2.65×10^{-25}	1.66×10^{-6}	0.75	4×10^{8}
(h)	3.98×10^{-17}	248.75	5×10^{-9}	6×10^{16}
(i)	5.63×10^{-12}	3.52×10^{7}	3.5×10^{-14}	8.5×10^{21}
(j)	3.98×10^{-19}	2.49	5×10^{-7}	6×10^{14}
(k)	1.33×10^{-14}	8.30×10^{4}	1.5×10^{-11}	2×10^{19}
(l)	7.95×10^{-26}	4.97×10^{-7}	2.5	1.2×10^{8}

3. (a) 2.65×10^{-27} J = 1.66×10^{-8} eV
(b) 5.30×10^{-23} J = 3.31×10^{-4} eV
(c) 2.65×10^{-19} J = 1.66 eV
(d) 3.61×10^{-19} J = 2.26 eV
(e) 4.68×10^{-19} J = 2.92 eV
(f) 5.23×10^{-19} J = 3.27 eV
(g) 9.94×10^{-19} J = 6.21 eV
(h) 2.65×10^{-13} J = 1.66×10^{6} eV = 1.66 MeV
(i) 3.31×10^{-10} J = 2.07×10^{9} eV = 2.07 GeV

4. (a) The hydrogen spectrum was the simplest to analyse and, following Balmer's mathematical analysis, it assisted Bohr to hypothesise the existence of discrete orbits for electrons in order to try to explain the spectrum.
(b) The Balmer equation describes the series of electron transfers from higher level orbits to $n = 2$ specifically in the hydrogen spectrum. The first 4 transitions produced are easy to measure visible lines.
(c) Spectra in general, the hydrogen spectrum in particular stimulated many scientists to study the structure of matter in order to explain the spectra. The hydrogen spectrum stimulated Balmer, the Balmer equation stimulated both Bohr and Rydberg, and the Bohr model was the stimulus for future models. Without the hydrogen (or other) spectrum, these models may not have been developed.

6. (a) A
(b) Bohr's postulates represent the conditions which must be true in order for his model to work.

6. D

7. C

8. B

9. (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.

10. B

11. (a) A
(b) This is a convention used in all sciences to distinguish exothermic and endothermic processes. The energy values in all exothermic processes are reported as negative values, so these values are showing energy released, and this occurs when electrons fall to lower levels.

12. B

13. C

Set 26 Energy Levels and the Bohr Atom

1. (a) Balmer derived his equation by trial and error from the spectral lines in the visible hydrogen spectrum.
(b) Rydberg generalised Balmer's equation to account for the wavelengths of the spectral lines in the hydrogen spectrum.
(c) Bohr's model matched the ideas in both equations as his energy levels identified actual physical concepts for the numbers used by Balmer and Rydberg. Following Bohr's proposal of the energy levels for electrons, the Rydberg equation was modified into the form we use nowadays, with Bohr's level number ($n = 1$, $n = 2$ and so on) replacing Rydberg's integral number (m = the number of the line in the spectrum).
(d) It correctly predicted the ionisation energy of hydrogen to be 13.6 eV.
(e) The Bohr model also predicted other series in the hydrogen spectrum (only the Balmer and Paschen series had been discovered).
(f) The black lines in an absorption spectrum are there because electrons in hydrogen atoms have absorbed energy equivalent to those wavelengths to rise to higher energy levels. In cold hydrogen, the electrons are in their lower energy levels and this energy absorption can occur, so the absorption lines appear in the spectrum. However, in very hot hydrogen, the lower energy levels are empty because the electrons are already excited to higher levels. Therefore some lower energy spectral lines will not be visible in the absorption spectrum of very hot hydrogen.

2. (a) From the diagram, E = 10.20 eV. From Rydberg, E = 10.22
(b) From the diagram, E = 13.06 eV. From Rydberg, E = 13.08
(c) From the diagram, E = 1.89 eV. From Rydberg, E = 1.89
(d) From the diagram, E = 2.55 eV. From Rydberg, E = 2.56
(e) From the diagram, E = 0.66 eV. From Rydberg, E = 0.66
(f) From the diagram, E = 0.97 eV. From Rydberg, E = 0.97

3. (a) 1.2×10^{-19} J = 0.75 eV and 7.0×10^{-20} J = 0.437 eV
(b) Another transition energy value is 0.313 eV = 5.008×10^{-20} J
(c) 7.55×10^{13} Hz
(c) From $n = 6$ to $n = 4$

4. (a) X = Lyman series

Y = Balmer series

Z = Paschen series

(b) The Balmer series is in the visible light spectrum. Lyman is in ultraviolet and Paschen in infra-red. These parts of the spectrum were not known at the time of Balmer and certainly no method was known to detect them.

5. (a) Wavelength for the change = 1282 nm so from $v = f\lambda$, frequency = 2.34×10^{14} Hz

(b) Wavelength for the change = 486 nm so from $v = f\lambda$, frequency = 6.17×10^{14} Hz

(c) Wavelength for the change = 94 nm so from $v = f\lambda$, frequency = 3.19×10^{15} Hz

(d) Wavelength for the change = 656 nm so from $v = f\lambda$, frequency = 4.57×10^{14} Hz

(e) Wavelength for the change = 410 nm so from $v = f\lambda$, frequency = 7.32×10^{14} Hz

6. (a) $E = hf = 1.55 \times 10^{-19}$ J = 0.97 eV

(b) $E = hf = 4.09 \times 10^{-19}$ J = 2.56 eV

(c) $E = hf = 2.11 \times 10^{-18}$ J = 13.2 eV

(d) $E = hf = 3.03 \times 10^{-19}$ J = 1.89 eV

(e) $E = hf = 4.85 \times 10^{-19}$ J = 3.03 eV

7. (a) Ground state is not −13.6 eV.

(b) The values given are the energy values for an electron transfer from a higher to a lower level, therefore energy is emitted not absorbed.

(c) Energy involved = 30.6 − 7.65 = 22.95 eV (added) = 3.672×10^{-18} J = 5.54×10^{15} Hz

(d) From the diagram, maximum energy = 122.4 eV = 1.958×10^{-17} J. From $E = hf$, this corresponds to a frequency of 2.96×10^{16} Hz.

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.

9. (a) C

(b) Shortest wavelength corresponds to the highest frequency which indicates the highest energy, so the largest emission jump is from $n = 6$ to $n = 2$. Note that the jump from level 2 to 6 would require an input of energy and would be part of an absorption spectrum.

10. (a) B

(b) The two possibilities are the sum of and the difference between the values given. The sum represents successive falls from (say) level 4 to level 2 then a second fall from level 2 to level 1. For the other line, the higher value could represent a fall from 4 to 1 and the lower value from 2 to 1, in which case the difference represents a fall from 4 to 2.

11. (a) D

(b) This energy value does not correspond to any of the energy differences between levels, so it would not be transferred from the photon to any electron.

12. (a) A

(b) The total energy involved will be the same as long as the initial and final energy levels are the same regardless of the steps taken to get there.

13. (a) C

(b) The electron could fall directly to level 2 (one spectral line), or it could fall to level three (another line) and then to level 2 (the third line). As each of these jumps involves a different amount of energy, each will produce an independent spectral line.

14. (a) D

(b) Ionisation energy is the energy to remove an electron completely – this is the ground state energy as a positive value.

15. (a) C

(b) $n = 4$ has an energy value of −0.95 eV and $n = 2$ has an energy value of −3.67 eV. The difference between them is 2.72 eV and this is how much energy would be released by an electron falling from 4 to 2.

16. (a) B

(b) The Balmer series refers to electron falls to level 2, so the second line in the equivalent Balmer series for this element would be from level 4 to level 2 which is 3.67 − 0.95 = 2.72 eV.

Set 27 Limitations of the Bohr Model

1. (a)

Spectral line	n	λ calculated	λ experimental
H_α	3	656.1	656.21
H_β	4	486.0	486.07
H_γ	5	433.93	434.01
H_Δ	6	410.06	410.12
H_ε	7	396.90	396.81
H_ζ	8	388.80	388.75
H_η	9	383.44	383.40
H_θ	10	379.69	379.50

(b) The figures are very similar, the sum of the differences in the 8 figures being 0.69, the average difference = 0.086. The largest difference is 0.19 on the last transition = 0.05% error.

(c)

Spectral line	Transfer from	λ (calculated) nm	λ (experimental) nm
H_α	3	656.3	656.21
H_β	4	486.17	486.07
H_γ	5	434.08	434.01
H_Δ	6	410.21	410.12
H_ε	7	397.04	396.81
H_ζ	8	388.94	388.75
H_η	9	383.57	383.40
H_θ	10	379.82	379.50

(d) Again the figures are very similar, although the error using the Rydberg equation is larger than using the Balmer equation. The sum of the differences in the 8 figures is 1.16, the average difference = 0.145. The largest difference is 0.32 on the last transition = 0.084% error.

(e)

Spectral line	Transfer from	λ from Rydberg (nm)	λ experimental (nm)
Hydrogen Paschen	6 to 3	1093.89	1099.45
Hydrogen Paschen	5 to 3	1281.91	1280.80
Hydrogen Paschen	4 to 3	1875.24	1882.38
Hydrogen Lyman	6 to 1	93.76	93.83
Hydrogen Lyman	5 to 1	94.96	95.13
Hydrogen Lyman	4 to 1	97.23	97.4
Hydrogen Lyman	3 to 1	102.55	103.1
Hydrogen Lyman	2 to 1	121.54	121.8

(f) For the Paschen series, the sum of the differences in the 3 figures is 14.51, the average difference = 4.84. The largest difference is 7.14 on the last transition = 0.38% error.

For the Lyman series, the sum of the differences in the 5 figures is 4.84, the average difference = 1.12. The largest difference is 0.45 on the second last transition = 0.44% error.

(g) The Rydberg is most accurate for the Balmer series and is less accurate for the others processed here. Its use as a predictor of the wavelengths for hydrogen however seems fairly reliable, and the errors are small.

(h) Given that the Bohr model works quite well for hydrogen, these results do not really highlight the weakness that it does not work as well for larger atoms. It is thought that the influence of the other electrons and the larger number of protons in nuclei attribute to the inaccuracies in the predictions of emitted wavelengths when comparing experimental and Rydberg predictions. In addition, if orbits are not circular as proposed by Bohr, then energy values and therefore wavelengths of emitted radiation will be different from different positions around the orbit.

2. (a) The Bohr model cannot explain the varying intensities (brightness or thickness) of some spectral lines compared to others.

(b) Because the energy values for each electron transfer are quantised, then the most common transfers will be the one(s) which involve the quantised energy amounts the element is subject to. This will depend on its temperature and the energy being added to it.

(c) The lowest energy transfer in the hydrogen spectrum is $n = 2$ to $n = 1$, so this involves the least energy, and it would be assumed that this amount of energy would be more readily available than any higher amounts, so more transfers occur between these levels than any others.

3. (a) X = very strong field, Y = normal (no field), Z = strong field.

(b) Y = Zeeman effect, X = anomalous Zeeman effect.

(c) The Bohr model has no explanation for these observations.

(d) Moving charged particles are deflected by magnetic fields, and electrons are moving charged particles, so perhaps the interaction between the electrons and the magnetic field changes their energy slightly.

4. (a) 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.

(b) The left hand end – the short wavelength and therefore the high frequency end. In addition, gamma rays are known to be the highest energy waves.

(c) The high energy end of the spectrum is due to the oscillation of the nuclei in atoms, not electron transfers between levels.

(d) None of the rest of the electromagnetic spectrum (apart from Hertz waves) were known at the time, and the electromagnetic model had not really been fully accepted.

5. It was a mixture of classical and quantum physics which did not sit well with physicists.

6. (a),(b) Electrons in an atom exist in stable, circular orbits – Bohr didn't know what these orbits looked like, but assumed them to be circular. This still left Bohr's model with the same weakness as Rutherford's model – there was no explanation for the existence of these 'stable' orbits.

Electrons in stable orbits do not emit radiation – This was one of the observations about atoms that Bohr's model could not explain, but it was an observed fact, so it had to be.

Electrons absorb or emit specific quanta of energy when they move from one stable energy level to another – This idea explained Planck's quanta, photoelectric quanta and the spectra of elements.

(c) It was far better at explaining observations about matter (especially chemical reactions) than any other model, and so it was the best to use at the time. It has been modified by several other models since inception.

(d) The models after the Bohr model are difficult to understand and are built on the foundation of the Bohr model so in order to progress, students need to understand the Bohr model – so it is taught in high schools.

(e) At high school and university level, the Bohr model is an essential piece of knowledge that leads into more complex quantum models of the atom. In essence, while some of the basic ideas in the Bohr model are carried through to more modern models, the model itself has been discarded in favour of quantum models.

Set 28 Bohr and De Broglie

1. (a) De Broglie proposed that if things considered to be waves could exhibit particle properties, then things considered to be particles could also exhibit wave properties.

(b) De Broglie used the idea of electrons as waves to propose that the allowed electron orbits were those that fitted standing waves in them.

(c) The standing wave concept for electron orbits explained the stability of the orbits, and why there were a limited number of discrete orbits around an atom.

(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.

(e) His equation $mvr = \frac{nh}{2\pi}$ included mass (a classical concept) and Planck's constant (a quantum concept).

2. (a) It attempts to show the standing wave orbits around an atom.

(b) $\lambda = 2\pi r$

(c) $\lambda = \pi r$

(d) $\lambda = \frac{2\pi r}{3}$

(e) $\lambda = \frac{2\pi r}{n}$

3. From $\lambda = \frac{h}{mv} = 1.33 \times 10^{-36}$ m

4. (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.

5. 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.

6. From $\lambda = \frac{h}{mv}$, for X, $\lambda = \frac{h}{4mv}$

For Y, $\lambda = \frac{h}{m2v}$

So, ratio X : Y = 1 : 2

7. From $\lambda = \frac{h}{mv} = 9.7 \times 10^{-10}$ m

8. From $\lambda = \frac{h}{mv} = 2.20 \times 10^{-15}$ m

9. From $\lambda = \frac{h}{mv} = 1.58 \times 10^{-8}$ m

10. From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 0.036$ m s^{-1}

11. From $\lambda = \frac{h}{mv} = 1.49 \times 10^{-36}$ m

12. From $\lambda = \frac{h}{mv} = 2.76 \times 10^{-35}$ m

13. From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 1.347 \times 10^{6}$ m s^{-1}

14. From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 9419$ m s^{-1}

15. From $\lambda = \frac{h}{mv} = 1.32 \times 10^{-13}$ m

16. From $\lambda = \frac{h}{mv} = 3.68 \times 10^{-34}$ m

17. From $\lambda = \frac{h}{mv}$, $v = \frac{h}{m\lambda} = 0.125$ m s^{-1}

Set 29 Pauli, Quantum Numbers and the Exclusion Principle

1. (a) Most probably Heisenberg's explanation of the Žeeman and anomalous Zeeman effects which involved quantum mathematics and the idea of quantum numbers.

(b) The principal quantum number (n) defined the energy level of the electron.

The orbital quantum number (l) described the shape of the energy level. This could have any value from 0 (circular orbit) upwards (orbit more elliptical).

The third, orbital magnetic quantum number (m_l) described the orientation of the orbit with reference to the x, y and z axes in space. This can have values ranging from +l to 0 to –l.

The fourth, spin quantum number (m_s), $+\frac{1}{2}$ or $-\frac{1}{2}$, indicated whether the electron spins clockwise or anticlockwise.

(c) Pauli's exclusion principle proposed that no two electrons could have all four quantum numbers identical. At least one must be different.

(d) The third proposal of the magnetic quantum number.

2. (a) Pauli and Bohr both worked on theoretical models of the atom. Neither had experimental data to back up their statements, but relied on their theory being able to explain the observations of other scientists.

(b) Bohr had an ability to link other scientists' new ideas and to see the connection between ideas in one field (e.g. black body radiation) and apply it to another field (atomic structure). Pauli had the advantage of building on top of Bohr's model.

(c) Bohr was actually attempting to explain patterns in the properties of chemicals. Pauli was attempting to explain atomic spectra.

(d) Pauli's quantum numbers helped to account for the different energy levels in the Bohr atom.

(e) When the same result in science is obtained from two or more different directions the results support each other and increase the reliability and validity of the scientific proposal being tested or developed.

3. Very simply, the cartoon is saying that two objects cannot occupy the same space at the same time which alludes to electrons having to be in different quantum positions around the atom.

4. (a) C

(b) Pauli's idea was applied to explain electron suborbits, the relatively large sizes of heavier atoms (and the high conductivity of metals).

5. (a) B

(b) It explained why heavier atoms are so much larger than lighter atoms (they need more electron orbits to hold the extra electrons), and it accounts for the existence of s, p, d, f etc suborbits within electron orbits.

Set 30 Schrödinger, Heisenberg and Dirac

1. (a) Pauli and Heisenberg (1923) both proposed replacing the semiclassical mathematics of Bohr by quantum ideas, deriving equations to describe the atom using matrix mathematics. Schrödinger was working on a similar purpose using a wave mechanics model.

(b) An alternate model was favoured because of the limitations in the Bohr model, especially the fact that it was a mixture of classical and quantum physics.

(c) They accepted Schrödinger's more understandable 1926 wave mechanics model, often called the 'electron cloud' model because it described the electronic structure of an atom in terms of the mathematical probability of finding the electrons in certain regions of the space around the nucleus, because it had more familiar concepts and equations, and it seemed to do away with the difficulties of the developing quantum theory, and fitted in with Pauli's exclusion principle put forward in 1925.

(d) It was not so much new evidence that the model was based on, but new mathematics which was able to describe and predict behaviour more accurately than models before it.

(e) It is important to understand the limitations of the Bohr model and that other models have been proposed to solve the Bohr problems. However, the mathematics of these new models is far too complex to study at this level. It is sufficient to simply be made aware of them.

(f) Perhaps the main change understandable at this level is the idea that electron orbits would not be simple as proposed by Bohr, but would have 'levels within levels' – or subshells as we now know them – the s, p, d, f and g subshells containing mathematically defined maximum numbers of electrons, all obeying the Pauli exclusion principle.

(g) New observations gathered with high technology enables scientists to observe and measure more accurately. Changes to developing models are always subject to change because of this.

2. (a) It is not surprising to have people arguing over the superiority of their intellectual ideas. In such a high profile area, it is also not surprising that these two scientists would defend their ideas against each other. It does seem though that their arguments have diverted from scientific fact and become a little more emotional than might be expected of scientists at this level of importance.

(b) It is probable that, like today, very few scientists would have understood the mathematics of quantum physics, so both models would have been found to be quite difficult to understand. However, as stated in 1(b) above they accepted Schrödinger's more understandable 1926 wave mechanics model because it described the electronic structure of an atom in terms of the mathematical probability of finding the electrons in certain regions of the space around the nucleus, because it had more familiar concepts and equations, and it seemed to do away with the difficulties of the developing quantum theory, and because it fitted in with Pauli's exclusion principle.

(c) Heisenberg's matrix mathematics was just too abstract and difficult to understand. It was not because it described the atom less accurately than Schrödinger, it was just too hard to visualise a physical model from his mathematics. In fact, Schrödinger later proved that Heisenberg's work was actually describing the atom in the same way as his wave mechanics model – just coming at it from a different viewpoint.

(d) Because it described the electronic structure of an atom in terms of the mathematical probability of finding the electrons in certain regions of the space around the nucleus, because it had more familiar concepts and equations, and it seemed to do away with the difficulties of the developing quantum theory, and fitted in with Pauli's exclusion principle put forward in 1925.

(e) Any similar conclusions from different approaches serve to support each other and to strengthen the scientific principles being studied. The validity of both models was enhanced by the fact that they arrived at the same descriptions of the atom.

(f) (i) No. All models before them had similar problems and they were also not useless. They all served to increase scientific understanding of the structure of matter and to form the foundation for improvements to be made by future models. Their limitations served to direct the focus of future study towards better models.

(ii) As stated by Bernard of Chartres in the 12th century, and used by Sir Isaac Newton, this illustrate the idea of 'standing on the shoulders of giants'. Most developments in all areas of study start with small advances by people, and improve as knowledge and technologies improve. Subsequent people can make bigger advances but each advance builds on the work of those who preceded them. This is the pathway of scientific discovery throughout the ages.

3. (a) Dirac's work has been described as 'a more profound and significant general formulation of quantum mechanics than was achieved by any other in this field'. The Dirac equation, which describes the behaviour of fermions (fundamental atomic particles) explained the spin of electrons. The Dirac field is said to be as important to theoretical physics as the work of Maxwell and Einstein. Dirac is regarded as the founder of quantum electrodynamics, being the first to use that term.

(b) Dirac's mathematics also predicted the existence of antimatter, specifically the positron which was discovered in 1932.

(c) The Dirac equations, as modified by Heisenberg in 1934, accurately describe all elementary matter particles such as today's quarks and leptons.

4. (a) The diagram is representing the idea of Schrödinger's 'levels within levels' – the subshells of electron orbits.

(b) They label the shells in order from the nucleus and represent the principal quantum number from Pauli's exclusion principle.

(c) These simply number the shells/energy levels in order of distance from the nucleus.

(d) These are the labels given to describe each subshell.

(e) Experimental evidence shows that the energy values of the 4s suborbital electrons are less than that of the 3d electrons.

(f) The arrows represent the spin of the two electrons that occupy that particular energy level.

(g) Only two electrons can occupy any particular subshell position (they will have opposite spin to satisfy the Pauli exclusion principle).

(h) To represent the electrons in the electron pair having opposite spin directions.

(i) Because it explained experimental observations on the structure and behaviour of matter better than previous models.

(j) Having electrons in the 'same' energy level, but with very slightly different energy values, having different spin, and different magnetic properties according to the Pauli exclusion principle, their separation by strong magnetic fields can be explained.

5. (a) The observer effect notes that measurements of certain systems cannot be made without affecting the systems. For example, the observer effect would say that looking at a quantum particle will change the nature of the quantum particle and so we therefore have to be careful in drawing conclusions from observations made.

Heisenberg discovered a problem in the way one could measure basic some of the basic physical variables in the equations. His analysis showed that uncertainties, or imprecision, always turned up if one tried to measure the position and the momentum of a particle at the same time. These uncertainties in the measurements were not the fault of the mathematics, said Heisenberg; they were part of the nature of quantum mechanics. This explanation of the observed errors has become known as the Heisenberg uncertainty principle.

(b) If a particle has a uniquely defined de Broglie wavelength, then its momentum is known precisely but all knowledge of its position is lost.

Set 31 Albert Einstein and the Photoelectric Effect

1. (a) The photoelectric effect – when light of an appropriate frequency is shone onto a metal surface, electrons are emitted from that surface.

(b) Heinrich Hertz, in his experiments with the production and discovery of what we now call radio waves in 1887.

(c) The radio waves Hertz discovered were the first part of the electromagnetic spectrum to be found. Only visible light was known at the time. He could not have knowingly shone UVL on his apparatus because it had not been discovered.

(d) Hertz died very shortly after making this discovery. It was only known about because he had recorded his observations in his lab notes. The discovery had not been reported officially.

2. (a) Its amplitude.

(b) Its amplitude.

(c) Its frequency.

(d) The threshold frequency of the photoelectric effect. Below the threshold frequency, no matter how high the intensity of the incident radiation, no photoemission occurs.

(e) The work function = hf_o

3. (a) Greater intensity of electromagnetic radiation means more photons each with the same energy. So more photoelectrons will be emitted (one for each photon) but each photon having the same energy, there is no increase in *KE* of the electrons – just more electrons.

(b) Increasing the anode voltage increases the potential difference between the anode and cathode and accelerates the emitted electrons across the gap faster. However, once all surface electrons are collected from the cathode, the photocurrent reaches a maximum value.

(c) Negative polarity of the anode decreases the rate at which photoelectrons cross the gap. As the negative polarity increases, it is not only harder for the electrons to cross the gap, but also to break away from the cathode atoms. At a particular voltage, the stopping voltage, the negative potential applied stops photoemission.

(d) This is the quantum property of the photons – all or nothing energy transfer – so if the energy of the photon is below the threshold energy, not enough energy is available to cause photoemission, so it does not occur. Increased intensity simply means more photons, none of them having enough energy to cause emission.

4. (a) The threshold frequency.

(b) Classical physics predicted emission at any frequency as the electrons on the surface atoms of the emitter gradually absorbed energy from the continuous wave bombardment of the radiation until they had enough energy to be released. Electrons would be released eventually at all frequencies.

(c) Classical physics is Newtonian physics, pre 1900s physics, physics that applies to objects that are larger than atoms. Quantum physics is post 1900s physics, physics that incorporates both the wave and particle natures of matter, and is most relevant for particles of atomic size or smaller. The behaviour of these particles cannot be adequately predicted using classical physics.

5. (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.

6. (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 eyes of other scientists.

7. (a) Assuming that the energy of blue light photons is above the threshold energy (a realistic assumption), their energy will transfer completely to the valence electrons in the atoms of the cathode and cause them to be emitted from the surface.

(b) The kinetic energy of each electron as it leaves the surface will be equal to the energy of the photon minus the work function.

(c) The electron will move towards the anode because of the potential difference between the anode and cathode and is not in the direction required to attract and therefore accelerate it towards the collector plate.

(d) The reading on the ammeter would be recorded for successive increases in the applied voltage across the anode/cathode gap.

(e) To determine the minimum voltage required to reduce the photocurrent to zero.

(f) The kinetic energy of the electron when released from the cathode will be used in attempting to move against the applied field. When the work required to move between the electrodes equals the *KE* of the photoelectrons, no current will be flowing.

(g) The stopping voltage, V_s, which is equal (via $W = qV_s$) to the kinetic energy of the photoelectrons.

(h) hf = energy of the incident photons

Φ = work function of the emitter

$hf_o - \Phi$ = kinetic energy of the photoelectons

$\frac{1}{2}mv^2$ = kinetic energy of the photoelectons

qV_s = work done by the electric field in stopping the photoelectron = kinetic energy of the photoelectons

(i) Conventional current is in the opposite direction to electron flow, which is what is shown, and is therefore correct.

(j) Photocurrent would increase as UV photons have more energy than blue photons, so the *KE* of the emitted electrons would be increased, so they would move faster to the anode. Since current is electron flow per second, current will increase.

(k) Conventionally in questions like this, we consider the energy of red photons to be below the threshold energy, so on this basis, there will be no current flow as no electrons will be emitted.

(l) Increased intensity means more photons each with the same energy, so photocurrent will increase to a maximum value (when all relevant surface electrons than can escape are hit). Once too many electrons leave the cathode the positive charges in the metal atom nuclei exert too much attractive force so no more escape.

(m) It would not affect the results because the applied stopping voltage will stop all electrons having the energy qV_s.

Set 32 More about the Photoelectric Effect

1. (a) C

(b) If intensity increases then more photons hit the surface so more photoelectrons can be emitted, but the *KE* of each electron will remain the same because the energy of each photon has not changed.

2. (a) D

(b) Blue has the highest frequency and therefore the highest energy per photon.

3. (a) A

(b) A longer wavelength for the orange light means a lower frequency, so assuming this is still above the threshold frequency, the photocurrent will decrease according to $E = hf$ although the increase in intensity (assuming above threshold frequency) will increase the photocurrent, so these two factors need to be considered. However, the only possible correct answer is A.

4. D

5. (a) B

(b) Increasing the intensity of the light increases the number of photons hitting the surface of the emitter, but there will be a maximum number of electrons available for emission on the surface layer, so photocurrent will increase to a maximum value.

6. (a) C

(b) Y starts to emit photoelectrons at a longer wavelength than X, so Y has a lower threshold frequency, and therefore a lower work function than X.

7. (a) A

(b) Energy of 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.

8. (a) C

(b) These are the only three with threshold frequency lower than the incident frequency.

9. (a) A

(b) Energy of photon $= \dfrac{hc}{\lambda} = \dfrac{(6.626\times10^{-34}\times3\times10^{8})}{(300\times10^{-9})} = 6.626 \times 10^{-19}$ 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.

10. D

11. C

12. D

13. A

14. A

15. C

16. B

17. (a) C

(b) Energy is directly proportional to frequency, therefore it is inversely proportional to wavelength, i.e. C.

18. (a) D

(b) Gradient (equal to Planck's constant in each case) must be the same, and because of the threshold frequency, graphs must intercept the *x*-axis not the *y*-axis – therefore (D).

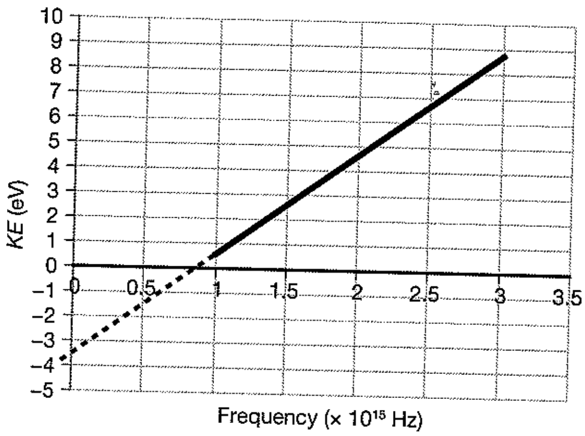
Set 33 A Work Function Experiment

1. (a) Stopping voltage is the potential difference required between the anode and cathode to stop all photoelectrons from the cathode reaching the anode, that is, so current in the circuit is zero.

(b)

Wavelength of incident light (nm)	Frequency of incident light (× 10^{15} Hz)	Energy carried by light beam (eV)	Stopping voltage (V)	Kinetic energy of emitted electrons (eV)	Work function of emitter (eV)
100	3.0	12.42	4.1	8.8	3.6
150	2.0	8.28	2.8	4.6	3.7
200	1.5	6.21	2.0	2.6	3.6
250	1.2	4.97	1.4	1.4	3.6
300	1.0	4.14	1.0	0.5	3.6
350	0.86	3.55	0.6	No electrons emitted	-
400	0.75	3.11	0.4	No electrons emitted	-
450	0.67	2.76	0.0	No electrons emitted	-
				Average work function	3.6

(c)



(d) From the extrapolation, work function ≈ 3.5

(e) The values are close, 3.5 compared to 3.6 which represents a 2.8% difference.

(f) The calculated value will be more accurate as we have had to estimate the graph intercept. Perhaps if the graph were larger the intercept could be determined more accurately.

(g) Threshold frequency ≈ 6×10^{14} Hz.

Set 34 Interference Supports the Dual Wave/Particle Model

1. (a) Diffraction is the spreading out of waves, usually in a circular pattern when they meet the edge of a barrier or pass through a narrow slit.

(b) Interference is a phenomenon in which two waves superimpose to form a resultant wave. For example, a double slit diffraction will produce two isolated sources of circular wavelets which can then interfere with each other as they pass through the same medium.

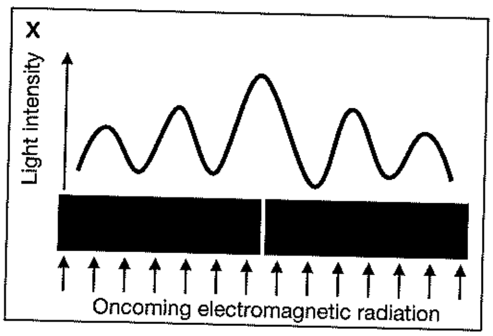
2. (a) The dual wave/particle model of electromagnetic radiation states that we can only explain all of the properties of electromagnetic radiation by considering it to have a wave nature in some situations and a particle nature in other situations. It proposes that all waves and all matter exhibit both wave and particle properties.

(b) Because, although the dual theory applies to all matter, it is only at the quantum level the dual theory is needed to explain the behaviour of these particles.

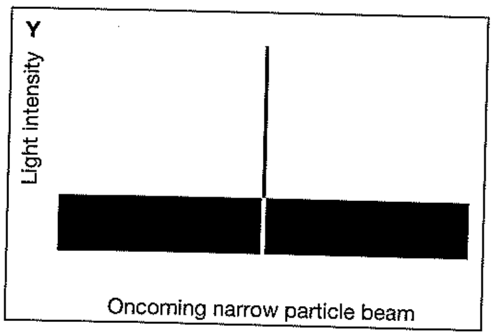
(c) Interference and diffraction effects.

(d) The photoelectric effect.

3. (a) (i)



(ii)



(b) Thomas Young.

(c) It indicates that the single photon has wave nature not particle nature.

(d) Yes, it certainly does! This is why we have a dual theory because we expect the photon to behave as a particle, but it obviously does not for this property. This is exactly the type of situation that caused the proposal of the dual theory.

(e) Theories attempt to explain observations. Neither the wave nor the particle theory can explain all the observations of properties of electromagnetic radiation, so in that regard, they are not correct. The dual wave/particle model is a compromise that scientists have made – that is – they admit that the wave and particle models are not good enough to explain everything, but in the absence of a theory which will, they have adopted the dual model until a more complete model is found.

4. (a) De Broglie.

(b) He was attempting to explain why Bohr's atomic electron orbits were stable. He proposed that if the electrons were waves, then when the circumference of the orbital was an integral number of wavelengths of the electron wave, then stable standing waves would be produced at those particular distances from the nucleus.

(c) Because only very specific radii will result in the circumference of the electron orbit being an integral number of wavelengths of the electron wave, this explains the discrete orbital positions (the principal quantum number).

5. If you understand this then your understanding of physics is better than this author's. The course you study here introduces basic ideas and understandings of physics to you and includes small bits like this so that you are aware that what we have studied is really only the beginning of the journey into physics. There is much more, and most of it is much more complicated. If you continue the journey, I wish you well.

Set 35 The Standard Model of Matter

1. The standard model of matter is the model developed in the 1960s based on the fundamental particles being quarks and leptons.

2. As scientific discovery and knowledge increased, existing models were found not to explain new observations on the behaviour of matter. Modifications and/or new models needed to be developed to account for these new observations.

3. It was found that protons and neutrons were not fundamental particles, but were composed of quarks. Other particles had also been discovered and these had to be fitted into a model for the atom also.

4. (a) A fundamental particle is one which cannot be subdivided into smaller particles.

(b) Protons, neutrons and electrons.

(c) Quarks and leptons (including the electron).

(d) Given that the model was developed to take the new fundamental particles into account, their role was crucial in the changes that occurred to the model.

5. Yes/no. It indicated that it was incomplete in that it needed to incorporate the other particles being discovered, particularly the quarks and the now non-fundamental nature of protons and neutrons. However, the general structure of nuclei has been maintained as has the electron shell structure for electron distribution around the nucleus.

6. All the examples given in the question are explained by the electron energy levels proposal from the Bohr model. The standard model changes were directed at the nature of fundamental particles and the nucleus. These changes do not affect electron level structure, and therefore do not change the usefulness of this aspect of Bohr's model.

7. (a) They would no longer be classified as fundamental.

(b) The new particles they are composed of would be the new fundamental particles, as well as the current leptons.

(c) The leptons would remain as fundamental particles as this discovery would not affect their nature.

(d) It would change the identity of the fundamental particles within the nucleus, but would probably have little effect, if any, on the rest of the model.

(e) No. All science is a developing study. As technologies and knowledge improves, then so does our understanding of the nature of matter. The standard model is a tool that represents our current level of understanding and rests on hundreds of years of study and development. Its existence, like all models before it, is a necessary and valued step towards the future.

(f) The development of more powerful particle accelerators is enabling more detailed study of the nature of matter. The energy required to progress beyond the quark stage is only just becoming available to us in these devices.

(g) The technology to provide the huge amounts of energy to particles before colliding them with others has not been available.

8. (a) Nucleons are particles contained within nuclei.

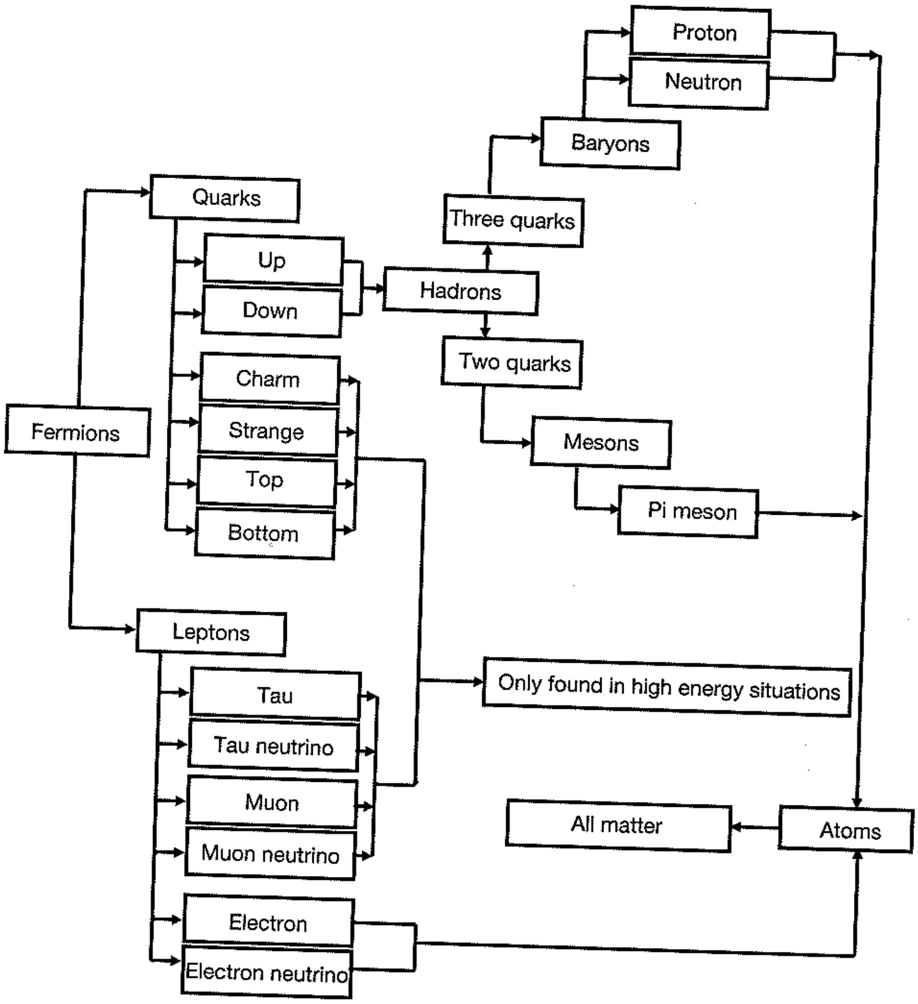
(b) Protons, neutrons and pi mesons.

9. Once the structure of the nucleus began to unfold, and the relatively huge size of the electrostatic repulsion between protons was compared with the tiny gravitational force between them, it became necessary to invent the strong nuclear force.

10. Scientists studying nuclear transformations following the discovery of radioactivity, noticed that the laws of conservation of energy and momentum did not seem to be followed, and the energies of emitted beta particles were too varied.

Set 36 Components of the Standard Model

1.



2. Hadrons are composed of quarks held together by the strong nuclear force. Bayrons are a subset of hadrons which contain three quarks as opposed to mesons which have two quarks.
3. Antineutrino.
4. D
5. C
6. D
7. C
8. B
9. D
10. D
11. B
12. D
13. A
14. C
15. B

Set 37 More about Quarks

1. (a) Quarks are one of the two families of fundamental particles. (L)
   (b) There are six of them and they have the names up (u), down (d), charm (c), strange (s), top (t) and bottom (b). (D)

(c) They are grouped in pairs, called generations, according to their charge and masses, which seem to increase from generation to generation. (F)

(d) Quarks are fermions (fundamental particles) and respond to electromagnetic, weak, gravitational and strong interactions. (I)

(e) Being fermions, quarks obey the Pauli exclusion principle which states that in an atom, no two fermions can have the same four quantum numbers. (B)

(f) The four quantum numbers are the principal quantum number (the energy level), a magnetic, a momentum and a spin quantum number. (G)

(g) The quantum numbers of fundamental particles describe their properties and location. (A)

(h) In terms of the quantum numbers, what the Pauli exclusion principle is saying is that two fermions cannot occupy the same position at the same time. (K)

(i) All quarks have baryon number of $+\frac{1}{3}$ and a lepton number of 0. (E)

(j) Antiquarks have a baryon number of $-\frac{1}{3}$ and a lepton number of 0. (J)

(k) Quarks join together to form the larger particles of matter collectively known as hadrons. (M)

(l) The are two types of hadrons – the baryons consisting of three quarks and the mesons which contain a quark and an antiquark. (H)

(m) Mesons are extremely unstable and decay almost as soon as they form into other particles. (C)

2.

Quark	Generation	Symbol	Charge	Baryon number	Lepton number
Up	First	u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
Down		d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
Charm	Second	c	$+\frac{2}{3}$	$+\frac{1}{3}$	0
Strange		s	$-\frac{1}{3}$	$+\frac{1}{3}$	0
Top	Third	t	$+\frac{2}{3}$	$+\frac{1}{3}$	0
Bottom		b	$-\frac{1}{3}$	$+\frac{1}{3}$	0

3.

Antiquark	Generation	Symbol	Charge	Baryon number	Lepton number
Antiup	First	$\bar{u}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
Antidown		$\bar{d}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0
Anticharm	Second	$\bar{c}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
Antistrange		$\bar{s}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0
Antitop	Third	$\bar{t}$	$-\frac{2}{3}$	$-\frac{1}{3}$	0
Antibottom		$\bar{b}$	$+\frac{1}{3}$	$-\frac{1}{3}$	0

4. (a) $c + c + s = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$

(b) $c + s + s = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$

(c) $t + t + b = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1$

(d) $t + b + b = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$

5. (a) $c + \bar{s} = \frac{2}{3} + \frac{1}{3} = +1$

(b) $\bar{c} + s = -\frac{2}{3} - \frac{1}{3} = -1$

(c) $t + \bar{b} = \frac{2}{3} + \frac{1}{3} = +1$

(d) $\bar{t} + b = -\frac{2}{3} - \frac{1}{3} = -1$

6. (a) pi$^+$ = could be $u\bar{d} = \frac{2}{3} + \frac{1}{3} = +1$

(b) pi$^-$ = could be $\bar{u}d = -\frac{2}{3} - \frac{1}{3} = -1$

(c) pi^0 = could be $u\bar{u} = \frac{2}{3} - \frac{2}{3} = 0$ or $\bar{d}d = \frac{1}{3} - \frac{1}{3} = 0$

7. (a) $d + d + u + u + \bar{d} = -\frac{1}{3} - \frac{1}{3} + \frac{2}{3} + \frac{2}{3} + \frac{1}{3} = +1$

(b) Being a combination of quarks, it will be a new type of hadron.

(c) Yes, in that the pentaquark needs to be added into the system.

(d) No. New technologies are always discovering new things in science. Sometimes this requires a change in the way we think, but in this case, it simply expands our knowledge and fits into an existing system.

Set 38 More about Leptons

1. (a) Leptons are any fermions that respond only to electromagnetic, weak, and gravitational forces. (D)
(b) Leptons do not take part in strong interactions. (I)
(c) Only the electron and the electron neutrino are found in normal matter. (F)
(d) The other leptons, the muon, muon neutrino, tau and tau neutrino, are also found only in energetic nuclear disintegration. (H)
(e) The electron, muon and tau carry a charge of −1, the neutrinos have a charge of 0. (A)
(f) Leptons have a baryon number of 0 and a lepton number of 1. (J)
(g) For each lepton there is also an antilepton. (C)
(h) Antileptons have a baryon number of 0 and a lepton number of −1. (G)
(i) All leptons and antileptons obey the Pauli exclusion principle. (B)
(j) Being discrete particles, the masses of the leptons are more easily determined. (E)

2.

Lepton	Generation	Symbol	Charge	Baryon number	Lepton number
Electron	First	e^-	−1	0	1
Electron neutrino		ν_e	0	0	1
Muon	Second	μ^-	−1	0	1
Muon neutrino		ν_μ	0	0	1
Tau	Third	τ^-	−1	0	1
Tau neutrino		ν_τ	0	0	1

3.

Antilepton	Generation	Symbol	Charge	Baryon number	Lepton number
Positron	First	e^+	+1	0	−1
Electron antineutrino		$\bar{\nu}_e$	0	0	−1
Antimuon	Second	μ^+	+1	0	−1
Muon antineutrino		$\bar{\nu}_\mu$	0	0	−1
Antitau	Third	τ^+	+1	0	−1
Tau antineutrino		$\bar{\nu}_\tau$	0	0	−1

Set 39 Baryon Numbers

1. (a) With the development of quark theory in the 1960s, baryon number became a property of the quarks. (C)
   (b) Quarks are assigned a baryon number of $+\frac{1}{3}$. (E)
   (c) The proton and neutron were each given a baryon number of +1. (I)
   (d) When antiprotons and antineutrons were discovered in 1965 they were given a baryon number of −1. (G)
   (e) Antiquarks are assigned a baryon number of $-\frac{1}{3}$. (A)
   (f) Mesons, particles that are made up of a quark and antiquark, have a net baryon number of 0. (H)
   (g) Particles that are not made up of quarks all have a baryon number of 0. (D)
   (h) The electron, positron, and photon were each given a baryon number of 0. (B)
   (i) Muons, antimuons, taus, antitaus, various neutrinos and bosons are all given a baryon number of 0. (F)
2. As their knowledge of the particles in matter and particle interactions improved some interactions which were predicted should occur either didn't, or if they did, then they involved different pathways to the ones predicted. The only way to account for these observations was to create a new conservation law involving the existence of baryon numbers.
3. The total baryon number of any closed system must be conserved.
4. A 'closed system' refers to one in which there are no external influences or particles acting within the system.
5. They are each made up of three quarks, and the baryon number of quarks is $+\frac{1}{3}$.
6. They are each made up of three antiquarks and each antiquark has a baryon number of $-\frac{1}{3}$.
7. Mesons are composed of one quark (baryon number $+\frac{1}{3}$) and one antiquark (baryon number $-\frac{1}{3}$) which gives them a net baryon number of zero.
8.

	Interaction	Charge conserved?	Baryon number conserved?	Is reaction possible in terms of charge and baryon number? If 'no', give reason
(a)	$p + p \rightarrow p + \pi^+$	Yes	No	No – baryon number not conserved
(b)	$e^- + p \rightarrow \nu_e + n$	Yes	Yes	Yes – charge and baryon number conserved
(c)	$p + n \rightarrow p + n + \pi^+$	No	Yes	No – charge not conserved
(d)	$n \rightarrow p + e^- + \bar{\nu}_e$	Yes	Yes	Yes – charge and baryon number conserved
(e)	$\nu_e + \tau^- \rightarrow e^- + \nu_\tau$	Yes	Yes	Yes – charge and baryon number conserved
(f)	$\nu_e + n \rightarrow p + e^-$	Yes	Yes	Yes – charge and baryon number conserved
(g)	$\nu_\tau + n \rightarrow p + \tau^-$	Yes	Yes	Yes – charge and baryon number conserved
(h)	$n + p \rightarrow \pi^+ + \pi^-$	Yes	No	No – baryon number not conserved

Set 40 Lepton Numbers

1. The lepton number of a particle is equal to the number of leptons minus the number of antileptons in the structure of the particle.
2. The lepton number of each generation of leptons must be conserved in a particle interaction.
3.

Electron generation	Symbol	Lepton number ($L_{(e)}$)	Muon generation	Symbol	Lepton number ($L_{(\mu)}$)	Tau generation	Symbol	Lepton number ($L_{(\tau)}$)
Electron	e^-	1	Muon	μ^-	1	Tau	τ^-	1
Electron neutrino	ν_e	1	Moun neutrino	ν_μ	1	Tau neutrino	ν_τ	1
Positron	e^+	−1	Antimuon	μ^+	−1	Antitau	τ^+	−1
Electron antineutrino	$\bar{\nu}_e$	−1	Muon antineutrino	$\bar{\nu}_\mu$	−1	Tau antineutrino	$\bar{\nu}_\tau$	−1

4. If a lepton and a neutrino are on the same side of the equation for an interaction:
(a) Electrons, negative muons and negative tau must be accompanied by an antineutrino.
(b) Positrons, positive muons and positive tau must be accompanied by a neutrino.
If a lepton and a neutrino are on the opposite side of the equation for an interaction:
(a) Electrons, negative muons and negative tau must have a neutrino on the other side.
(b) Positrons, positive muons and positive tau must have an antineutrino on the other side.

5.

Lepton number	τ^-	$\rightarrow$	μ^-	$\bar{\nu}_\mu$	ν_τ	Conserved or not?
L_e	0	=	0	0	0	Yes
L_μ	0	=	1	−1	0	Yes
L_τ	1	=	0	0	1	Yes

6.

Reaction	Charge conserved	Baryon number conserved	L_e conserved	L_μ conserved	L_τ conserved	Reaction feasible on these criteria?
$K^+ \rightarrow \mu^+ + \nu_\mu$	Yes	Yes	Yes	No	Yes	No
$\Lambda \rightarrow p + \pi^-$	Yes	No	Yes	Yes	Yes	No
$\mu^- \rightarrow e^- + \bar{\nu}_{e-} + \nu_\mu$	Yes	No	Yes	Yes	Yes	No
$\Omega^- \rightarrow \Xi^0 + \pi^-$	Yes	Yes	Yes	Yes	Yes	Yes
$\Sigma^0 \rightarrow \Lambda + \gamma$	Yes	Yes	Yes	Yes	Yes	Yes
$n \rightarrow p + e^- + \nu_e$	Yes	Yes	No	Yes	Yes	No
$\Delta^+ \rightarrow \pi^+ + \pi^0$	Yes	No	Yes	Yes	Yes	No
$\Xi^0 \rightarrow p + \pi^0$	No	No	Yes	Yes	Yes	No
$\Sigma^+ \rightarrow p + K^0$	Yes	No	Yes	Yes	Yes	No
$n \rightarrow p + e^- + \bar{\nu}_{e-}$	Yes	Yes	Yes	Yes	Yes	Yes

7. (a) $\bar{\nu}_e$
(b) ν_e
(c) ν_μ
(d) e^+
(e) $\bar{\nu}_\mu$

Set 41 The Four Fundamental Forces

1.

Force	Electromagnetic force	Strong nuclear force	Weak nuclear force	Gravitational force
Bosons involved	Photon	Gluon	W^+, W^-, Z	Graviton (not yet found)
Number of bosons	1	1	3	1
Charge on the bosons	0	0	+1, −1, 0	0
Boson acts on ...	Anything with charge	Quarks	Leptons, quarks	Anything with mass

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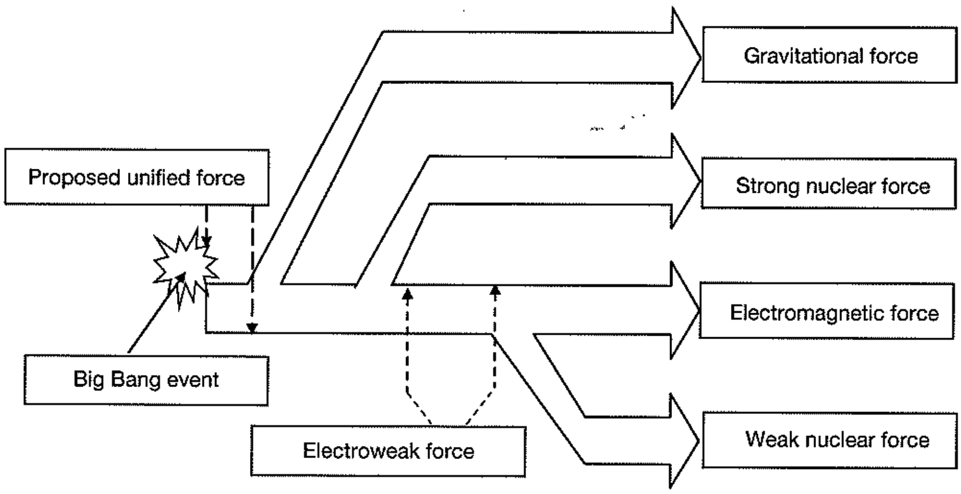
2.



Set 42 More about Bosons

Boson	Force responsible for	What it does
Photon	Electromagnetic force	• Binds charged particles, atoms and molecules together. • Acts over long distances. • Includes electrostatic and magnetic forces.
W-Boson	Weak nuclear force	• Interacts with nuclear particles to change them into other particles. • Carries either a positive or negative charge. • Either emitted or absorbed in quark or lepton changing interactions. • Acts over about 10^{-17} m.
And		
Z-Boson	Weak nuclear force	• Interacts with nuclear particles to change them into other particles. • Carries no charge. • Emitted or absorbed in weak interactions involving neutrinos. • Acts over about 10^{-17} m.
Gluon	Strong nuclear force	• Binds quarks together in hadrons. • Binds neutrons and protons together to form nuclei. • Acts over 10^{-15} m.
Graviton	Gravity	• Draws masses together. • Acts over very long distances. • (Not yet discovered.)
Higgs boson	Giving particles mass	• Proposed to be the field responsible for producing mass of particles. • Discovered in CERN on 4 July 2012.

Set 43 Simple Reaction Diagrams

1. (a) Feynman diagrams are diagrams used to illustrate the particles involved and the pathways taken by particles during particle interactions. Fenyman diagrams are spacetime diagrams which provide a shorthand method for studying the probability for particle interactions.

(b) A Feynman diagram is used to illustrate and describe *possible* particle interactions. They show the number of ways that bosons can be emitted and absorbed by other interaction particles.

2. (a) Lines: Solid lines represent quarks or leptons. Wavy lines represent photons, W and Z particles, and curly lines represent gluons.

(b) Time direction: In normal convention, Fenyman diagrams represent time either passing from left to right (as the examples in this workbook do) or from bottom to top (the convention used in some texts). The trend is for the use of the left/right convention universally.

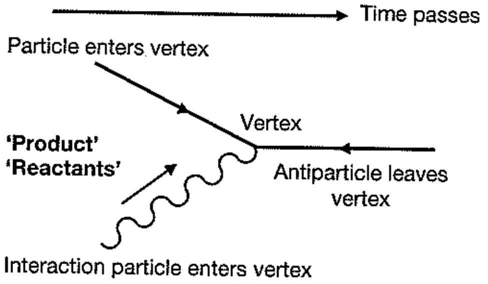
(c) Arrowheads: These represent the direction of movement of interacting particles either towards or away from vertices. Arrows drawn from left to right represent particles travelling forwards in time, arrows drawn right to left represent antiparticles travelling forwards in time.

(d) Particle labels: Simply identify the particles represented by the arrows in the diagram.

(e) Exchange particles: Exchange particles link vertices and are represented by wavy or curly lines without arrowheads. They are labelled with the symbol of the exchange particle and a discrete arrow showing the direction of the flow of the exchange particle.

(f) Vertices: Vertices represent the interaction of the particles. The conservation laws of mass, charge, lepton number, and baryon number must be obeyed at vertices.

3.

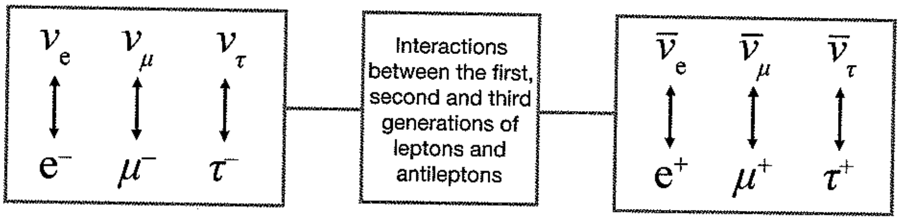


4. A Diagram shows a muon neutrino emitting a W^+ boson to form a muon.
B Diagram shows a muon neutrino emitting a W^+ boson to form a muon antineutrino.
C Diagram shows a tau emitting a W^- boson to form a tau neutrino.
D Diagram shows a tau antineutrino absorbing a W^- boson to form an antitau.

5. A Diagram shows a tau neutrino emitting a W^- boson to form a tau.
B Diagram shows an antimuon absorbing a W^- boson to form a muon antineutrino.
C Diagram shows an antitau emitting a W^+ boson to form a tau antineutrino.
D Diagram shows a muon emitting a W^- boson to form a muon neutrino.
E Diagram shows an antimuon emitting a W^+ boson to form a muon antineutrino.
F Diagram shows a tau antineutrino absorbing a W^+ boson to form an antitau.
G Diagram shows a muon neutrino absorbing a W^- boson to form a muon.
H Diagram shows a tau emitting a W^- boson to form tau neutrino.
I Diagram shows an electron emitting a W^- boson to form an electron neutrino.
J Diagram shows an electron neutrino absorbing a W^- boson to form an electron.

Set 44 Lepton Weak Interactions

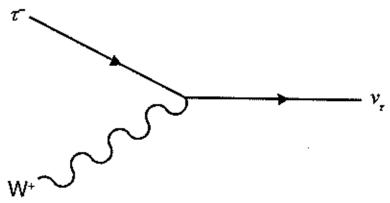
1. (a)



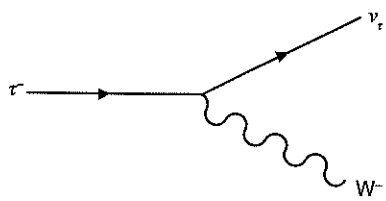
(b) The pairs are observed as occurring together in particle interactions (note that some cross-generation reactions do occur).

2. (a) Feynman vertices as used in this book are read from left to right. (D)
(b) Feynman vertices are sometimes drawn (not in this book) to be read from bottom to top. (G)
(c) In all particle interactions lepton number must be conserved. (F)
(d) In all particle interactions baryon number must also be conserved. (C)
(e) In all particle interactions charge is also conserved. (A)
(f) Charge conservation is done by assigning the boson an appropriate charge. (E)
(g) If two particles emerge from a vertex, then they must be a matter-antimatter pair of the same type. (H)
(h) If a lepton enters a vertex, then its generation partner will leave the vertex. (B)

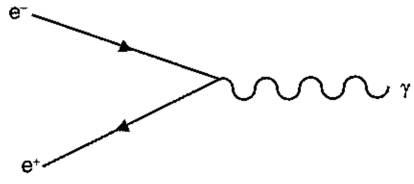
3. (a) Negative tau absorbs a boson.



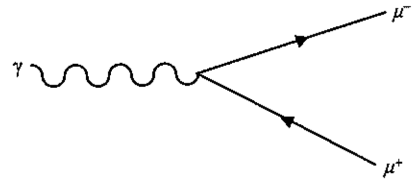
(b) Negative tau emits a boson.



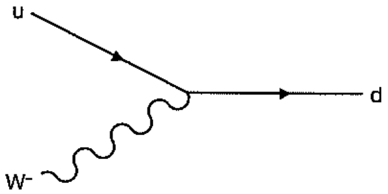
(c) Electron and positron annihilate to produce a boson.



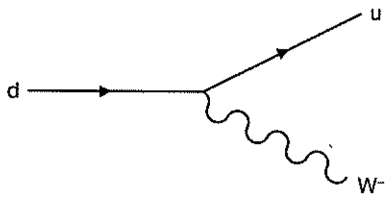
(d) Exchange particle emits a muon and another particle.



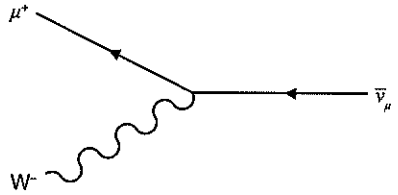
(e) Down quark absorbs a boson to produce an up quark.



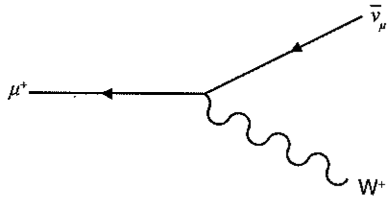
(f) Down quark emits a boson to produce an up quark.



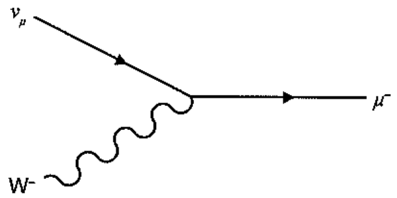
(g) Positive muon absorbs a boson.



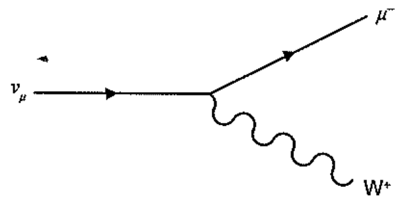
(h) Positive muon emits a boson.



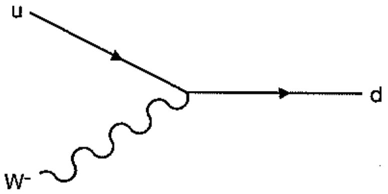
(i) Muon neutrino absorbs a negative boson.



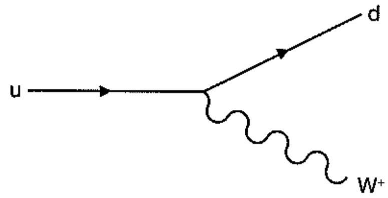
(j) Muon neutrino emits a positive boson.



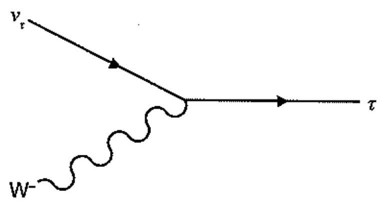
(k) Up quark absorbs a boson.



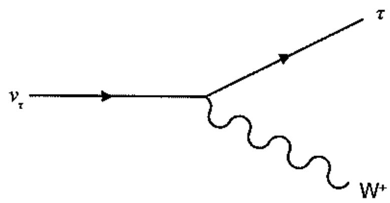
(l) Up quark emits a boson.



(m) Tau neutrino absorbs a negative boson.



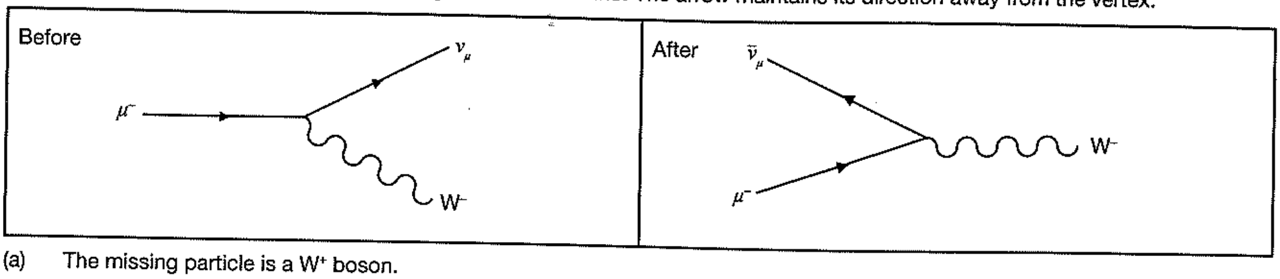
(o) Tau neutrino emits a positive boson.



Set 45 Crossing Symmetry

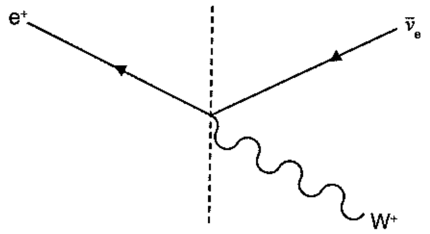
1. Crossing symmetry refers to rotating the components of a vertex so that all or some of the 'products' become 'reactants' and/or vice versa.
2. Answers will vary, for example:
   (a) $X \rightarrow Y + Z + \overline{W}$
   (b) $W \rightarrow Y + Z + \overline{X}$
   (c) $W + X + \overline{Y} \rightarrow Z$
   (d) $W + \overline{Y} \rightarrow \overline{X} + Z$
   (e) $X + \overline{Z} \rightarrow \overline{W} + Y$

3. When crossing symmetry is carried out, the particle becomes its matter-antimatter pair when it crosses to the other side of the vertex, and the arrow maintains its direction either towards or away from the vertex. In the example shown, the emitted muon neutrino crosses over to become an incoming muon antineutrino. The arrow maintains its direction away from the vertex.

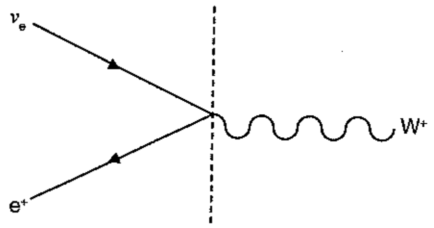


4. (a) The missing particle is a W⁺ boson.

(b)



(c)



Set 46 Crossing Symmetry Predictions

1. (a) Crossing symmetry refers to the process of swapping either a reactant or a product in a particle interaction diagram to the opposite side of the reaction.

   (b) Crossing symmetry can be used to predict other particle interactions.

   (c) When crossing symmetry occurs, the particles become their antimatter partner. For example, a muon on the left (reaction side) of the interaction will be accompanied by an arrow heading towards the vertex. When the crossing symmetry occurs it moves to the right and becomes an antimuon accompanied by an arrow that points towards the vertex.

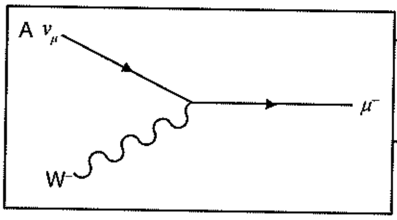
   In other words, if an arrow points towards (or away) from a vertex originally, then when the crossing symmetry occurs, the arrow continues to point towards (or away) from the vertex.

2. (a) The arrows on the lines representing the passage of particles could be interpreted to represent the way they travel through time. So, an arrow pointing to the right represents a particle moving forwards in time. An arrow pointing to the left would therefore indicate a particle travelling backwards in time.

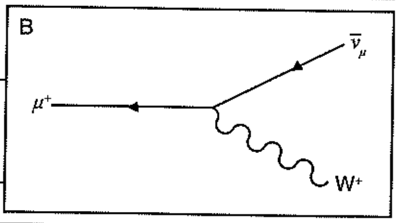
   (b) Matter particles in Feynman diagrams are considered as moving forwards in time while antimatter particles could be regarded as moving backwards through time.

   (c) There is still significant debate occurring in quantum mechanics as to whether particles actually do travel backwards in time.

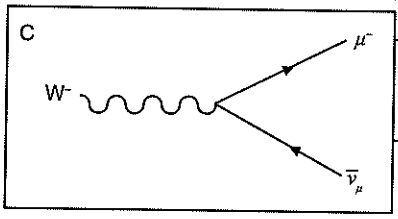
3.



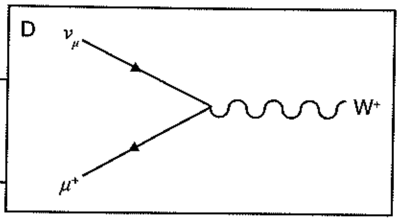
Muon neutrino absorbs a W⁻ boson to produce a muon.



Antimuon decays to produce a muon antineutrino and a W⁺ boson.



W⁻ boson decays to produce a muon and a muon antineutrino.

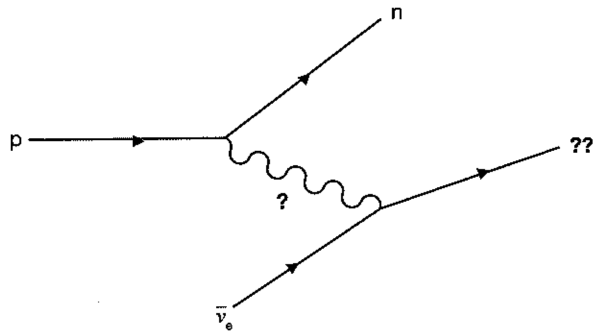


Muon neutrino and antimuon annhilate each other to produce a W⁺ boson.

Set 47 More Complicated Vertices

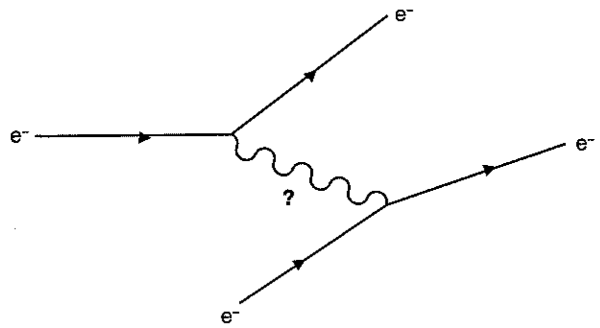
1. (a) Zero.
   (b) Zero.
   (c) It is a virtual boson because it exists for only a very short time before decaying into the neutron and the electron neutrino.
   (d) Exchange particle must be a W^+ boson. The proton carries a +1 charge which must be emitted in order for it to become a neutron.
   (e) The W^+ boson is subsequently absorbed by the electron to change it into an uncharged electron neutrino.
   (f) The first vertex clearly shows the proton interacting to produce the neutron and an exchange boson. In order to conserve charge at this vertex, the boson must be a W^+. The second vertex clearly shows the incoming electron interacting with the W^+ to produce the electron neutrino.
   (g) Exchange particle must be a W^+ boson. The proton carries a +1 charge which must be emitted in order for it to become a neutron. This has not changed compared to the other two diagrams.
   (h) The first vertex clearly shows the proton interacting to produce the neutron and an exchange boson. In order to conserve charge at this vertex, the boson must be a W^+. The second vertex clearly shows the W^+ decaying to produce the electron neutrino and a positron.
   (i) Yes. On the incoming side is the +1 from the boson, and on the outgoing side is the +1 from the positron.

2. (a)



   (b) W^+
   (c) A positron, e^+

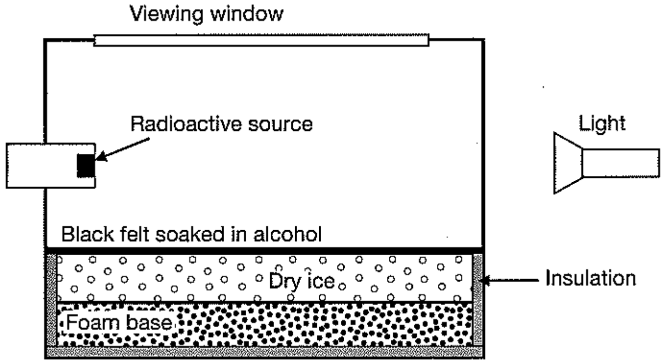
3. (a)



   (b) Given that charge is conserved before and after each interaction shown in the diagram, the boson must be uncharged, so is either a photon or a Z boson. Given that neither of the interaction particles (the electrons) have been involved in a change in charge, the more likely boson is the photon.

Set 48 Uncovering Matter Particles

1. (a)



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(b) Dry ice is solid carbon dioxide.

(c) Dry ice maintains the temperature of the chamber at a very low level (dry ice sublimates or changes directly into its gaseous form at −78.5°C).

(d) The alcohol evaporates and fills the chamber with a cold vapour of alcohol. When charged particles hit the vapour they cause it to condense and form small droplets of liquid alcohol.

(e) A typical cloud chamber contains a space saturated with a vapour which condenses into small droplets when charged particles hit its molecules. The charged particles leave tracks of condensed droplets behind them as they pass through the bubble chambers. Detailed analysis of the tracks, looking at how the tracks of the particles curved in a magnetic field, and applying the laws of conservation of momentum and energy revealed particles of differing charges and masses.

2. (a) They are oppositely charged because they spiral in opposite directions. X carries a negative charge (apply the RHPR) and Y has a positive charge.

(b) If they have equal speeds and charges, then the force on each due to their motion in the magnetic field ($F = Bqv$) will be the same magnitude. Because this force is a centripetal force ($F = \frac{mv^2}{r}$) which, when rearranged leads us to $r = \frac{mv^2}{F}$, the larger radius curvature must be because X has more mass than Y.

(c) As they move, the particles will slow down and the force will have more effect on them. Note that the force depends on v, whereas r depends on v^2, so although the force also decreases as they slow down, the effect on the radii is greater.

Set 49 Nuclear Accelerators

1.

Accelerator	Advantages	Disadvantages
Linear	Easier to construct. Less expensive. Do not need magnets. Do not need large radii.	Radiation loss large for small particles. Cannot be used to study large particles. Very long length needed for high energies.
Cyclotron	Cheap to build. Good for medical uses.	Cannot be used for large particles.
Synchrotron	Can be used for large particles. Can produce very high energy particles. Higher chance for collisions in detectors.	Energy losses are large. Very expensive to build. Need expensive magnets. Very large diameter.

2. (a) From $E = \frac{V}{d} = \frac{24\,000}{0.03} = 8 \times 10^5$ V m^{-1} (or N C^{-1})

(b) From $F = Eq = 8 \times 10^5 \times 1.6 \times 10^{-19} = 1.28 \times 10^{-13}$ N

(c) From $F = ma$, $a = \frac{1.28 \times 10^{-13}}{9.1 \times 10^{-31}} = 1.41 \times 10^{17}$ m s^{-2}

(d) $W = qV = 1.6 \times 10^{-19} \times 24\,000 = 3.84 \times 10^{-15}$ J

(e) From $W = \Delta E_K = \frac{1}{2}mv^2$, $v^2 = \frac{2 \times 3.84 \times 10^{-15}}{9.1 \times 10^{-31}}$

Therefore $v = 9.2 \times 10^7$ m s^{-1}

3. (a) From $E_K = \frac{1}{2}mv^2 = qV$

$2400 \times 1.6 \times 10^{-19} = \frac{1}{2} \times 9.1 \times 10^{-31} \times v^2$

$v = 2.9 \times 10^7$ m s^{-1}

(b) 4.5×10^{-14} N

(c) 1.7 cm

4. (a) Top plate. Field lines are directed from positive to negative plates.

(b) From $E = \frac{V}{d}$, $= \frac{300}{0.005}$, $E = 60\,000$ V m^{-1}

(c) From $F = Eq = 60\,000 \times 1.6 \times 10^{-19} = 9.6 \times 10^{-15}$ N towards the top plate.

(d) From $F = ma$, $a = \frac{F}{m} = \frac{9.6 \times 10^{-15}}{9.11 \times 10^{-31}} = 1.05 \times 10^{16}$ m s^{-2} towards top plate.

(e) From $W = qV = \Delta E_K = 1.6 \times 10^{-19} \times 150 = 2.40 \times 10^{-17}$ J (the electron only moves through 150 V).

5. (a) The more massive ion will be P. If the two ions enter with the same kinetic energy, the more massive ion will have the lesser velocity. The magnetic force on each, $F_B = Bqv$ will therefore only differ as their velocities differ (B and q the same for each). The force on the more massive particle is therefore less, so its radius of curvature will be larger.

(b) If kinetic energies are equal, then $(\frac{1}{2}mv^2)_{\text{more massive}} = (\frac{1}{2}mv^2)_{\text{less massive}}$

Therefore $(5v^2)_{\text{more massive}} = (3v^2)_{\text{less massive}}$

Therefore $v_{\text{more massive}} : v_{\text{less massive}} = \sqrt{3} : \sqrt{5}$

Therefore velocity more massive : velocity less massive = 0.775 : 1

(c) Force on more massive : force on less massive = 0.775 : 1

(d) 193.75 mm

(e) 87.3 mm

(f) Substituting the values obtained into the equation, we get $m_1(r_2)^2 = m_2(r_1)^2$

6. From $F = Bqv = \dfrac{mv^2}{r}$, $r = \dfrac{mv}{Bq} = \dfrac{(9.1\times10^{-31}\times6.48\times10^{7})}{(2.25\times10^{-5}\times1.6\times10^{-19})} = 16.4$ m

7.

Part	Name of part	General purpose of part
1	Electron gun	This contains a cathode which is a thermionic emitter which produces electrons which are then accelerated to about 90 keV by an applied 90 kV electrical potential difference.
2	Linear accelerator	This contains a device which separates the electron beam into discrete packets ('bunches') of electrons and then accelerates each packet to about 100 MeV over a distance of 15 metres.
3	Booster ring	About 130 m in circumference, this part of the synchrotron accelerates electron packets to 3 GeV.
4	Storage ring	216 m in circumference, this ring contains insertion devices which increase the radiation emitted by the electrons, focuses them and keeps them circulating for up to 20 hours.
5	Beamlines	Refers to the line along which synchrotron radiation travels in short linear accelerators (up to 100 m long) from the storage ring of the synchrotron to hit targets in the various laboratories built at their ends. It may also refer to the line of travel of the electrons within the storage ring of the synchrotron.
6	Laboratory	Scientific workshops at the end of beamlines where scientific research is done.

Set 50 The Higgs Boson

1. The Higgs boson or Higgs particle is an elementary particle predicted by the standard model in 1964, and discovered in 2012, to explain how particles have mass.

2. The so-called Higgs energy field is proposed to exist everywhere in the Universe and as particles move around in this field, they interact with and attract Higgs bosons, which cluster around the particles in varying numbers to give it mass.

3. It was (and still is) difficult to detect the Higgs boson because they not only exist for an extremely short time, but they also have a large mass (compared to other particles), so it required a huge amount of energy to create one.

4. (a) The use of the capital 'G', and the use of the word 'god' is unfortunate because it is misleading. The nickname had nothing to do with religion.

(b) Lederman has been reported as saying that he wanted to call it the 'goddamn particle' because 'nobody could find the goddamm thing.'

5. (a) The confirmation of a prediction by any theory strengthens the credibility of that theory. So the discovery of the Higgs boson adds credibility to the standard model of matter as being a good model.

(b) No. A law in science requires direct observations of the factors involved. With theories like the standard model of matter, scientists make observations of effects of particles they cannot see and base their understandings on those observations. When observations that don't fit into the theory are observed, then scientists know that the theory has weaknesses or is wrong, and they modify it to suit the new observations. Laws are laws are laws – they are known to be 'correct' science and should never need modifying.

(c) The discovery of pentaquarks in 2003 requires a modification to include them in the model, and also suggests the possibility of other quark particles, maybe quadraquarks, or hexaquark particles. Only time will tell, and each new discovery will require modifications to the standard model.

(d) There are some observations recently at CERN that suggest that quarks may not be fundamental, but made up of smaller particles.

(e) While this is not yet confirmed, if it is found to be true, then the standard model would need to change to incorporate the new fundamental particles and redefine quarks as not being fundamental.

6. (a) The Universe.

(b) Particles of matter.

(c) Higgs bosons.

(d) Matter particles with less mass.

(e) Matter particles with more mass.

(f) The movement of particles moving through the Higgs field works in much the same way. Certain particles will attract larger clusters of Higgs bosons. The more Higgs bosons a particle attracts, the greater its mass will be.

Set 51 Ideas Leading to the Big Bang Theory

1. Albert Einstein: One of the consequences of Einstein's work on gravity and special relativity was that his mathematics predicted that the Universe was expanding. However, he didn't believe it! Einstein firmly believed that the Universe was constant and introduced a 'cosmological' constant into his equations to force them to give him the result he wanted – that the Universe was static.

   Vestro Slipher: In 1912, Slipher, through his work on examining the spectra of stars, discovered the Doppler effect. He proposed that galaxies moving away from us produced a spectrum with a red shift and those moving towards us would produce a spectrum with a blue shift.

   Alexander Friedmann: 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.

   Edwin Hubble: In 1927 Hubble applied the idea of the Doppler shift to his newly discovered galaxies. His results surprised everyone, including himself. Nearly all galaxies were moving away from us, no matter in which direction he looked. This was the first concrete evidence for the expansion of the Universe. Hubble also showed that the further away from us galaxies are, the faster they are moving away, and that this is a mathematically direct relationship. This enables us to calculate the speed and the distance of galaxies from us by simply measuring the extent of their red shift.

   Georges Lemaître: In 1927, 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. He likened Hubble's expanding Universe model to an exploding bomb, with pieces moving outwards in all directions. This implied that the matter of the Universe was initially concentrated in one position, and then, for some reason 'exploded' outwards.

2. Advances in technology, specifically developments in telescopes, including lenses and reflecting mirrors and spectrographs were available to them.

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) The red shift is produced by galaxies that are moving away from us resulting in us observing light with a longer wavelength than that emitted by the galaxy. The blue shift is caused by galaxies moving towards us, resulting in us seeing light of shorter wavelength than that emitted.

   (c) 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.

   (d) 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.

   (e) Galaxy B is stationary relative to Earth. Its spectrum is the normal reference spectrum, and is 'in between' the red and blue shifted spectra.

   Galaxy A is showing a blue shift due to its motion towards Earth.

   Galaxy C is showing a red shift due to its motion away from Earth.

4. A will hear a sound with a longer wavelength (lower frequency/pitch) than that emitted by the object because the object is moving away from this observer. B will hear sound of shorter wavelength (higher frequency and therefore higher pitch) than that emitted by the moving object because the object is moving towards this observer.

5. (a) A value for Hubble's constant.

   (b) Through Hubble's law, we use it to determine the age of the Universe, or the distance to a galaxy having determined its velocity from its spectrum red shift.

   (c) Given the spread of the plot points, different people may draw slightly different lines of best fit. However, the variation in their gradients should not be significant, so the value should be quite reliable.

   (d) Again, given the spread of the data in the graph given, using fewer plot points may result in a spread of significant difference and result in a significantly different line of best fit and therefore gradient. The value in this situation would not be as reliable.

   (e) As shown below, the mathematics of the use of the gradient of a graph like this to determine the age of the Universe is valid.

   From the equation: Average speed $= \dfrac{\text{distance}}{\text{time}}$

   Therefore $D = vt$

   From the graph, gradient = Hubble's constant H = velocity ÷ distance to galaxy $= \dfrac{v}{D}$

   From which $D = \dfrac{v}{H}$

   Equating the two equations for distance: $vt = \dfrac{v}{H_0}$

   Dividing both sides by v, we get t, so that t, the age of the Universe, is given by $t = \dfrac{1}{H_0} \approx$ (13.81 billion years)

Set 52 The Steady State Theory

1. The steady state theory proposed that the overall density of the Universe was kept constant despite its expansion, by the continuous creation of matter (hydrogen atoms).
2. It doesn't. It just states that the Universe had always existed, but made no attempt to explain neither its origin nor its expansion.
3. Diagram A represents the steady state theory where new galaxies are created to fill in the gaps between existing galaxies as the Universe expands, thus maintaining its unchanging density.

   Diagram B represents the Big Bang theory which accept the expansion and decreasing density of the Universe as a result.
4. (a) The rate of expansion of the Universe measured in 1948 gave an age for the Universe of only a few billion years – well below the calculated age of the Solar System. This placed the idea of the Big Bang theory in considerable doubt.

   (b) Technology in 1948 was not good enough to give an accurate measure of the rate of expansion.

   (c) When technology improved, better data was available.
5. (a) In a steady state, with continuous creation of matter, there would be a mixture of young and old galaxies throughout the Universe. In a big bang galaxies would age with time. Astronomers could look back in time by looking at more distant galaxies. Observations in 1948 found that more distant galaxies were older than closer galaxies.

   (b) In the 1960s astronomical observations showed that quasars and radio galaxies were found only at large distances (therefore could have existed only in the distant past) from Earth and not in closer galaxies. While the Big Bang theory predicted this, the steady state theory predicted that such objects would be found uniformly throughout the Universe.

   (c) One of the major arguments against the steady state theory was its explanation of the uniformity in the cosmic background radiation. The steady state theory explained the background microwave radiation as the result of light from ancient stars that has been scattered by galactic dust. However, the cosmic background radiation level was found, in 1964, to be uniform in all directions, making it impossible to explain as being produced by numerous point sources.
6. (a) When we look at distant galaxies we are seeing them as they were when the light that we are observing was emitted. For example, a galaxy a million light years away will appear to be a million light years younger than it actually is because it has taken that long for the light to reach us.

   (b) With current technology, this is correct. We could only see it in real time if we were to visit it.

   (c) The Big Bang theory predicts that we will see galaxies in the early stages of their evolution at large distances because of the time it takes electromagnetic radiation to travel from them to us. The steady state theory requires an even distribution of new galaxies in amongst the old as they are formed to fill empty spaces and so cannot account for these observations.

Set 53 The Big Bang Theory

1. The Big Bang theory proposes that the Universe began with an 'event' that produced an enormous amount of energy in a single position, known as the singularity, and that all matter has condensed from this energy as it expanded outwards and cooled.
2. (a) The Big Bang produced an enormous amount of energy. (G)

   (b) The Universe started at intense heat and has been cooling ever since. (D)

   (c) The Universe was initially compressed into zero volume and has been expanding since the 'Big Bang'. (I)

   (d) The temperature of the Big Bang is estimated to have been about at 10^{32} K. (A)

   (e) Matter as we know it cannot exist at this temperature. Only pure energy existed. (C)

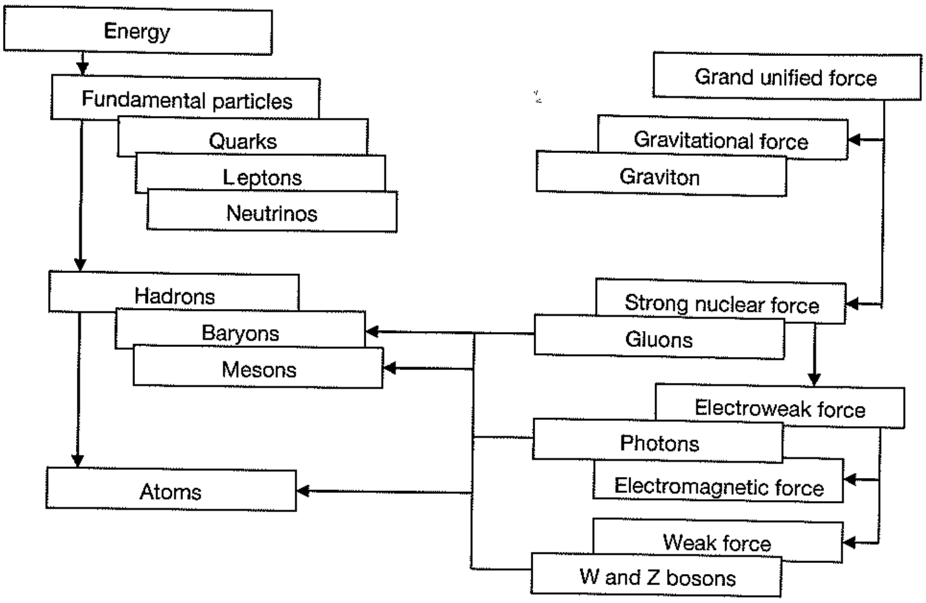
   (f) As the Universe cooled, the energy started changing into matter. (B)

   (g) The Universe started as energy, condensing to simple particles first, then to more complex particles as it expanded and its temperature fell. (F)

   (h) Accretion of newly formed matter particles by gravitational forces slowly formed gas clouds. (E)

   (i) Further accretion of matter within gas clouds saw the beginning of stars and eventually galaxies. (H)
3. Elements heavier than helium are proposed to have been formed in fusion reactions in the cores of stars, much later than the Big Bang event.

4.



Set 54 Evidence for the Big Bang

1. (a) The red shift describes the displacement of the spectral lines in the light emitted by galaxies towards the red end of the spectrum when compared to the spectrum produced by a similar, stationary emitter.

(b) Vestro Slipher using a 60 cm telescope at the Lowell Observatory, Arizona in 1912.

(c) In 1927 Hubble and Humason, observing with the 250 cm telescope at Mount Wilson, California, applied the idea of the Doppler shift to many more distant galaxies.

(d) Nearly all galaxies were moving away from us, no matter in which direction he looked. Hubble also showed that the further away from us galaxies are, the faster they are moving away, and that this is a mathematically direct relationship.

(e) This enables us to calculate the speed and the distance of galaxies from us by simply measuring the extent of their red shift.

(f) This was the first concrete evidence for the expansion of the Universe.

(g) The red shift is produced by galaxies that are moving away from us resulting in us observing light with a longer wavelength than that emitted by the galaxy.

(h) 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.

(i) A blue shift will be produced by any galaxies that are moving towards us, resulting in us seeing light of shorter wavelength than that emitted.

2. (a) Three to one.

(b) Calculations have shown that if the Universe began with a big bang, then hydrogen and helium would have formed in those proportions.

(c) About 99%.

(d) All of the radioactively stable elements, especially those with atomic mass equal and below that of iron (56).

(e) No, it is thought not. These elements are proposed to have formed from the fusion of lighter elements and these did not exist early in the timeline of the Big Bang.

(f) Stars the mass of the Sun can fuse helium into carbon which remains in the core and becomes its white dwarf remnant. More massive class O and B stars can fuse elements in their core up to Fe/Ni in the periodic table. Then the core collapses in and then rebounds as a supernova explosion. The tremendous heat and pressure of this forges all other elements.

(g) The remnants of a supernova spread out but eventually recondense into new stars. These are second generation stars.

3. (a) We know that 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. We would also expect older stars to have less helium than younger stars (due to its conversion to heavier elements). However, they don't. The calculations which lead to these conclusions favour a big bang expansion.

(b) At very long distances away from Earth, almost at the edges of the known Universe (well ... at the limit of our technology to see back that far).

(c) Blue stars are extremely hot and bright, with surface temperatures of 30 000 to 50 000 K. They have 10 to 50 solar masses and can be up to 25 times larger than the Sun. These are amongst the hottest and brightest in the known Universe. Blue supergiants are much smaller than red supergiants.

Because of their extreme masses they have short life spans of less than 10 million years and are mainly observed at the edges of galactic spiral arms where new stars form as gas is swept up. The best known example is Rigel, the brightest star in the constellation of Orion. Its mass is about 20 times that of the Sun, and its luminosity is more than 60 000 times greater. 13 of the 30 brightest stars visible to the naked eye are blue supergiants.

Hot blue stars stars are very luminous and some lose mass very rapidly because their radiation pressure outwards is so high that it tends to strip off their own gaseous envelopes before they can expand to red supergiants. Instead, they maintain an extremely high temperature and their blue-white colour as blue supergiants. A massive core does not build up as convection carries and disperses higher mass elements throughout the star. No iron core is available to contract and cause a supernova which is the fate of those less than 40 solar masses. Rather the star will simply contract inwards and because of its mass, form a black hole.

4. (a) 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 and from other, closer galaxies. This evidence is found. At large distances from us, many galaxies are radio galaxies – they emit much radiation in the radio frequencies the production of which is stimulated by high energy EMR from blue giant stars. This observation supports the Big Bang theory.

(b) Blue stars are very hot, and have a much shorter life span than stars like the Sun. It is consistent with a big bang that young blue stars will only be visible at huge distances from us because closer in, they will have aged and changed. The fact of this observation gives evidence of younger galaxies at huge distances, supporting the ageing concept following the Big Bang.

(c) No. We are 'looking back into time' and seeing these galaxies as they were billions of years ago – the time it has taken their light to reach us. Their state at our time now will have changed considerably – they will now be as old as the stars around us, and perhaps no longer exist as radio galaxies with many hot, blue stars.

5. (a) 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 early 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.

(b) The fact that particle physicists and astronomers have come to the same conclusions from different directions and methodologies provides support for both sets of observations and conclusions. They reinforce each other and this provides support in turn for the Big Bang proposal.

(c) Astronomy is the study of the heavens and of the objects that make up the Universe. Cosmology is the application of knowledge about the Universe to propose theories for its creation and evolution.

(d) Through land based telescopes, telescopes on satellites, including optical, infra-red, X-ray and other wavelength telescopes. Through spectral analysis of the EMR emitted by stars and galaxies.

6. (a) The cosmic background radiation is simply the radiant energy radiated from the matter in space because it is at a temperature higher than absolute zero, in the same way that any hot matter radiates infra-red energy.

(b) 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 about 1.9 mm throughout all of space. Scientists have calculated that if the Universe started with a big bang and expanded at the calculated rate, then the expansion would have resulted in its cooling down to about 3 kelvins. This has been found to be correct, and therefore provides evidence for the Big Bang.

(c) George Gamow, a former student of Friedmann, predicted in 1948 that the expansion of the Universe would have resulted in its cooling down to about 3 kelvins. This has been found to be correct.

(d) Two engineers, Arnold Penzias and Robert Wilson working on a new radio receiver at the Bell Laboratories in 1964 could not eliminate a persistent, annoying noise in their horn antenna detector. They had accidentally discovered the predicted background radiation, while other astronomers in nearby Princeton who were searching for it were unable to detect it.

(e) The kinetic theory of matter tells us that temperature is a measure of the average kinetic energy of the particles of matter. Radiant energy is emitted by objects if they are at a higher temperature than their surroundings and absorbed if at a lower temperature. In space, where there is little matter, the radiant energy exists because it has been (and is still being) emitted by the atoms of matter that are there according to Max Planck's black body radiation concepts. In addition, the energy produced by the Big Bang that has not been converted to mass is radiating outwards and decreasing in intensity. At this stage, it is equivalent to a black body emitting radiation of wavelength about 1.9 nm which indicates a space temperature of about 2.7 K.

(f) The satellite and instrument technology to make the measurements required were not available until the 1980s and 1990s.

Data Sheet

Acceleration of free fall, g	$9.81\ \mathrm{m\ s^{-2}}$
Gravitational constant, G	$6.67 \times 10^{-11}\ \mathrm{N\ m^2\ kg^{-2}}$
Avogadro constant, N_A	$6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
Gas constant, R	$8.31\ \mathrm{J\ K^{-1}\ mol^{-1}}$
Boltzmann constant, k	$1.38 \times 10^{-23}\ \mathrm{J\ K^{-1}}$
Stefan-Boltzmann constant, s	$5.67 \times 10^{-8}\ \mathrm{W\ m^{-2}\ K^{-4}}$
Coulomb constant, k	$8.99 \times 10^{9}\ \mathrm{N\ m^2\ C^{-2}}$
Permittivity of free space, e_0	$8.85 \times 10^{-12}\ \mathrm{C^2\ N^{-1}\ m^{-2}}$
Permeability of free space, m_0	$4\pi \times 10^{-7}\ \mathrm{T\ m\ A^{-1}}$
Speed of light in a vacuum, c	$3.00 \times 10^{8}\ \mathrm{m\ s^{-1}}$
Planck constant, h	$6.63 \times 10^{-34}\ \mathrm{J\ s}$
Elementary charge, e	$1.60 \times 10^{-19}\ \mathrm{C}$
Electron rest mass, m_e	$9.110 \times 10^{-31}\ \mathrm{kg} = 0.000549\ \mathrm{u} = 0.511\ \mathrm{MeV}\ c^{-2}$
Proton rest mass, m_p	$1.673 \times 10^{-27}\ \mathrm{kg} = 1.007276\ \mathrm{u} = 938\ \mathrm{MeV}\ c^{-2}$
Neutron rest mass, m_n	$1.675 \times 10^{-27}\ \mathrm{kg} = 1.008665\ \mathrm{u} = 940\ \mathrm{MeV}\ c^{-2}$
Atomic mass unit, u	$1.661 \times 10^{-27}\ \mathrm{kg} = 931.5\ \mathrm{MeV}\ c^{-2}$

1 light year (ly) = 9.46×10^{15} m

1 parsec (pc) = 3.26 ly

1 astronomical unit (AU) = 1.50×10^{11} m

1 radian (rad) = $\dfrac{180°}{\pi}$

1 kilowatt hour (kWh) = 3.60×10^{6} J

1 atm = $1.01 \times 10^{5}\ \mathrm{N\ m^{-2}}$ = 101 kPa = 760 mmHg