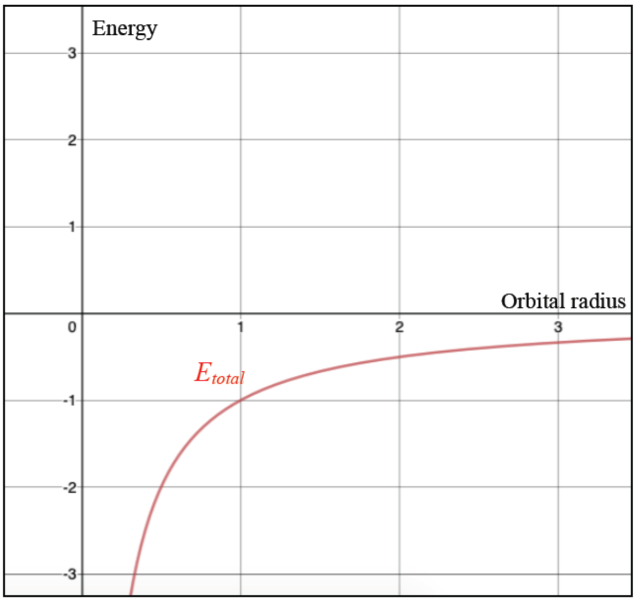
Q3
A sniper is shooting at a hanging target that is 250 m away. The target is horizontal in line with the barrel of the gun. As soon as the sniper pulls the trigger, the target will drop and fall to the floor. Air resistance is negligible. Should the sniper aim just above, just below, or at the target? Give reasons for your answer.

3 marks

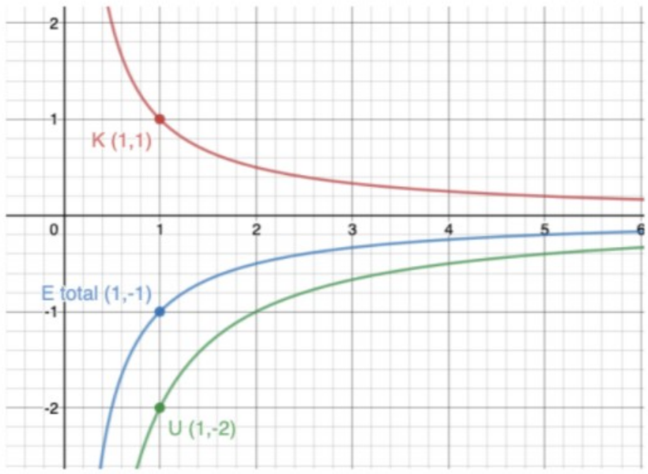
- The sniper should aim directly at the target.
- Aiming horizontally means the bullet and the target will both have an initial vertical velocity of zero.
- Both will accelerate downwards in unison since acceleration is the same for both. The horizontal motion of the bullet is independent of its vertical motion, so the bullet will stay in line with the falling target, eventually striking it.

Question 26 (5 marks)



a) The graph shows the total energy of an orbiting satellite versus its orbital radius. Sketch two lines on the graph to show the satellite's kinetic and gravitational energies. **2**

b) Calculate the change in gravitational potential energy when a 300 kg satellite orbiting Earth increases its orbital altitude from 100 km to 200 km. **3** a)

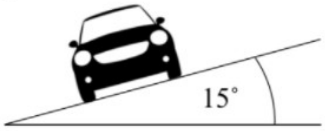


b)

$M = 6.0 \times 10^{24}$ kg $m = 300$ kg $r_i = 100 \times 10^3 + 6.371 \times 10^6$ m $r_f = 200 \times 10^3 + 6.371 \times 10^6$ m	$\Delta\text{GPE} = \text{GPE}_f - \text{GPE}_i$ $\Delta\text{GPE} = -\frac{GMm}{r_f} - \left(-\frac{GMm}{r_i}\right)$ $\Delta\text{GPE} = \mathbf{2.8 \times 10^8}$ **J increase**

Question 21 (5 marks)

(a) A car is travelling at the design speed of a banked track with a turning radius of 30.0 m, as shown in the diagram. The mass of the car is 1000 kg. **2**



Determine the design speed of the track.

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(b) If the car was to increase its speed by 5 m s^{-1} and maintain the same radius, what friction force would be required by the tyres. **3**

Question 21 (a)

Criteria	Marks
Correctly determines design speed.	2
Attempts to derive correct equation	1

Sample answer:

$v = \sqrt{\tan\theta\, gr}$

$v = \sqrt{\tan 15 \times 9.8 \times 30}$

$v = 8.88$ m s^{-1}

Question 21 (b)

Criteria	Marks
Calculates correct friction force down the slope	3
Calculates x component of friction force	2
Calculates the difference in centripetal force	1

Sample answer:

$F_{c2} = \frac{mv_2^2}{r}$ $\quad$ $F_{c1} = \frac{mv_1^2}{r}$

$F_{c2} = \frac{1000 \times 13.9^2}{30}$ $\quad$ $F_{c1} = \frac{1000 \times 8.9^2}{30}$

$F_{c2} = 6417$ N $\quad$ $F_{c1} = 2626$ N

The difference in centripetal force is the horizontal force provided by the friction.

$\Delta F_c = F_{c2} - F_{c1}$

$\Delta F_c = 3792$ N

$f = \frac{\Delta F_c}{\cos 15}$

$f = \frac{3792}{\cos 15}$

$f = 3926$ N down the slope

Question 22 (5 marks)

During a game of cricket, the batsman hits a six (the ball clears the fence boundary on the full). The cricket ball is hit at an angle of 35° from the horizontal at 28 m s^{-1}, 1.1 m above the ground. Air resistance is negligible.

(a) If the ball just clears the fence 74 m from where it was hit, calculate the height of the fence. **3**

(b) Determine the speed of the ball when it reaches the fence. **2**

Question 22 (a)

Criteria	Marks
Calculates the height of the fence correctly	3
Calculates the change in vertical displacement	2
Shows relevant working out	1

Sample answer:

$\Delta x = u_x t$

$t = \frac{\Delta x}{u \cos\theta}$

$t = \frac{74}{28\cos 35}$

$t = 3.27$ s

$\Delta y = u_y t + \frac{1}{2}at^2$

$\Delta y = (28\sin 35 \times 3.27) - 4.9(3.27)^2$

$\Delta y = 0.81$ m

$h_f = \Delta y + 1.1$

$h_f = 1.92$ m

Question 22 (b)

Criteria	Marks
Calculates correct speed	2
Calculates correct y component of the speed	1

Sample answer:

$v_y = u_y + at$

$v_y = 16.1 - 9.8 \times 3.27$

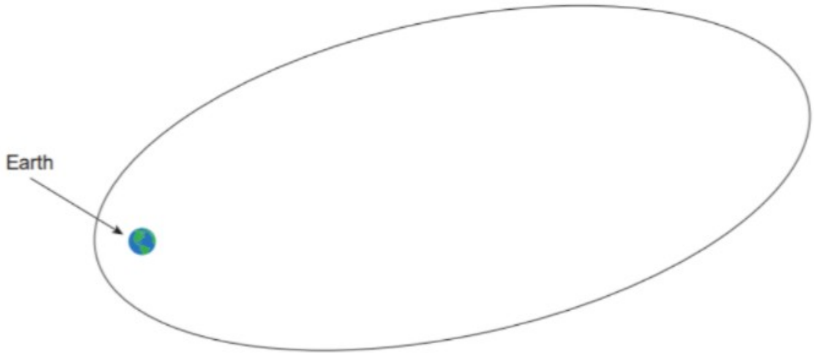
$v_y = -15.6$ m s^{-1}

$v = \sqrt{{v_y}^2 + {v_x}^2}$

$v = 27.7$ m s^{-1}

Question 22 (3 marks)

In 2018 a satellite named Transiting Exoplanet Survey Satellite (TESS) was launched. The satellite travels in an elliptical orbit around the Earth. The diagram below shows an elliptical orbit.



Explain why energy is conserved in an elliptical orbit. **3**

Question 22

Criteria	Marks
• Applies a thorough understanding of the behaviour of a satellite in an elliptical orbit recognising and describing that there is no external force applied to the satellite and that the law of conservation of energy applies to the satellite motion	3
• Applies a good understanding of the behaviour of a satellite in an elliptical orbit recognising that the law of conservation of energy applies to the satellite motion	2
• Applies an understanding that the motion of a satellite in an elliptical orbit is an application of the law of conservation of energy	1

Sample answer

For a satellite the sum of the initial kinetic and potential energy plus any external work done on the satellite will equal its final kinetic and potential energy. This can be expressed as

$$KE_i + PE_i + Wext = KE_f + PE_f$$

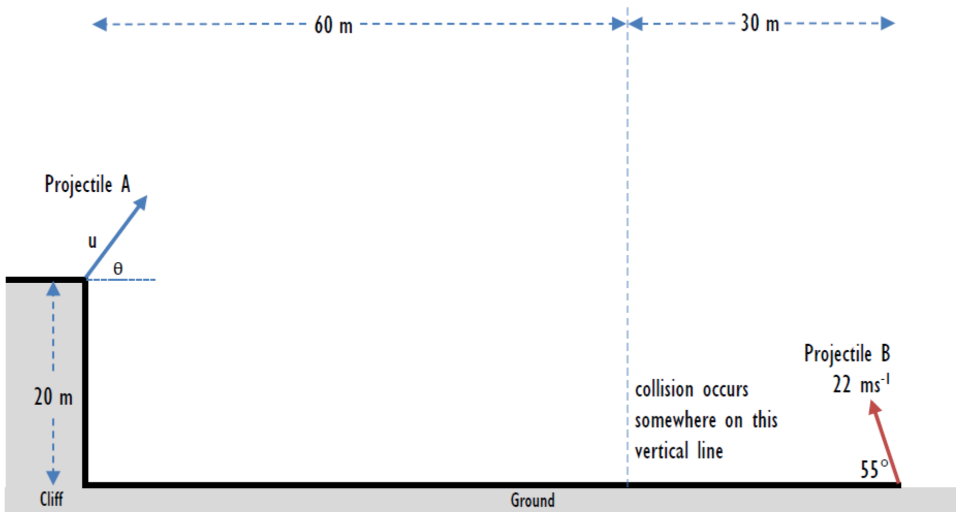
The W_{ext} term in this equation is representative of the amount of work done by external forces and for the satellite, the only force is gravity. Since gravity is an internal force, the W_{ext} term is zero. The equation can then be simplified to the following form.

$$KE_i + PE_i = KE_f + PE_f$$

Thus the total mechanical energy of the system is conserved. That is, the sum of kinetic and potential energies is unchanging. So while energy can be transformed from kinetic energy into potential energy, and vice versa, the total amount of energy remains the same meaning an increase in KE leads to a decrease in PE or a decrease in KE leads to an increase in PE and that is happening constantly in an elliptical orbit.

Question 22 (6 marks) **Marks**

Two projectiles (A and B) are launched simultaneously from two different points, as shown below, and collide 2.4 s later. They collide in mid-air 60 m to the right of the cliff, which is 30 m to the left of where projectile B was launched from. The cliff is 20 m high. Projectile B is launched at an initial speed of 22 m s^{-1} at an angle of 55° to the ground.



(a) Determine the magnitude of the initial vertical velocity of projectile B.

.... **1**

....

(b) Calculate projectile A and B's vertical height from the ground when they collide.

.... **1**

....

(c) Calculate the magnitude of projectile A's initial horizontal velocity.

.... **1**

....

(d) Determine the initial launch speed (u) and the launch angle (θ) of projectile A for this collision to occur.

.... **3**

(a) Determine the magnitude of the initial vertical velocity of projectile B. **1**

$u_y = 22 \sin 55 = 18\ ms^{-1}$

(b) Calculate projectile A and B's vertical height from the ground when they collide. **1**

$\Delta y = u_y t + \frac{1}{2} a t^2$

$= 18 \times 2.4 - 4.9 \times 2.4^2 = 15\ m$

(c) Calculate the magnitude of projectile A's initial horizontal velocity. **1**

$\Delta x = u_x t$

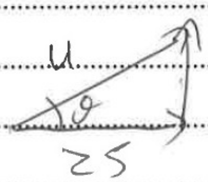
$60 = u_x \times 2.4$, $u_x = 25\ ms^{-1}$

(d) Determine the initial launch speed (u) and the launch angle (θ) of projectile A for this collision to occur. **3**

For A , $\Delta y = u_y t + \frac{1}{2} a_y t^2$

$-5 = u_y \times 2.4 - 4.9 \times 2.4^2$

$u_y = 9.68\ ms^{-1}$



$u = 26.8\ ms^{-1}$

$\theta = \tan^{-1} \frac{9.68}{25}$

$= 21.2°$

For 3 marks :

- Identifies $\Delta y = -5m$
- Finds u_y (correct equation) - $9.7 ms^{-1}$
- Combines with u_x from c) to get
- u and θ

Main issues : - identifying $\Delta y = -5$
- remembering g is -ve if u +ve
- re-arranging equation

Question 21 (5 marks)

A satellite in a low earth orbit of 800 km is in danger of falling out of orbit. The owners decide to manoeuvre the satellite safely to a lower orbit of 600 km.

(a) Calculate the increase in velocity required by the satellite to remain in the lower 600 km orbit. **2**

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(b) Explain how a change in altitude can increase the satellite's orbital velocity. **3**

Question 21 (5 marks)

(a) 2 marks

	Criteria	Marks
•	Calculates correct answer with working	2
•	Calculates either correctly	1

Sample answer:

$v = \sqrt{\frac{GM}{d}}$ where G = 6.67 x 10 $^{-11}$; M = 6 x 10^{24}; d = 6.38 x 10^{6} + (0.6 or 0.8 x 10^{6})

$v = \sqrt{\frac{6.67 \times 10^{-11} x\, 6.0 \times 10^{24}}{6.98 \times 10^{6}}}$ $\quad\sqrt{\frac{6.67 \times 10^{-11} x\, 6.0 \times 10^{24}}{7.18 \times 10^{6}}}$

$v = \sqrt{\frac{400.2 \times 10^{12}}{6.98 \times 10^{6}}}$ $\quad\sqrt{\frac{400.2 \times 10^{12}}{7.18 \times 10^{6}}}$

$v = \sqrt{57.3 \times 10^{6}}$ $\quad\sqrt{55.7 \times 10^{6}}$

= 7.57 x 10^{3} ms^{-1} $\quad$ 7.47 x 10^{3} ms^{-1}

Therefore, an increase of 100 ms^{-1}

(b) 3 marks

Criteria	Marks
• Identifies that the lower orbit needs a higher velocity • Outlines how a change in altitude means a change in the satellite's potential energy • Correctly links the change in PE to an increase in velocity	3
• Identifies that a change in altitude means a change in the satellite's gravitational potential energy • Links this in some way to increased velocity	2
• Identifies in some way that a change in altitude means a change in the satellite's gravitational potential energy	1

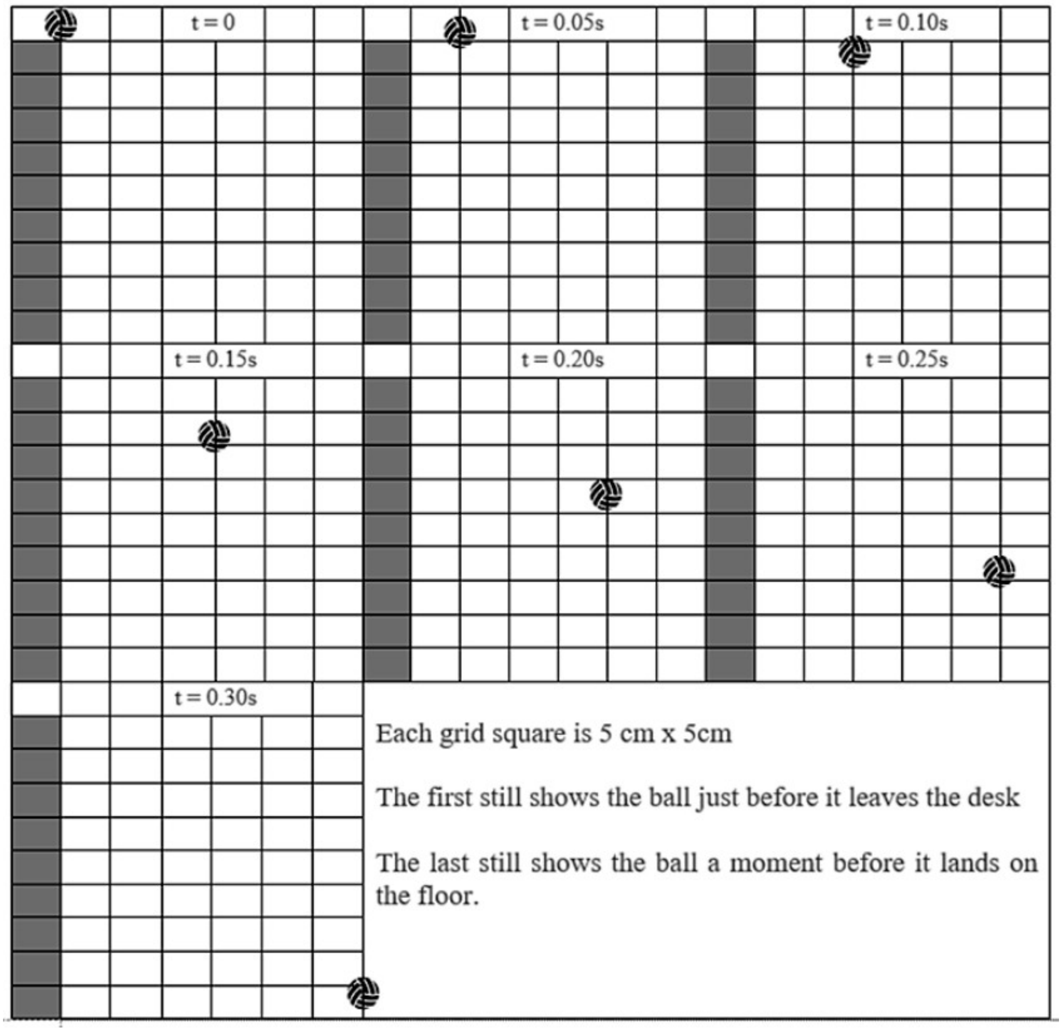
Sample answer:

The satellite requires a higher velocity if it is to maintain a lower orbit. As the satellite is manoeuvred into the lower orbit, it undergoes a loss in potential energy. As energy must be conserved, this loss of potential energy is converted to an increase in kinetic energy which increases the satellite's orbital velocity.

Question 22 (8 marks)

Students conducted an experiment to analyse the motion of projectiles. They used their phones to film a ball rolling off a desk with various horizontal launch velocities. They used a large, scaled grid for the background.

The picture below shows the consecutive stills they produced for their first launch velocity. The time between each frame is 0.05 seconds.



(a) Calculate the ball's first launch velocity. **1**

(b) Calculate the range of the ball for a horizontal launch velocity of 3 ms^{-1}. **2**

(c) Use the students' results to explain how the acceleration due to gravity could be determined. **4**

(d) Outline a source error that could impact upon the accuracy of their results. **1**

Question 22 (8 marks)

(a) 1 mark

Criteria	Marks
• Identifies that the ball travels 5 cm every 0.05s and does calculation correctly	1

Sample answer:

v = d/t

= .05/.05

= 1ms^{-1}

(b) 2 marks

Criteria	Marks
• Determines time of flight and then determines correct range	2
• Determines time of flight correctly OR does range calculation correctly	1

Sample answer:

$$t = \sqrt{\frac{2s}{a}} \qquad = \sqrt{\frac{2 \times 0.45}{9.8}} \qquad = 0.303 \text{ s}$$

Therefore range = 3 x .303 = 0.91m

(c) 4 marks

Criteria	Marks
• Shows comprehensive understanding of how gravity could be determined – *Clearly describes how to accurately use students' data to get vertical distance travelled AND time taken off grids* – *Identifies correct equation to use for calculating g* – *Then clearly demonstrates how to determine g from extracted data using either a graphical method or using arithmetic average*	4
• Shows solid understanding of how gravity could be determined	3
• Shows some understanding of understanding of how gravity could be determined	2
• Provides some relevant information	1

Sample answer:

For vertical analysis in this experiment s = ½ gt^2

To get a good average for all their frames they can use the concept of the equation for a straight-line y = mx to plot **s** on the y axis and $\mathbf{t^2}$ on the x axis. This means **½** g will be the gradient of the line of best fit. (OR they could use an arithmetic average by using a rearrangement of s = ½ gt^2; g = $2s/t^2$ to calculate g for each time frame and then average the results)

Students need to use the scale and grid lines to measure the vertical distance to the bottom of the ball in each time interval and record their results in a table, they then need to use the time indicated on each frame; making sure they use standard SI units for each.
To plot a graph, they need to calculate t^2 for each time interval. They can then plot each t^2 against the vertical displacement for that time frame, A straight line of best fit can then be drawn, and the gradient (rise over run) determined. Once determined as m = ½ g then g = 2 x the gradient

(OR To do the arithmetic average they need to do a calculation for each time frame. Then determine the average.)

For example, in the final frame of 0.30s the distance to the bottom of the ball is 44 cm or 0.44 m then 2 x 0.44/0.09 = 9.78 ms^{-1}

(d) 1 mark

Criteria	Marks
• Identifies a source of error and links it in some way to a measurement	1

Sample answer:
Distances could be inaccurate if students are not careful to make sure they use the same point on the ball for each displacement measurement.

Question 24 (4 marks)

A distant sun has several planets orbiting it. Information on the planets' orbital radius and period are set out in the table below.

Planet	*Radius in metres*	*Period in seconds*
Hellebore	6.2×10^{8}	4.2×10^{4}
Dalia	**?**	8.4×10^{4}
Protist	1.56×10^{9}	1.68×10^{5}

(a) Calculate the orbital radius of Dalia. **2**

(b) Compare the gravitational field strength experienced by Hellebore and Protist. **2**

Question 24 (5 marks)

(a) 2 marks

Criteria	Marks
• Correctly calculates answer with working using Kepler's Law relationship	2
• Calculates an answer with an error using Kepler's Law relationship	1

Sample answer with thought process:

$\frac{r^3}{T^2} = \text{constant}$ $\frac{(6.2\times10^8)^3}{(4.2\times10^4)^2} = \text{constant}$ $\frac{238.3\times10^{24}}{17.6\times10^8} = 13.54\times10^{16}$

Therefore constant = 13.54×10^{16} rearrange equation to make radius of Dalia the subject:

$r^3 = T^2\, 13.54\times10^{16}$

$r^3 = (8.4 \times10^4)^2 \times13.54\times10^{16}$

$r^3 = 955.4 \times10^{24}$

$r = \sqrt[3]{955.4 \times10^{24}} = 9.85 \times 10^8$ m

(b) 2 marks

Criteria	Marks
• Describes the relationship between radius and gravitational strength as an inverse square relationship $g = \frac{GM}{r^2}$ • Uses inverse square to relate variations in radius of each planet to strength of field	2
• Identifies the relationship between radius and gravitational strength as an inverse square relationship	1

Sample answer:

Both Protist and Hellebore will experience a gravitational field according to: $g = \frac{GM}{r^2}$.

As Protist is 2.5 times further away from their sun than Hellebore; and gravitational field strength is an inverse square relationship meaning $g \propto \frac{1}{r^2}$.

Therefore, Hellebore will experience $\frac{1}{2.5^2}$ or about 6.3 times the gravitational field of Protist.

Question 21 (6 marks) **Marks**

The planet Mercury has a mass of 3.30×10^{23} kg and a radius of 2.44×10^{6} m.

(a) Calculate the escape velocity at the surface of Mercury. **3**

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(b) For a spacecraft with a mass of 1.40×10^{3} kg, calculate the change in gravitational potential energy moving the spacecraft from the surface of Mercury to a radius of 4.94×10^{6} m. **3**

....

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Question 21 (6 marks) **Marks**

The planet Mercury has a mass of 3.30×10^{23} kg and a radius of 2.44×10^{6} m.

(a) Calculate the escape velocity at the surface of Mercury. **3**

1 $V = \sqrt{\frac{2GM}{r}}$

1 $= \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 3.3 \times 10^{23}}{2.44 \times 10^{6}}}$

1 $= 4.25 \times 10^{3}$ m/s

Max 2 if used $V = \sqrt{\frac{GM}{r}}$ orbital velocity!

(b) For a spacecraft with a mass of 1.40×10^3 kg, calculate the change in gravitational potential energy moving the spacecraft from the surface of Mercury to a radius of 4.94×10^6 m.

3

$E_i = \frac{-GMm}{r_i} = -1.26 \times 10^{10}$ J (1)

$E_f = \frac{-GMm}{r_f} = -6.24 \times 10^9$ J (1)

Note $\boxed{r_f = 4.94 \times 10^6 \text{ m}}$

$\Delta E = E_f - E_i = 6.39 \times 10^9$ J (1)

For an object initially travelling at escape velocity at distance 'r' from centre of field:

$$E_i = K_i + P_i = \tfrac{1}{2}mv_e^2 - \frac{GmM}{r}$$

After infinite time the object is stationary outside the field.

$$E_f = K_f + P_f = 0.$$

$E_i = E_f$ (conservation of energy)

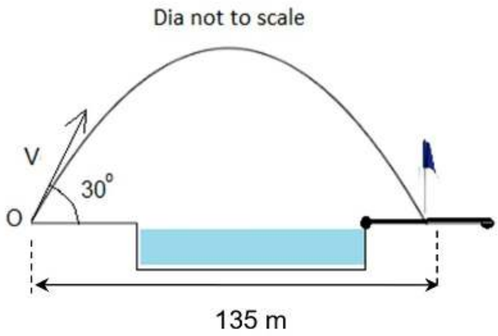
$$\therefore \tfrac{1}{2}mv_e^2 - \frac{GmM}{r} = 0$$

$$v_e^2 = \frac{2GM}{r}$$

$$v_e = \sqrt{\frac{2GM}{r}}$$

Question 21 (4 marks)

A golfer strikes the ball at 30° to the horizontal and hits a "hole-in-one" 135 m away as shown in the diagram below.

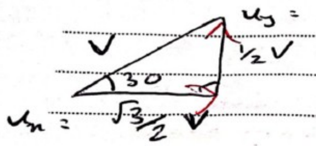


a) Calculate the magnitude of the initial velocity of the ball? **4**

135 m

a) Calculate the magnitude of the initial velocity of the ball? 4

4



now $x = u_x t$

$135 = \frac{\sqrt{3}}{2}V \times t$

$t = \frac{270}{\sqrt{3}V}$

now $y = 0$ at $t = \frac{270}{\sqrt{3}V}$

$0 = u_y t + \frac{1}{2}a_y t^2$

$0 = \frac{1}{2}V \times \left(\frac{270}{\sqrt{3}V}\right) + \frac{1}{2} \times -9.8 \times \left(\frac{270}{\sqrt{3}V}\right)^2$

$0 = \frac{270}{2\sqrt{3}} - 4.9 \times \frac{24300}{V^2}$

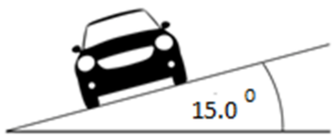
$\frac{4.9 \times 24300}{V^2} = \frac{270}{2\sqrt{3}}$

$V = \sqrt{\frac{4.9 \times 24300 \times 2\sqrt{3}}{270}}$

$V = 39\ m\,s^{-1}$

Question 22 (5 marks)

(a) A car is travelling around a frictionless banked track, angled at 15.0°, and having a turning radius of 26.0 m, as shown in the diagram. The centripetal force acting on the car is 3040 N.



3

Determine the mass of the car.

(b) If the above banked corner is no longer frictionless. Justify one way in which the frictional forces could impact on the motion of the car around the corner.	**2**

$\theta = 15.0°$ $r = 260\,m$ $F_c = 3040\,N$ $g = 9.8\,ms^{-2}$

$F_c = R\sin\theta = \frac{mg}{\cos\theta} \times \sin\theta$

$F_c = mg\tan\theta$

$\therefore 3040 = m \times 9.8 \times \tan 15.0$

$\therefore m = \frac{3040}{9.8\tan 15.0} = 1157.6973...$

$\doteq 1.16 \times 10^3\,kg$ (3 sig. figs)

on the motion of the car around the corner. **2**

The frictional forces between the tyres and the road would produce a force parallel to the plane of the road, proportional to the normal reaction exerted on the tyres by the road, and the coefficient of friction of the surface. The horizontal component of this frictional force would act towards the centre of the circle, increasing the centripetal force acting on the car. According to $F_c = \frac{mv^2}{r}$, an increase in centripetal force whilst keeping mass and velocity constant will result in a smaller turning circle than without friction (i.e. lower radius, r)

Question 23 (5 marks)

(a) Show that the total energy of an orbiting satellite is half its gravitational potential energy **3**

(b) Explain why the gravitational potential energy of an orbiting satellite is negative. **2**

(a) Show that the total energy of an orbiting satellite is half its gravitational potential energy

~~The kinetic ener~~ An orbiting satellite is travelling in circular motion where the gravitational force supplies the centripetal force

① $F_c = F_g$

$\frac{mv^2}{r} = \frac{GMm}{r^2}$

$v^2 = \frac{GM}{r}$

② To find KE

$KE = \frac{1}{2}mv^2$

from ① $= \frac{1}{2} \times m \times \frac{GM}{r}$

$= \frac{GMm}{2r}$

③ Total energy is the kinetic energy added to the potential energy

$E_T = E_P + E_K$

$= -\frac{GMm}{r} + \frac{GMm}{2r}$

$= +\frac{GMm}{r}\left(-1 + \frac{1}{2}\right)$

$= -\frac{GMm}{2r}$

④ consider: (E_P) $U = -\frac{GMm}{r}$ $\therefore \frac{U}{2} = -\frac{GMm}{2r}$

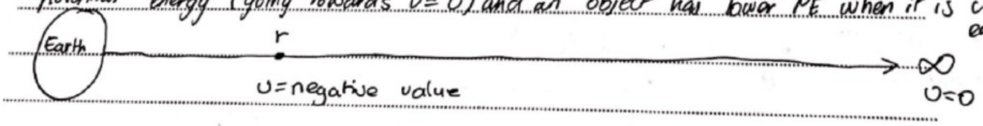
$\therefore E_T = \frac{U}{2}$, $E_T = \frac{E_P}{2}$

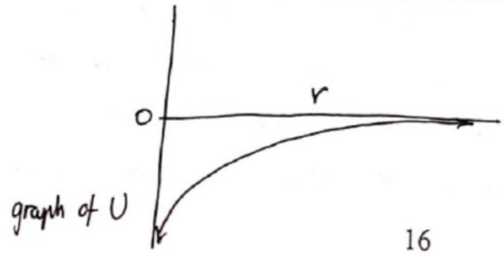
3

(b) Explain why the gravitational potential energy of an orbiting satellite is negative. **2**

According to the equation $U = -\frac{GMm}{r}$ at a point $r = \infty$ $U = 0$ therefore all value less than ∞ must yeild an U of less than 0. Hence any number less than 0 is negative. Hence as a object moves away from earth, it gains potential energy (going towards $U = 0$) and an object has lower PE when it is closer earth

2





Question 7 Beware

A cricket ball is thrown from one player to another player 95 metres away. What is the slowest speed at which it can be thrown and still cover the distance? 3 marks

Question 7:

Optimum angle is $\theta = 45°$.

$s_x = 95 \rightarrow u_x t = 95$

$t = 95/u_x$

$s_y = 0 \rightarrow u_y t + \frac{1}{2} a_y t^2 = 0$

$u_y + \frac{1}{2} a_y t = 0$

$u_y - 4.9 \times 95/u_x = 0$

$u_y = 465.5/u_x$

$V\sin 45° = 465.5/V\cos 45°$

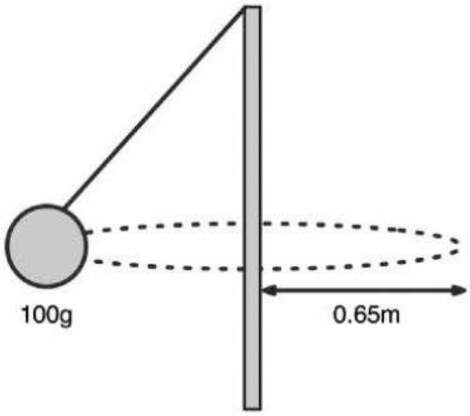
$V^2 = 931$

$\underline{V \approx 30.51\ ms^{-1}}$

- 1 mark for identifying optimum angle
- 1 mark for progress towards solution
- 1 mark for solution

Question 7 Beware

A 100 g ball is swung around from the top of a stick, in a circle of radius 0.65 metres. A student observes that the ball is spinning around in the circle about 45 times per minute.



(a) Calculate the angular velocity of the ball. 2 marks

(b) Draw a vector diagram showing the forces acting on the ball. 2 marks

(c) Calculate the magnitude of the centripetal force required to keep the ball moving in uniform circular motion. 2 marks

(d) Calculate the tension force provided by the rope. 3 marks

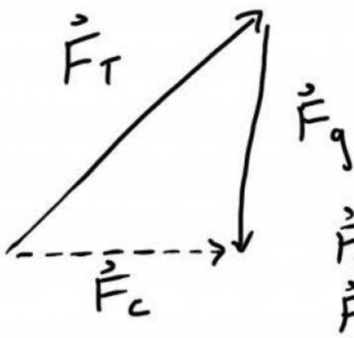
Question 7 a.

$$\omega = \frac{\Delta\theta}{\Delta t}$$

$$= \frac{2\pi}{45/60}$$

$$\approx 8.38 \text{ rad/s}$$

Question 7 b.



$\vec{F}_T$ = Tension
$\vec{F}_g$ = Gravity
$\vec{F}_c$ = Centripetal

Question 7 c.

$m = 0.1\,kg \quad r = 0.65\,m$

$$v = \frac{2\pi r}{T} = \frac{2\pi \times 0.65}{60/45}$$

$$\approx 3.06\,ms^{-1}$$

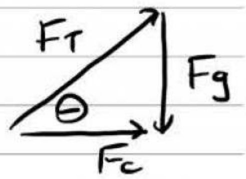
$$F_c = \frac{mv^2}{r} = \frac{0.1 \times 3.06^2}{0.65}$$

$$\approx \underline{1.44N}$$

Question 7 d.

$F_c = 1.44N.$

$F_g = mg$
$= 0.1 \times 9.8$
$= 0.98N.$



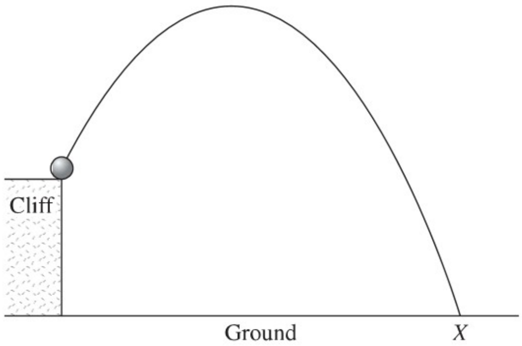
$F_T = \sqrt{0.98^2 + 1.44^2}$
$\approx 1.74\,N.$

$\theta = \tan^{-1}(0.98/1.44)$
$\approx 34.24°$

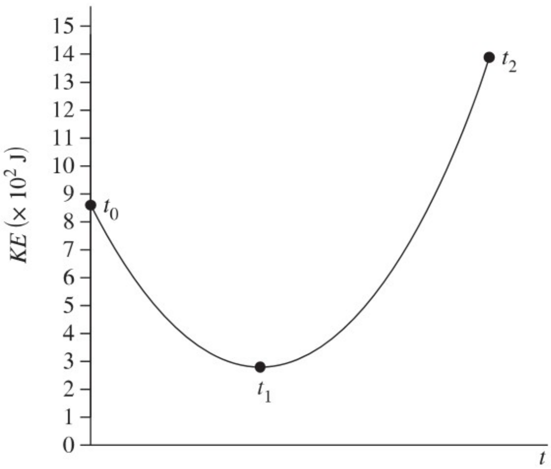
Tension is 1.74N at 34.24° to the horizontal!

Question 34 (7 marks)

A 3.0 kg mass is launched from the edge of a cliff.



The kinetic energy of the mass is graphed from the moment it is launched until it hits the ground at X. The kinetic energy of the mass is provided for times t_0, t_1 and t_2.



Time (t)	*KE* (J)
t_0	864
t_1	284
t_2	1393

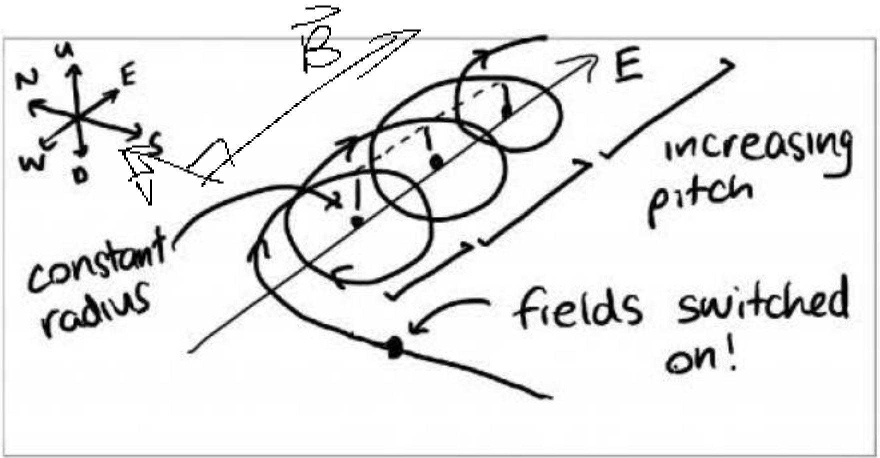
Question 34 continues on page 33

Q7
An electron is travelling north at a constant speed. An electric and magnetic field are switched on at the same time with opposite directions. The magnetic field is applied to the east, and the electric field is applied to the west. These fields can be considered to be infinitely large.

Explain the motion of the electron after the fields are switched on, using a diagram to help demonstrate your answer.

5 marks

- The electric field will cause the electron to accelerate to the east.
- The magnetic field will cause the electron to undergo uniform circular motion in the North/South, Up/Down plane.
- These components combine and cause the electron to spiral.
- Each circle in the spiral has a fixed radius but each individual spiral is longer in the east/west direction (increasing pitch).
-



Q4
In class, you conducted a practical investigation into the forces between two parallel current carrying wires.

a) Describe the investigation you conducted, including identifying the independent and dependent variables.

3 marks

b) Discuss the validity, accuracy and reliability of the experiment you conducted.

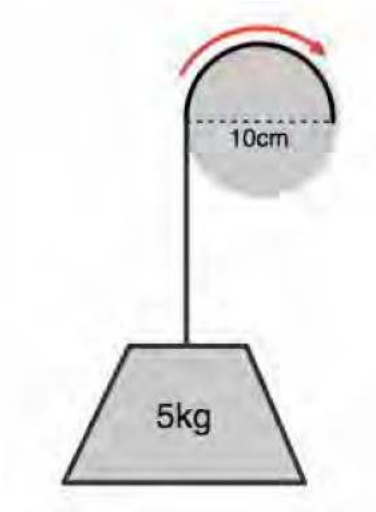
4 marks
Q4 In class, you conducted a practical investigation into the forces between two parallel current carrying wires. a) Describe the investigation you conducted, including identifying the independent and dependent variables. 3 marks • The investigation involved using a scale to measure weight differences in a current carrying wire, due to the force from another current carrying wire, in order to verify the value of μ_0. • The independent variable was current and • the dependent variable was the force produced. b) Discuss the validity, accuracy and reliability of the experiment you conducted. 4 marks • The experiment was accurate, • yielding a value close to the expected value for μ_0. • The experiment was also reliable, as a line of best fit was used to analyse results, though the existence of one outlier does suggest reliability could have been improved. • The experiment was not totally valid, however, since the distance between the wires could not be measured with total accuracy, and the wires were not perfectly parallel.
Q8 Explain why transformers are used in the distribution of electrical energy. 5 marks
• Transformers are used to reduce power loss when transmitting electrical energy long distances. Power loss in distribution lines is given by $P = I^2R$, • so losses are reduced by stepping up voltage and stepping down current using a step up transformer. • Step down transformers then decrease the voltage before it is used by consumers, since the high transmission voltages are not safe for direct use. This efficiency improvement

reduces costs while maintaining safety for the public.

- Transformers also allow different appliances to be used from a single supply. They allow high voltage appliances,
- like washers/dryers, to be connect to the same supply as low voltage ones like laptops. Each device contains a transformer to step up/down the voltage as required. This system facilitates the use of devices as we are accustomed to in modern life.

Q4

A motor has a radial, 0.4 T magnetic field and a shaft with diameter 10 cm. It is being used to lift a 5 kg weight, as shown below.



The coil used in the motor is square, with 4 cm sides and 150 turns. Calculate the current required in the coil of the motor to lift the weight.

5 marks

- $W = mg = 5(9.8) = 49\,N$
- $\tau = Frsin\theta = 49\left(\frac{0.1}{2}\right)(\sin 90) = 2.45\,Nm$
- $\tau = BAIn\,(cos\theta = 1\,for\,radial\,field)$
- $I = \frac{\tau}{BAn} = \frac{2.45}{0.4(0.04)^2(150)} = ¿$
- $I = 25.52\,A$

~~Q5~~

~~Explain how ‘back emf’ affects the design of DC motors.~~

~~3 marks~~

- ~~Back emf is the induced emf which opposes the supply in a spinning electric motor.~~
- ~~Motors are designed to have a supply current larger than what is actually required, so that~~

~~after back emf, the current in the coil produces the desired torque. However, this is only when the coil is spinning. The full supply current will flow in the coil on start-up.~~

- ~~The coil in a DC motor is designed to have a large enough resistance to carry the full supply current without overheating or otherwise being damaged.~~

Q6

A student proposes an electric vehicle design where each wheel will be driven by a convertible electric apparatus connected to a battery. While accelerating, the apparatus will act as a motor, using energy from the battery. When braking, the apparatus will act as a generator to charge the battery.

a) With reference to Lenz's law, explain how electromagnetic induction is applied in magnetic braking.

4 marks

b) A student claims this vehicle will never need to be recharged. Is this claim correct? Justify your answer.

3 marks

Q6

A student proposes an electric vehicle design where each wheel will be driven by a convertible electric apparatus connected to a battery. While accelerating, the apparatus will act as a motor, using energy from the battery. When braking, the apparatus will act as a generator to charge the battery.

a) With reference to Lenz's law, explain how electromagnetic induction is applied in magnetic braking.

4 marks

- Lenz's law dictates that induced currents will flow to oppose the change that created them.
- This is the essence of magnetic braking.
- Large conductive plates are fixed to the object in motion. If these plates enter a magnetic field (eg approach a strong permanent magnet) then eddy currents will be formed due to electromagnetic induction. These currents flow to create an opposing magnetic field.
- Since the change was induced by a motion in one direction, the opposing field results in a force in the other direction due to Lenz's law, thus deaccelerating the object.

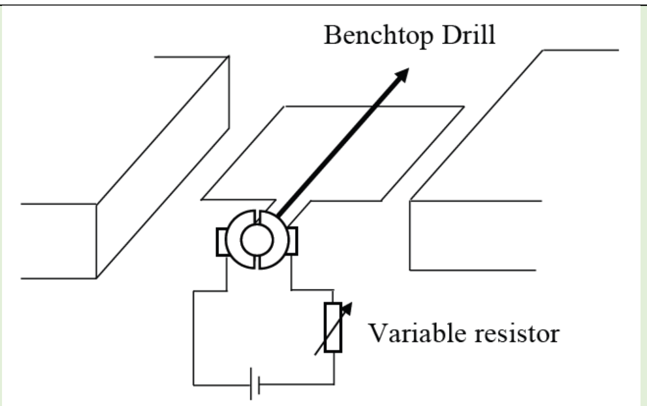
b) A student claims this vehicle will never need to be recharged. Is this claim correct? Justify your answer.

3 marks

- This claim is incorrect.
- The energy transformations involved are not 100% efficient.
- In converting electrical energy to kinetic energy and back again, energy is lost due to friction, resistive heating in the rotor coils, and (while motoring) back emf. Energy could also be used in the car's instruments. Eventually, these inefficient transformations require the battery to be recharged.

~~Q36~~

~~A simple DC motor is used to drive a benchtop drill. The motor is connected in series with a variable resistor to protect the windings in the coil as shown in the diagram below.~~



~~The variable resistor is adjusted to have a large resistance when the motor is starting up and the resistance is slowly lowered as the motor reaches its operating speed.~~
~~Explain improvements that can be made to motors to minimise the issues with torque and back emf.~~

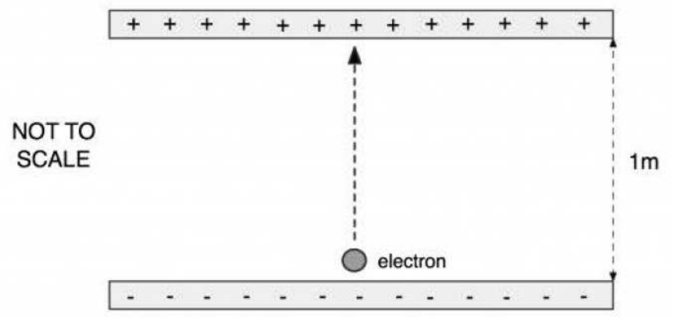
~~8 marks~~

- Student outlines 4 improvements to the DC motor drawn above and details the Physics principle that governs this improvement and how this principle plays role. Student must include at least 1 improvement that addresses torque and 1 improvement that addresses back emf.
  - Eg
  - More coils, higher current etc
  - Orient coils and split ring commutators in multiple directions
  - Back emf is the induced emf which opposes the supply in a spinning electric motor. Motors are designed to have a supply current larger than what is actually required, so that after back emf, the current in the coil produces the desired torque. However, this is only when the coil is spinning. The full supply current will flow in the coil on start-up. The coil in a DC motor is designed to have a large enough resistance to carry the full supply current without overheating or otherwise being damaged.
- OR
- Student describes 3 improvements to the DC motor drawn above and explains the Physics principle that governs this improvement and details how this principle plays role (diagrams). Student must include at least 1 improvement that addresses torque and 1 improvement that addresses back emf.

Common mistakes were:
- BACK EMF!!!! Most were not only wrong but started to contradict yourselves mid-sentence. Back emf is not a source of energy loss. You can’t stop/reduce back emf ever. It is inherent in the nature of the motor.
- Listing a set of improvements is not explaining.
- Using an equation to explain is not correct, e.g. “Increasing the current increases the torque because $\tau = nBIA$.”

Question 3

Two parallel plates set up half a metre apart. The voltage can be used to accelerate particles from rest, from one plate to another.

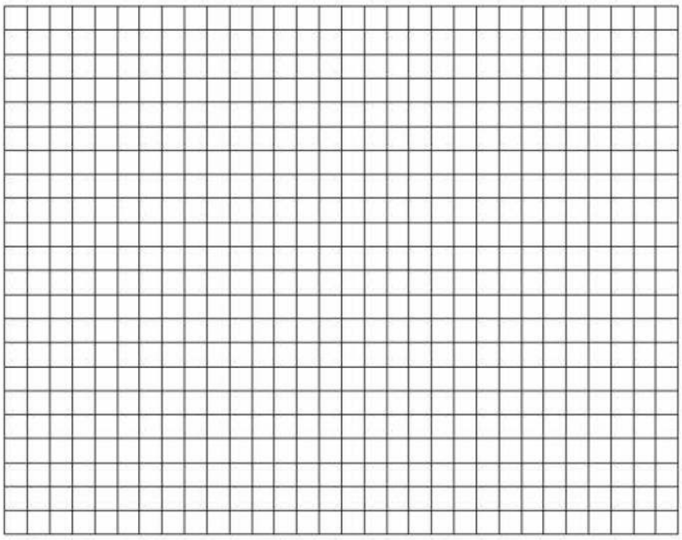


(a) An electron is used in this setup with a voltage of 10,000V, as shown. Calculate the speed of the electron when it strikes the top plate. 3 marks

The same setup and procedure is now used to measure the charge on another particle. It has already been determined that the particle has a mass of 1.5×10^{-20} kg, and the experiment is repeated for various voltages. The particle moves from the top plate to the bottom plate, and the results of the experiment are in the table below.

Voltage (V)	Square of Velocity (m^2s^{-2})
10,000	1.1×10^6
20,000	2.3×10^6
30,000	3.1×10^6
40,000	4.3×10^6
50,000	5.0×10^6

(b) Graph the data on the grid below. 3 marks



(c) Estimate the charge on the particle. 2 marks

Question 3 a.

$E = V/d = 10{,}000/0.5 = 20{,}000\ NC^{-1}$

$F = Eq$

$= 20{,}000 \times 1.602 \times 10^{-19}$

$= 3.204 \times 10^{-15} N.$

$a = F/m = 3.204 \times 10^{-15} / 9.109 \times 10^{-31}$

$= 3.52 \times 10^{15}\ ms^{-2}$

$v^2 = u^2 + 2as.$

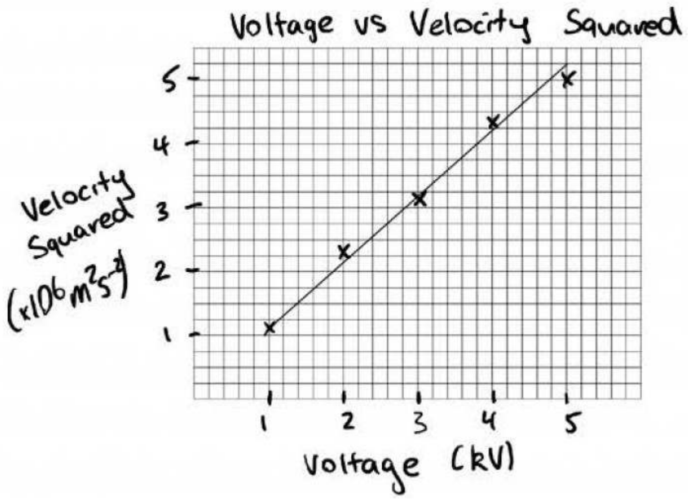
$= 0^2 + 2 \times 3.52 \times 10^{15}$

$= 7.03 \times 10^{15}$

$\therefore\ v = \sqrt{7.03 \times 10^{15}}$

$= 8.38 \times 10^{7}\ ms^{-1}$

Question 3 b.



- 1 mark: correct plotting of points
- 1 mark: appropriate line of best fit
- 1 mark: axis labels/title

Question 3 c.

$$\text{Gradient of Line} = \frac{(5.25-1.1)\times 10^6}{(5-1)\times 10^3}$$

$$= 1.0375\times 10^3.$$

$$\frac{1}{2}mv^2 = Fs$$

$$= Vq$$

$$v^2 = \frac{2q}{m}V.$$

$$\text{So} \quad \frac{2q}{m} = 1.0375\times 10^3$$

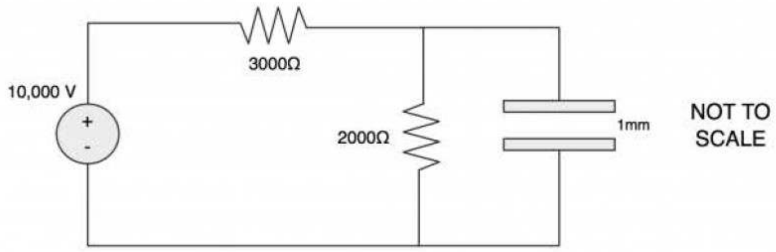
$$q = \frac{1.0375\times 10^3 \times m}{2}$$

$$= \frac{1.0375\times 10^3 \times 1.5\times 10^{-20}}{2}$$

$$\approx \underline{7.782\times 10^{-18}}$$

Question 4

Two parallel conductive plates are connected to an electrical circuit as shown below. The plates are 1 mm apart.



(a) Calculate the voltage difference between the plates. 3 marks

(b) Calculate the magnitude of the electric field between the plates. 1 mark

Question 4 a.

$R_T = 3000 + 2000 = 5000$

Current in Circuit: $I = V/R$

$= 10{,}000/5000$

$= 2A.$

So $V_2 = IR_2 = 2 \times 2000 = 4000V$

So $\underline{V_{plates} = 4000V}$

- 1 mark: identifying that no current flows through the plates/some other comprehension of the problem
- 1 mark: calculating the current through the resistors
- 1 mark: calculating the voltage

Question 4 b.

$E = V/d = 4000/0.001$

$= 4 \times 10^6 \ NC^{-1}$

A current carrying wire will experience a force inside a magnetic field. Explain this phenomenon in terms of the effects on specific particles.

3 marks

Question 5:

A current consists of many moving negative charges (electrons). Each of these creates its own small magnetic field, and so will experience a force due to its motion in the magnetic field. The force on the current carrying wire is just the sum of all of these smaller forces on each moving charge.

- 1 mark: identifying that a current consists of many individual moving charges
- 2 marks: linking the force on these charges to the force on the wire

Question 3

We can model power lines on transmission towers as parallel current-carrying wires. Two such power lines are hanging one metre apart, carrying a current of 50 A in opposite directions.

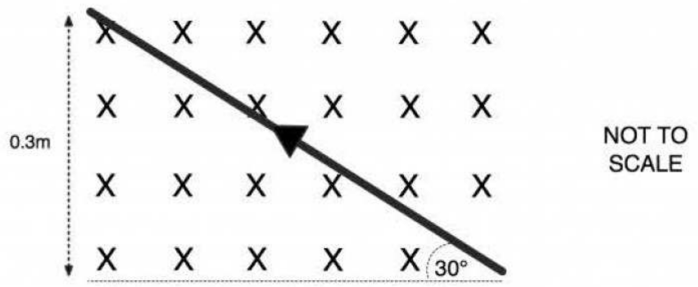
(a) Is the force between the wires attractive or repulsive? 1 mark

(b) Calculate the magnitude of the force experienced by a one kilometre length of these wires. 2 marks

(c) Briefly explain why the wires experience this force. 2 marks

Question 5

The diagram below shows a wire carrying a 1.5A current in a 2T magnetic field.



Calculate the magnitude of the force on the wire. 3 marks

Question 5:

$\sin 30° = 0.3/L$

$\therefore L = 0.3/\sin 30°$

$= \underline{0.6m}$

$F = BIL\sin\theta$

$= 2 \times 1.5 \times 0.6 \times \sin 90°$

$= \underline{1.8N}$

A wire carrying an AC current is placed inside a magnetic field. Briefly explain the behaviour you expect the wire to exhibit.

2 marks

Question 6:

The wire will oscillate/vibrate. The wire experiences a force due to the motor effect, but since the current swaps direction periodically, the force does as well. Thus, the wire will vibrate due to the alternating direction of force, with the period of oscillation dependent on the frequency of the current.

What is an ampere, as defined by the International System of Units?

1 mark

Question 7:

The current which must flow through two parallel wires, one metre apart, for a force of 2×10^{-7} Newtons to be produced between those wires.

A student places a wire in a magnetic field and passes a current of 2A through it. The student can't measure any force on the wire due to the motor effect. What is the likely cause of this?

1 mark

Question 8:

The wire is parallel with the magnetic field. According to $F = BIL\sin\theta$, no force will be produced if $\theta = 0°$.

Question 9

A 3 metre length of straight wire is running along the ground with a current of 4A flowing through it from north to south. The wire has a mass of 200 g per metre.

(a) In what direction should a magnetic field be applied to lift the wire? 1 mark

(b) Calculate the minimum magnitude of magnetic field required to lift the length of wire. 3 marks

Question 9 a.

The field should be applied west to east.

Question 9 b.

$W = mg$

$= (3 \times 0.2) \times 9.8$

$= 5.88N$

$\therefore F = BIL\sin\theta$

$B = \frac{F}{IL\sin\theta}$

$= \frac{5.88}{4 \times 3 \times \sin 90°}$

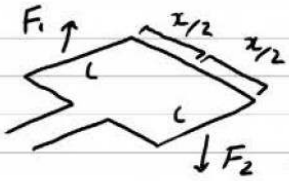
$= 0.49T$

Question 10

A rectangular coil with n turns of area A is parallel to a magnetic field B in a DC motor, with a current I flowing through it. By considering the forces on individual sides of the coil, prove that the torque generated by the motor at this moment is given by τ = nBIA.

4 marks

Question 10:

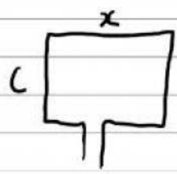


$\underline{F_T = (F_1 + F_2)n}$

$$
\begin{aligned}
F_T &= (F_1 + F_2)n \\
&= (2BIl\sin\theta)n \\
&= 2BIln \quad (\sin 90^\circ = 1).
\end{aligned}
$$

$$
\begin{aligned}
\tau &= rF\sin\theta \\
&= x/2 \times 2BIln \\
&= xBIln
\end{aligned}
$$

But $lx = A$



$\therefore \tau = nBIA$

Two coils are placed close to one another on a test bench. The first coil is connected to a large DC power supply and the second is connected to an ammeter. Explain what will be observed on the ammeter when the DC power supply is switched on.

3 marks

- The ammeter will briefly show a reading the moment the supply is switched on. When the current starts flowing through the first coil, it starts producing a magnetic field. In the brief time it takes to establish this field, the second coil experiences a changing magnetic flux, which produces an emf and a current by EM induction. The ammeter thus shows a reading. Once the field is established, the flux experienced by the second coil is constant, so no current flows.

- 1 mark: correct behaviour
- 1 mark: identifying that the first coil produces a magnetic field
- 1 mark: explaining how the brief change in flux induces a current

Question 3

A particular phone charger uses a transformer to step down the 240V supply voltage to 5V. The primary coil has 960 turns. Assume the transformer is ideal.

(a) How many turns are in the secondary coil? 2 marks

(b) A phone is plugged into the charger and it draws a current of 1A while charging. Calculate the cost of charging the phone for 24 hours if the price of energy is 30 cents per kWh. 3 marks

Question 3 a.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \rightarrow \frac{N_s}{N_p} = \frac{V_s}{V_p}$$

$$N_s = \frac{N_p V_s}{V_p}$$

$$= \frac{960 \times 5}{240}$$

$$= \underline{20 \text{ turns}}$$

Question 3 b.

$P = VI = 5 \times 1$ (on secondary side)

$= 5W.$

$E = Pt$

$= 5 \times 24$ hours

$= 5 \times (60 \times 60 \times 24)$

$= 432$ kJ

$1kWh = 1000 \times 60 \times 60 = 3.6 \times 10^6 J.$

$\therefore E = (432,000) \div (3.6 \times 10^6)$

$= 0.12$ kWh

$\therefore C = 0.12 \times \$0.30 \approx \$0.04$

(nearest cent).

- 1 mark: calculating the power input to the transformer
- 1 mark: converting the power consumption to a total energy requirement
- 1 mark: correct answer

Explain the link between Lenz's law and the conservation of energy.

3 marks

- Lenz's law states that all induced emfs act to form magnetic fields which oppose the change that created them. This ensures that no energy is created by electromagnetic induction, only transformed, thus maintaining the conservation of energy.
- If the induced emfs 'supported' the change, then the process would be self-perpetuating.

For example, if a current was induced in a coil by moving a magnet towards it, the induced current would attract the magnet further, creating more change in flux and thus more current, in a perpetual cycle that creates energy.

- This is impossible and Lenz's law guarantees that it doesn't occur and that energy is conserved.

A student drops a magnet through the opening of a coil connected to a light bulb. The student observes the light bulb illuminate as the magnet passes through the coil.
Describe the energy transformations taking place in this scenario and propose two changes the student could make to the experimental design to make the light bulb glow more brightly.

5 marks

- When the magnet is released, **potential energy** is converted to **kinetic energy** by gravity. Some of this kinetic energy is converted to **electrical energy** via induction. This is converted into **light energy** by the light bulb, and also into **heat energy**, due to the resistance of the coil and connected circuit.
  Improvements:
- Drop the magnet from **higher** above the coil. This will increase the rate of change of magnetic flux as the magnet is moving more quickly.
- Use a **stronger** magnet, which will increase the rate of change of magnetic flux, since the field used is stronger.

A student measures the input voltage/current of a particular transformer to be 240V, 0.5A. The output voltage/current is 12V, 6.6A.

(a) Calculate the efficiency of the transformer. 2 marks

(b) Explain the common sources of power loss in transformers, and the strategies used to reduce those losses. 4 marks

a. P_{in} = VI = 240(0.5) = 120 W

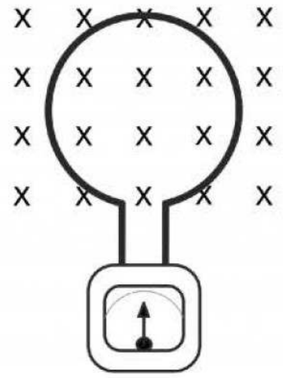
P_{out} = VI = 12(6.6) = 79.2 W

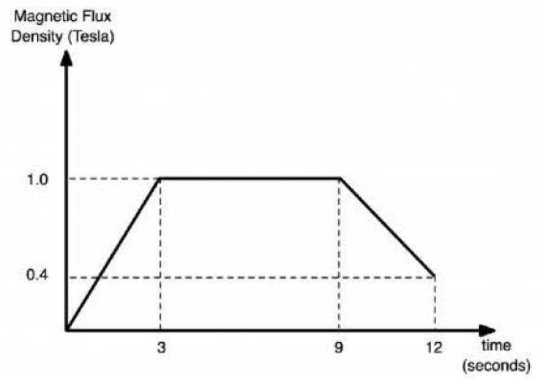
Efficiency = $\frac{79.2}{120} = 66\%$

b.

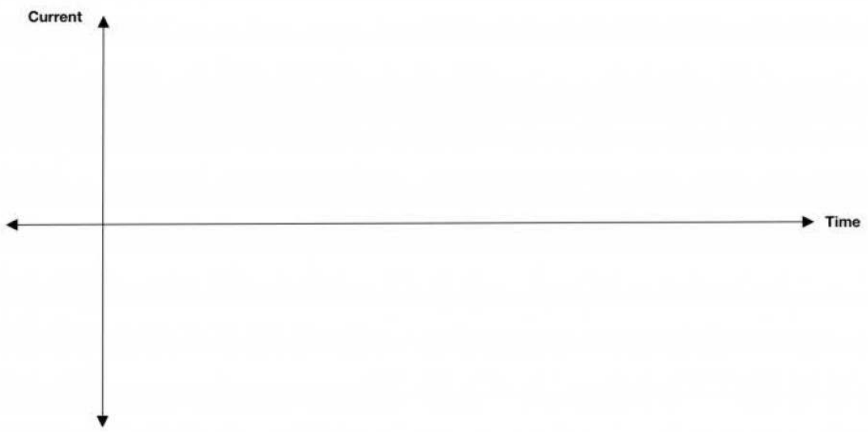
- Eddy currents
  - Form in the core of a transformer, induced by the changing flux it carries.
  - These are reduced by using insulative laminations in the core, which reduce the size of eddy currents without affecting the permeability of the core.
- Incomplete flux linkage
  - Not all flux generated by the primary coil reaches the secondary coil.
  - Flux leakage is reduced by using a highly permeable, minimally coercive material in the core.
- Excess heat:
  - Excess heat causes power loss, which is why transformers are fitted with oil or water-based cooling systems

A circular coil of radius 10 cm and resistance 0.5 ohm is connected to an ammeter and placed inside a magnetic field of varying strength. The ammeter is wired such that a current flowing anti-clockwise in the loop will yield a positive value, and a current flowing clockwise will yield a negative value. The strength of the field over 12 seconds is shown on the graph.





In the space provided, draw a graph of the value shown on the ammeter over the same time period, showing supporting calculations. 3 marks



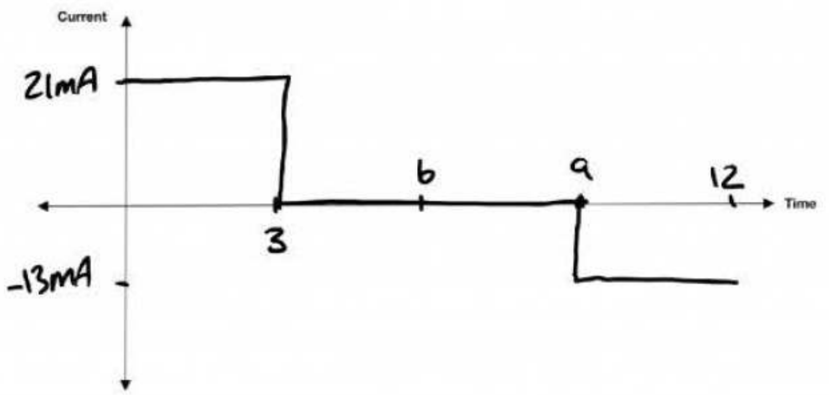
$$\varepsilon_1 = \frac{\Delta\Phi}{\Delta t} = \frac{\Delta B}{\Delta t} \times A = \frac{1}{3} \times 0.01\pi \approx 0.0105\text{V.}$$

$$\varepsilon_2 = I_2 = \underline{0\text{A.}}$$

$$\varepsilon_3 = \frac{\Delta B}{\Delta t} \times A = \frac{-0.6}{3} \times 0.01\pi \approx -0.0063\text{V.}$$

$$I_1 = \varepsilon_1/R \approx \underline{21\text{mA}}$$

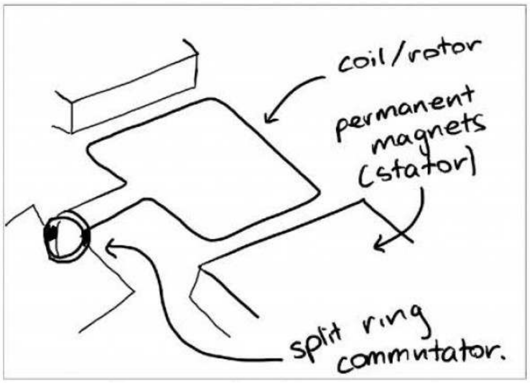
$$I_3 = \varepsilon_3/R \approx \underline{13\text{mA}}$$



- 1 mark: understanding that a constant current is induced when the flux is changing
- 1 mark: correct calculations
- 1 mark: correct graph, with correct directions

Draw a diagram of a simple DC motor, labelling significant parts. Describe the function fulfilled by each of these components.

5 marks



- The **stator** provides the magnetic field. The **coil** carries the current which interacts with this field via the motor effect to produce forces and a torque. The **split ring commutator** reverses the direction of the input current every half turn, to maintain a constant direction of torque and thus keep the motor spinning.
- 2 marks: diagram, showing the three significant parts of the motor
- 2 marks: correct descriptions of what these parts does
- 1 mark: fulfilling both of the above without any errors

Compare and contrast the structure and purpose of simple motors and generators.

3 marks

- Motors and generators have near identical structures but serve the opposite purpose. Both consist of a rotating coil in a magnetic field, connected to an external circuit via a split ring commutator or slip rings.
- A motor converts electrical energy from the circuit into mechanism energy via the motor effect,
- while generators take mechanical energy and convert it into electrical energy for the circuit, via EM induction.

With reference to appropriate Physics principles, explain how an AC induction motor operates.

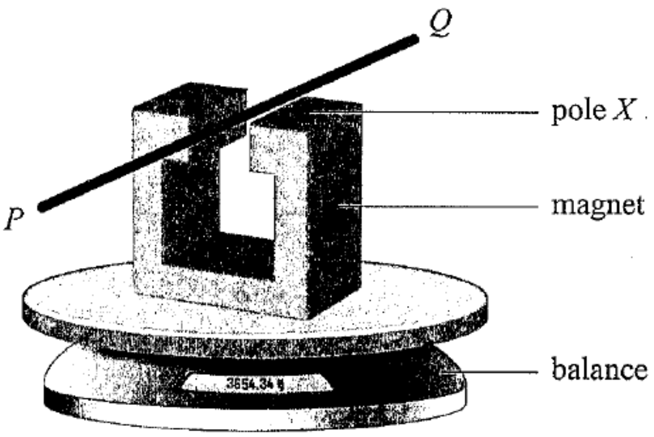
6 marks

- An AC induction motor consists of pairs of electromagnets around a conductive rotor.
- The electromagnets are switched on and off in sequence around the rotor, generating a rotating magnetic field (or equivalent labelled diagram).
- The rotor experiences a changing magnetic flux and currents form by EM induction (Faraday's law).
- Lenz's law states that these currents generate their own field to oppose the change that created them.
- In this context, this also causes the rotor to rotate, 'chasing' the rotating field.
- Controlling the motor is done by changing the intensity of the field and the speed at which it rotates. Otherwise, the AC induction motor operates at the frequency of AC power

supply.

Question 21 (5 marks)

A large horseshoe magnet produces a uniform magnetic field B between its poles. The magnet is placed on a digital balance and a secured copper rod placed between its poles as shown. The rod PQ is positioned perpendicularly to the magnetic field and horizontally to the pan of the balance. The length of the wire between the poles is 3.45 cm.



When a direct current of 3.2 A is passed through the rod from P to Q, the reading on the digital balance increases by 2.69 grams.

(a) Identify and explain the polarity of the magnet at pole X. **2**

(b) Calculate the magnetic field strength between the poles of the magnet. **3**

a) When current flows from P to Q, the force on the magnet is downwards as the reading on the balance increases. Given the perpendicular relationship between the direciton of the magnetic field, current and force, the magnetic field lines are directed away from pole X, making it the **north pole** of the magnet.

b) Force on the rod is calculated using balance reading:
F = mg = $2.69(10^{-3})(9.8)$ = 0.026 N
Magnetic field strength is calculated using F= BILsinθ:

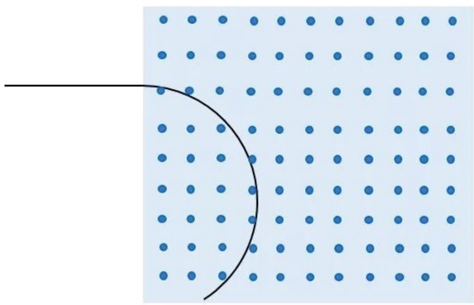
$$B = \frac{F}{ILsin\theta} = \frac{0.026362}{\sin 90(3.2)(0.0345)} = 0.24\,T\,(2\,sf)$$

Magnetic braking has advantages over conventional friction braking. However, the conservation of energy applies to both.
Describe how magnetic braking works and how the conservation of energy applies.

6 marks

- Magnetic braking utilises a strong source of a magnetic field (i.e. electromagnets) to induce eddy currents.
- One application is the electromagnets being placed either side of a spinning metal disc. The disc is a part of a rotating axle on a vehicle such as a train or car.
- As an area of the disc comes towards the electromagnets, **induced eddy currents** due to the increasing flux through the disc flow in such a direction such that the magnetic field they generate **opposes** the magnetic field from the electromagnets.
- As the same area of the disc moves away from the electromagnets, the eddy currents reverse and the magnetic fields attract. In both ways, the force on the disc opposes its rotation.
- Complying with the conservation of energy, the eddy currents produce heat due to heating in the disc.
- This heating comes from a loss of kinetic energy from the wheels. This heat can be dissipated more easily than in friction brakes as there is nothing in physical contact with the disc to hinder this.

The path followed by a positive ion entering a uniform magnetic field is shown in the figure below.



Positive ions travelling with the same velocity enter a uniform magnetic field initially at right angles to the field.

a) If two of the ions have equal masses but different charges, identify whether the ion with a smaller or larger positive charge will move in a path with a larger radius. Justify your identification.

3

b) If a positive ion is travelling with a velocity of 5.0×10^{7} m s^{-1} and the magnetic field is of intensity 3.5×10^{-3} T, determine the magnitude of the force per unit charge acting on the ion.

2

a) The force on a particle with charge q, enetering the magnetic field B with a velocity v is determined by F= Bqv. But if the charge is doubled, then the force becomes F=2Bqv. Since both charges have a common velocity at entry into the magnetic field, the force on the ion with the larger charge is twice as big. This force $F_c = \frac{mv^2}{r}$ is applied on the charged ions giving them a centripetal-like motion as it is applied at 90 degrees to the velocity direction at any time.
If the centripetal force experienced by the ion with the larger charged particle is doubled (yet the mass is almost constant for both ions as electron has only a small mass) and since the velocities are kept constant, the radius of the motion must be halved. Hence, the ion with the larger charge will have the smaller radius motion in the magnetic field.

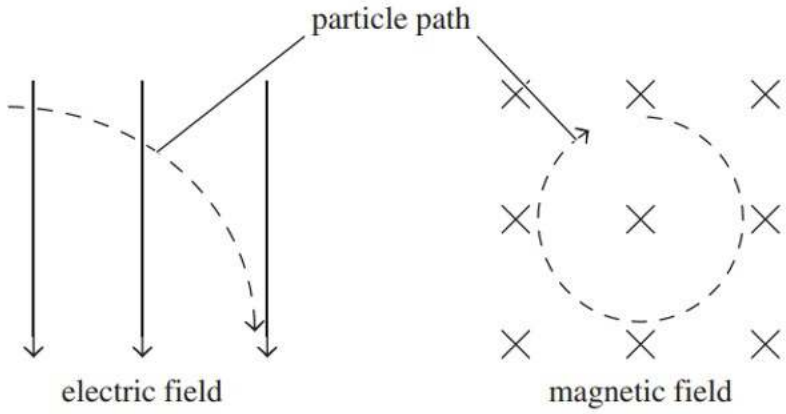
b) $\frac{F}{q} = Bv = 5*10^7 (3.5)(10^{-3}) = 175000\, N C^{-1}$

Compare the effects of electric and magnetic fields on a charged particle if the particle is initially moving perpendicular to the fields. Support your answer with a labelled diagram showing each field.

4 marks

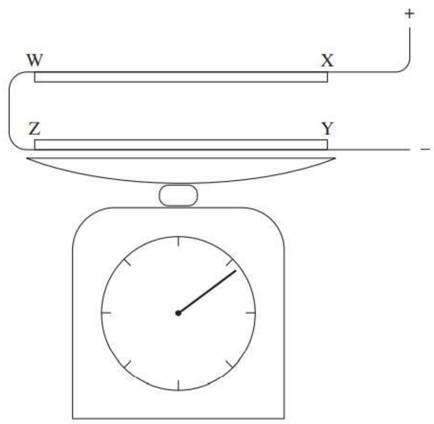
- Both electric and magnetic fields exert force on a charged particle.
- The difference between the effect that electric and magnetic fields have on a charged particle has to do with the particle's trajectory.
- An electric field exerts a force on a charged particle that is directed in the same direction as the field.
- A magnetic field exerts a force moving across the field, so the force will be directed perpendicularly to the field and the velocity of the charged particle.

- This will result in the direct trajectories; an electric field will produce a parabolic trajectory, whereas a magnetic field will produce a circular trajectory. This is shown in the following diagrams.



Question 33 (4 marks)

A teacher demonstrates the forces on two parallel identical copper conductors, as shown in the diagram. **4**



The top conductor WX is fixed, while the bottom conductor ZY lies on top of a balance. The distance between the conductors is 5 mm, and each conductor is 29 cm in length. Initially, the balance reads 4.5 grams for conductor ZY. When the current is switched on, the teacher records a reading of 4.56 grams.

Calculate the magnitude of the current.

$$force\ of\ repulsion = mg = 0.06\left(10^{-3}\right)\left(9.8\right) = 5.88 * 10^{-4}\ N$$

$$\frac{F}{l} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r},\ I = \sqrt{\frac{F\left(2\pi r\right)}{l\left(\mu_0\right)}}$$

Since the current is the same for both conductors, the magnitude of the current will be:

$$I = \sqrt{\frac{5.88\left(10^{-4}\right)\left(2\pi\right)\left(5.00\right)\left(10^{-3}\right)}{29.0\left(10^{-2}\right)\left(4\pi\right)\left(10^{-7}\right)}} = 7.12\ A$$

Assess the use of models in physics. In your answer, refer to the ideal transformer model and ONE other model.

6 marks

- Physics seeks to provide an accurate understanding of how the Universe works. Models help us to do this by allowing us to predict the outcome of specific situations. For example, the ideal transformer model allows us to predict the voltage supplied to the secondary circuit given the primary voltage and the number of turns in the coils.
- Similarly, Newton's equations of motion allow us to predict the maximum height, time of flight, range and final velocity of a projectile.
- However, models will often sacrifice accuracy for simpicity.
- The secdonary voltage in a transformer is less than what the ideal transformer model rpedicts because no allowance is made for resistive heat production.
- Also, when Newton's equations of motion are used to predict a projectile's trajectory, it is assumed that air resistance is zero, which it is usually not.
- Therefore, moels are very useful in helping us to understand the real world as long as we understand the limitations of the models we are using.

Mod 7

Q7
Discuss how the characteristics of distant stars can be determined by analysing their electromagnetic spectrum.

8 marks

Key features of stellar spectra are indicative of key characteristics.

- The surface temperature of a star is linked to the characteristic wavelength of its spectrum
- by Wein's Law, $\lambda_{max} = \frac{b}{T}$.
- The translational/rotational motion of a star can be inferred from any red/blue shift in its spectrum.
- The Doppler Effect causes blue shift for things moving towards us, and red shift for things moving away, so the motion of a star can be calculated from these frequency shifts.
- The chemical composition of the star can be determined based on the location of the spectral lines,
- since these lines are dependent on the emission/absorption spectra of the elements in the star.
- The density of a star is also linked to these spectral lines, but to their strength/width.
- The denser the star, the more of the element there will be, so the stronger its spectral lines will be.

Q6
In the 17th century, Isaac Newton and Christiaan Huygens proposed conflicting theories for the nature of light. Explain the evidence supporting each theory, and explain why one eventually prevailed.

8 marks

- Newton proposed a particle model of light
- while Huygen's proposed a wave model.
- Newton's particle model was supported because light didn't appear to require a medium, and waves were thought to need a medium to propagate through.
- Light also travels in straight lines, which is easily explainable with a particle model.
- Newton was also able to explain behaviour we typically associate with waves (like reflection) with his model.
- The evidence for Huygen's model included the partial reflection/refraction of light crossing a boundary, a behaviour which is exhibited by mechanical waves.
- The double slit experiment became the reason why the wave model prevailed. A particle model couldn't explain the observed interference patterns, which are easily explainable with a wave model.
- Thus, Huygen's model prevailed over Newton's

Q7

Explain how the inability of the wave model of light to explain certain phenomena led to the development of quantum physics.

9 marks

- The wave model of light was unable to explain the ultraviolet catastrophe.
- The classical wave model predicted that the intensity of black body radiation would tend to infinity at high frequencies,
- violating the conservation of energy.
- Planck resolved this by considering that radiation was only emitted in discrete packets, called ‘quanta’,
- each with energy E=hf. Associating these quanta with energy differences in atoms resolved the catastrophe.
- The theory was expanded on by Einstein in his particle model of light, which was proposed to explain the photoelectric effect.
- The emission of photoelectrons from metals, and the dependence of their kinetic energy on frequency rather than intensity of the radiation, violated the classical wave model.
- By considering energy per photon as E=hf and that each electron gained its energy from a single photon, the effect could be explained.
- Einstein and Planck’s work with quanta as the basis for quantum physics.

Q34
Outline the contribution of James Maxwell to our understanding of the nature of light and describe the experimental evidence found afterwards that supported Maxwell’s theory.
6 marks

- Maxwell predicted the existence of EM waves by combining the work of Faraday and Oersted, deducing that a moving charge would induce a changing electric field which would induce a changing magnetic field, inducing a changing electric field and so on (diagram encouraged).
- Hertz proved the existence of EM waves using radio waves (diagram encouraged)
- Maxwell then combined the work of Oersted and Faraday to derive the speed of EM

waves ($c=\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$), which was equal to the speed of light which had been experimentally measured, thus predicting that light was an electromagnetic wave.

- Hertz confirmed the speed of EM waves experimentally. Hertz used $c=f\lambda$, to find $c=3*10^8 m s^{-1}=\frac{1}{\sqrt{\mu_0 \varepsilon_0}}$.
- Maxwell predicted that light was part of a spectrum of EM waves with different wavelengths and frequencies but same speed in a vacuum.
- Hertz then confirmed this through his experiments with radio waves being an example of an EM wave with a different wavelength to light.

Question 30 (9 marks)

Explain how new evidence over time necessitated change in the model of light.

9 marks

- Isaac Newton's **particle model of light** described light made of corpuscles which varied in size depending on the colour of the light.
- In the 18th century, Young's double slit experiment showed that light diffracts when passing through a slit. This was evident in the interference patterns produce which are consistent with wave nature.
- This supported a **wave model of light** and thus Newton's particle model was replaced with the classical wave model.
- In the 19th century the photo-electric effect was observed and was not explainable using the classical model of light. The photo-electric effect is the emission of electrons from a metal when light above a certain frequency is incident upon the metal.
- A classical model would suggest that intensity, not frequency, is relate to electron ejection. Also, electron emission was almost spontaneous, where the classical wave model would predict that emission should occur after some time so as to allow energy to build up.
- In 1905, Albert Einstein was able to explain the photo-electric effect by using a particle model of light, where light was made up of packets of energy called photons.
- These photons would collide with electrons and would eject the electrons if they possessed enough energy, where energy is proportional to frequency (E=hf).
- The new evidence supported the particle model of light but since a wave model was

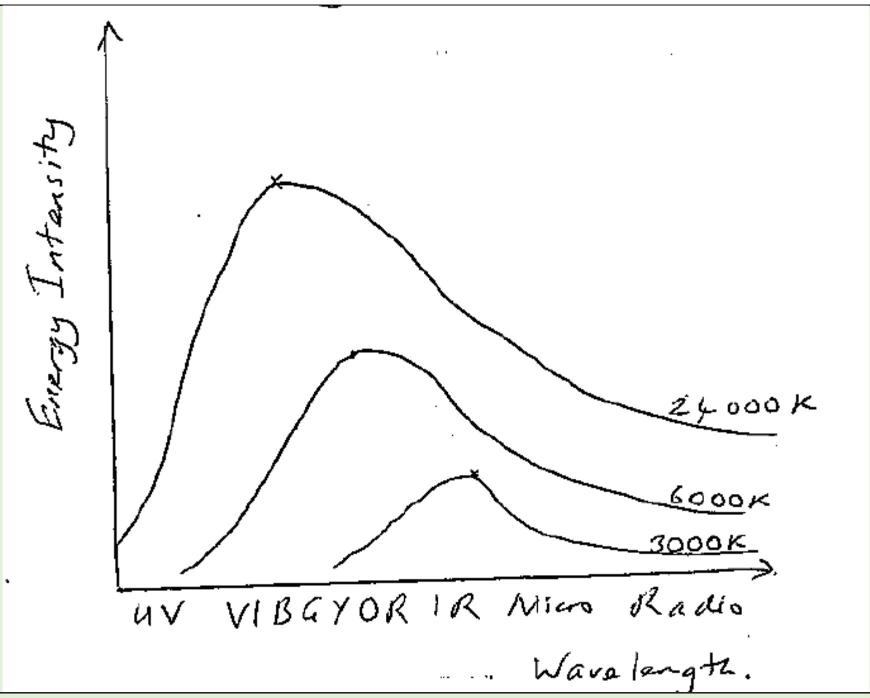
appropriate to describe other light phenomenon, such as diffraction, a new **particle-wave model** was adopted. This model indicates that light can behave as both a particle and a wave depending on the scenario.

- Thus, over time the emergence of new evidence regarding the nature of light has forced the scientific community to continually reassess the model of light.

Discuss the radiation emitted by hot bodies at specific temperatures and how this relates to the stars.
Illustrate your answer with a fully labelled graphical diagram.

4 marks

- **Dominant** wavelength of radiation is lower temperature increases.
- Stars are near ideal black bodies [or similar informative statement relevant to radiation from stars and black body radiation]
- 2 marks for correct graph:



Outline a procedure that could be used to perform an investigation in a school laboratory to verify Malus's Law.
Include any relevant diagrams.

5 marks

Malus's Law states that the intensity of polarised light, I_o, after it has passed through another polarising filter where the angles between the two polarisers is θ becomes $I = I_o \cos^2\theta$. A procedure that verifies this relationship is:

1. Obtain a source of polarised light – e.g. a laptop screen with a blank, white page.
2. Use a piece of polarised material and check the orientation of the source light so that maximum light passes through.
3. Using sticky tape, attach the polarising material so that it covers the light sensor on the front of a smartphone.
4. Install Physics Toolbox Suite (or similar) that can record the inclination of the phone and the light intensity.
5. Holding the phone at a constant distance from the polarised light source, record the illuminance (light intensity) as the phone's inclination is varied from 0° through to 90° from the polarised light source.
6. Record the results in a table, with 2 extra columns for cosθ and then $\cos^2\theta$.
7. Plot the light intensity, I, against the square of cosθ (i.e. $\cos^2\theta$). The gradient of the line of best fit is a value of the original light intensity, I_o.

(Appropriate diagram or sketch of phone with polarised material, laptop and inclination angle θ should be included).

Analyse how atomic clocks have been able to verify time dilation as described by Einstein.

3 marks

- In 1971, a physicist Joseph Hafele and an astronomer, Richard Keating devised an investigation whereby atomic clocks were flown in commercial aircraft around the world, some from east to west, others west to east. Another set of atomic clocks remained on the ground.

- Such clocks are accurate to within several billionths of a second.
- Despite the relatively slow speeds of the aircraft, the clocks flown disagreed with the stationary clocks when they were compared. Taking into account both the more complex general relativity effects and the special relativity effects, the amount of disagreement between the clocks matched that predicted, within experimental error.

Early scientists made exhaustive efforts to accurately measure the speed of light. Explain how it is that now, the speed of light is used to define the measure of distance.

3 marks

- The speed of light in a vacuum has a fixed velocity, from which all observers can define their own length scale.
- This means that there is no need to measure the speed of light because it is defined.
- If the velocity is known, then the distance that light travels in a specific period of time is a known distance. The metre is a unit of length defined by how far light travels in a well-defined period of time.

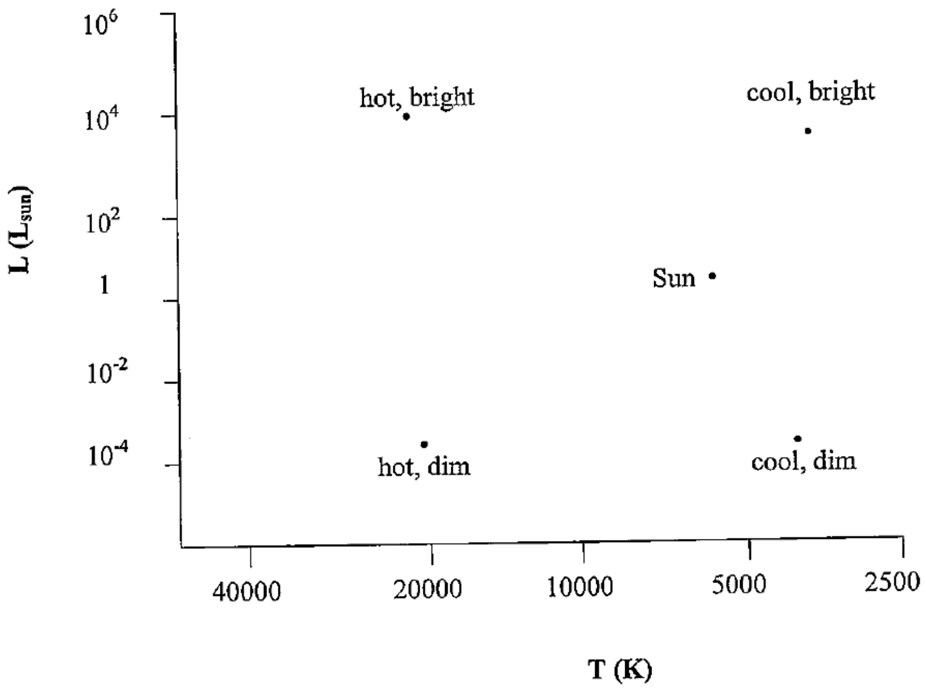
Discuss ONE historical and ONE contemporary method used to determine the speed of light.

4 marks

- In the early 1600s, Galileo attempted to discover the speed of light. He stood on a hilltop and had an assistant stand on a separate hilltop, having measured the distance between the two hills. Both participants had a lamp, and Galileo also had a timepiece. Galileo uncovered his lamp and began to keep time; when his assistant saw the light from Galileo's lamp, they uncovered their lamp. Galileo recorded the time until he saw the light from his assistant's lamp.
- By doing so, he was able to determine that the speed of light was ten times greater than the speed of sound.
- Foucault improved the calculation of the speed of light by using a similar apparatus to that used in Fizeau's method. Foucault shone a bright light through a rotating mirror that would block the light's path. Foucault observed the light hitting a plane surface 8 km away from the rotating mirror and was able to determine the speed of light based on the speed of rotation of the mirror, which periodically blocked the light from hitting the observed surface.
- His method determined the speed of light to be 298 000 kms^{-1}.

Mod 8

Max Planck, Albert Einstein, Niels Bohr, and Louis de Broglie made inspired guesses about how nature works. 'The limitations of classical physics gave birth to Quantum Physics.' With reference to TWO of these scientists, discuss TWO theories and ONE piece of evidence for this statement. 6 marks
The failure of classical Physics to adequately explain blackbody radiation, the photoelectric effect and the hydrogen atom ultimately demolished the foundations of classical Physics. • Max Planck explained the deviation of experiment to classical prediction for blackbody radiation. This is known as the UV catastrophe. • He stated that the energy of electrons comes in clumps – he named a clump of energy a quantum. • Louis de Broglie • proposed that wave-particle duality not only applied to light (as described by Einstein) but to everything in nature. De Broglie rewrote Einstein's equation. • The evidence that electrons propagate like a wave came when electrons were passed through a double slit and counted as they hit a screen. If the electrons travelled like a stream of particles, they would have simply piled up at two locations behind the two slits. But they didn't. They showed a double-slit interference pattern, bright bands and dark bands just like the ones produced by light waves. OR • Davisson and Germer experimentally confirmed de Broglie's prediction in 1927 when they bombarded the surface of a piece of nickel with electrons which were then scattered and detected by a moveable electron detector. They found the electrons were interfering with one another to produce a diffraction pattern. This evidence was ground-breaking in that it showed the limitations of classical physics in describing the nature of moving particles.
The Hertzsprung-Russell Diagram below is incomplete.



a) On the diagram, outline the area referred to as the Main Sequence.

1 mark

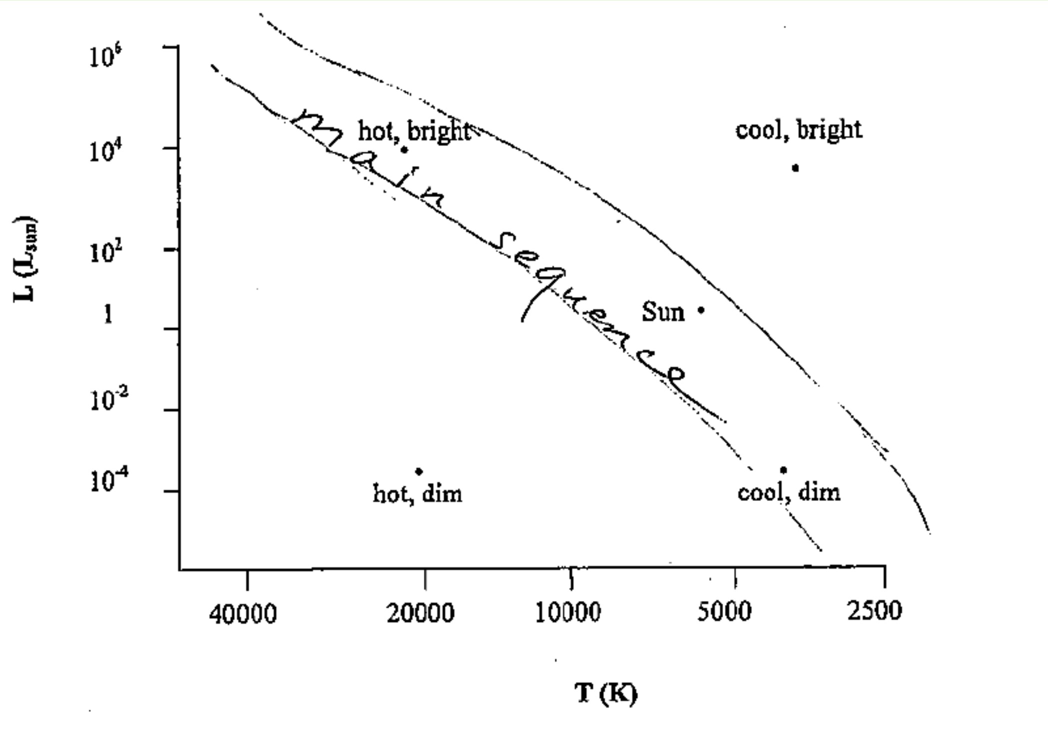
b) Identify the type of star represented as "cool, bright".

1 mark

c) Discuss use of colour to label the horizontal axis instead of temperature.

2 marks

a)

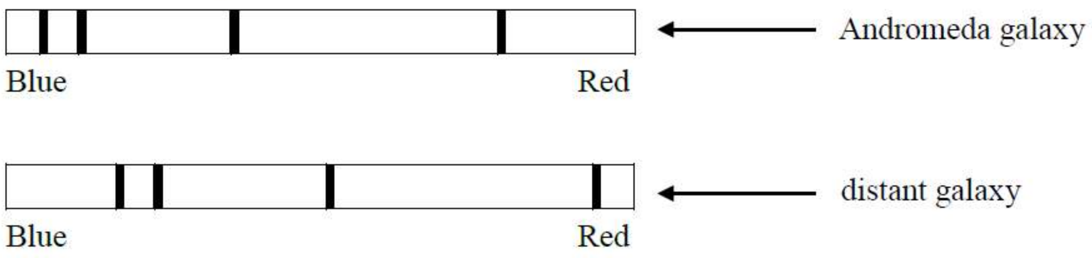


b) Red Giants

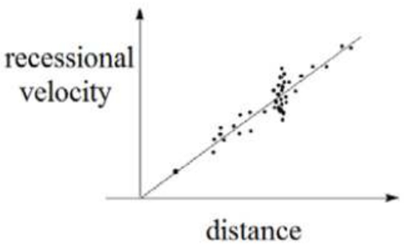
c) Temperature determines dominant wavelength and hence colour.
High temperature (left side of the graph) can be labelled as blue or blue-white.

Low temperature (right side of graph) can be labelled as red.

The absorption spectral lines for both our nearest galaxy Andromeda and a distant galaxy are shown in the absorption spectra below.



The graph below is often seen in astronomy.



Explain how both the absorption spectra and the graph can be used to support the Big Bang theory of an expanding universe.

5 marks

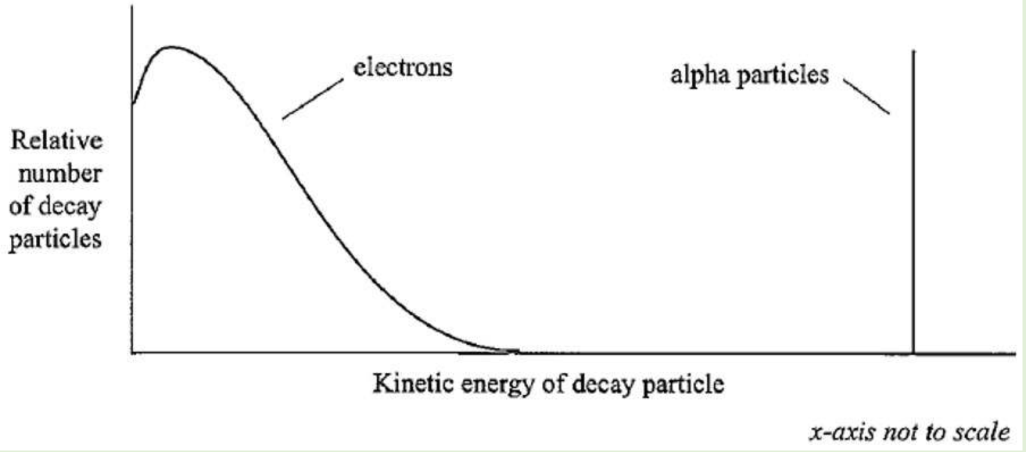
- The shift in the wavelengths of the absorption spectral lines towards the red end of the spectrum indicates
- the distant galaxy is moving away.
- From the v-d graph, it can be seen that the further away the galaxies are, the faster they are receding away
- which indicates that the universe is expanding.
- By reversing this expansion trend, a singularity is obtained, which implies that this expansion started from a point.

With reference to the Hertzsprung-Russell diagram, describe the life-cycle of a star like the Sun.

4 marks

- Main sequence → Red Giant → White dwarf (3 marks)
- A labelled diagram

The graph below compares the kinetic energy of alpha decay in platinum-190 and beta decay in cobalt-60 particles with respect to the relative number of decay particles with these energies.



Account for the differences in energies of these alpha and beta radioactive decay particles.

7 marks

- Radioactive decay is an exothermic process that produces energy according to the law of conservation of mass-energy. Unstable nuclei release particles from the nucleus with a kinetic energy associated with their mass and velocity ($E=1/2\ mv^2$).
- Alpha particles are helium nuclei containing two protons and two neutrons, while the beta particle shown on the graph is an electron.

- Alpha particles, therefore, have about 7000 times the mass of electrons and, therefore, significantly more kinetic energy. This feature is shown on the graph with alpha particles having much more kinetic energy than even the maximum kinetic energy of the beta particles.
- The other difference shown on the graph also relates to kinetic energy. All alpha particles are emitted with the same kinetic energy while beta particles are shown to have a range of kinetic energies.
- Every alpha emission produces the same helium nucleus with the same mass and speed, shown by a single vertical line on the graph indicating that all alpha particles are emitted with the same kinetic energy.
- In beta decay, two particles are produced: an electron and an antineutrino. While the antineutrino has an imperceptibly small mass compared with the electron, these particles are emitted at significant speeds. In each decay, the energy released from the nucleus as lost mass is the same, however, the kinetic energy carried by the decay particles can be apportioned differently.
- Since the graph shows only electrons (and not antineutrinos), a range of kinetic energies is observed. If the graph were to show the combined energy of electrons and antineutrinos, it would look the same as the line of alpha particles, however, the line would occur at a much lower kinetic energy.

a) Assess the limitations of the Rutherford and Bohr atomic model.

6 marks

b) Rutherford and Bohr's model of the atom is sometime referred to as 'classical physics'. Explain why Schrodinger's quantum mechanics improved our understanding of the model of the atom.

2 marks

a)

Rutherford's model of the atom was superior in the beginning: however, it has many limitations, including:

- An inability to explain the nucleus:
- An uncertainty on how to place the electrons around the dense region that is now known as the nucleus, and;
- An uncertainty on why the electrons orbiting the nucleus did not slow down and crash into each other

Later, Niels Bohr created a model of the atom that improved Rutherford's model. Overtime, Bohr's model of the atom also had limitations which include:

- An inability to predict the spectra of multi-electron atoms, and;
- An inability to explain the different intensities of lines or why some lines split into multiple, closely spaced lines.

b)

- Schrodinger's model of the atom was developed mathematically and the equations that he used could explain the probability or the certainty of a quantum event or quantum position in quantum mechanics.
- This improved the model of the atom from Bohr's model, as Schrodinger identified that the electrons were orbiting the nucleus within probability clouds and not fixed positions within the shell.

Describe one experiment conducted by a scientist that provided support for the existence of the electron and its properties.

3 marks

- Thomson's plum pudding model of the atom using cathode ray tubes.
- Thomson's charge-to-mass ratio experiment
- Millikan's oil drop experiment
- Eg
- Robert Millikan created an oil drop experiment to measure the charge of the electron.
- Millikan's apparatus comprised two metal electric plates within a container of water. Millikan sprayed oil drops within the container of water and applied a potential difference between the two plates to suspend the oil between them.
- This meant that the oil drop was balanced between the electrostatic and gravitational forces, and from this Millikan used $q_E = mg$ to determine that the charge on a drop was a multiple of 1.6×10^{19} C.

Outline the roles played by the four fundamental forces of nature and identify their respective bosons.

6 marks

- Gravitational force – acts over large distances between objects with mass, governed by $F = \frac{GMm}{r^2}$. Mediated by the hypothesized graviton.
- Electromagnetic force – forces between charged particles and between magnets, as well as the force on moving charges within a magnetic field. Mediated by the photon.
- Strong nuclear force: attractive force between nucleons (protons and neutrons) over very short distances that overcomes the electromagnetic force between protons in nuclei. Mediated by the gluon.
- Weak nuclear force: the force between nucleons, again acting only over very short distances such as those between these particles, responsible for beta decay. Mediated by the intermediate vector bosons (W and Z bosons).

Explain how the properties of stars can be determined from their spectra.

6 marks

- Composition
    - Absorption spectrum: When white light is passed through a gas, specific discrete wavelengths of light are absorbed depending on the composition of the gas. Each element has a specific pattern of spectra lines (wavelengths of light that are absorbed) and if this pattern is found in the spectrum of the star, then the surface of the star contains that element.
- Surface temperature
    - Blackbody radiation: Objects emit a continuous spectrum of light that depends on the temperature of the object. The wavelength where the peak intensity occurs can be used to calculate the surface temperature of the object (Wien's law $T = \frac{b}{\lambda_{max}}$). Stars are close to ideal blackbody radiators and by matching their spectra to a blackbody their surface temperature can be determined. (Surface temperature can also be determined by spectral class – the Relative intensity of spectral lines can also be used based on the ionisation the elements at the stars surface)
- Surface density:
    - Spectral line broadening: Stars with a higher density exhibit spectral broadening where the width (range of wavelengths) of absorption spectral lines is increased
- Radial velocity:
    - Doppler effect: When light is emitted from a moving object then the frequency of the light is shifted. (the velocity is always constant according to Einstein's 2nd postulate). An approaching object emitting light is catching up to the light that it is emitting so the distance between waves is shorter (shorter wavelength, higher frequency means the light is shifted towards the blue). Conversely a receding object's light will be red-shifted. The amount of shift can be used to find the objects velocity. Spectral lines occur at fixed wavelengths, so if a characteristic pattern is found to be shifted from where it should be then the objects radial velocity can be determined
- Rotational velocity
    - Spectral line broadening: A rotating star will blue-shift the light from the side that is approaching and red-shift the light from the side receding. This has the effect of broadening the range of wavelengths that a spectral line will be measured. If light can be sampled from either side independently, then this is an easier measurement.
- Comprehensive and concise explanation of at least 4 properties

Question 6

Explain two nucleosynthesis reactions which produce energy in stars.

8 marks

Proton-proton chain:

- Proton-proton chain reactions involve the fusion of protons.
- 2 marks: Two protons fuse into deuterium, and a third then fuses to form He-3. Combining two He-3 isotopes into He-4 releases two proteins, and the reaction continues. This fusion reaction process releases energy and is common in smaller stars. (or equations)

$$H_1^1 + H_1^1 \rightarrow H_1^2 + \bar{e}_1^0 + \nu_0^0$$

$$H_1^2 + H_1^1 \rightarrow He_2^3 + \gamma_0^0$$

$$He_2^3 + He_2^3 \rightarrow He_2^4 + H_1^1 + H_1^1$$

CNO cycle

- Carbon-nitrogen-oxygen reactions are more common in larger stars.
- 2 marks: A carbon-12 isotope fuses with two protons to yield Nitrogen-14. Nitrogen-14 then fuses with two more protons, briefly forming oxygen which quickly decays to a helium nucleus and carbon-12, with which the process repeats. (or equations)
- For both of these reactions, the fusion of lighter elements into heavier ones releases energy from the excess binding energy of the reactants.
- Larger and hotter stars are able to fuse the helium products of these reactions into carbon via the triple alpha process, and carbon into even heavier elements.

$$^{12}_{6}C + ^{1}_{1}H \rightarrow ^{13}_{7}N + \gamma$$

$$^{13}_{7}N \rightarrow ^{13}_{6}C + e^{+} + \nu_e$$

$$^{13}_{6}C + ^{1}_{1}H \rightarrow ^{14}_{7}N + \gamma$$

$$^{14}_{7}N + ^{1}_{1}H \rightarrow ^{15}_{8}O + \gamma$$

$$^{15}_{8}O \rightarrow ^{15}_{7}N + e^{+} + \nu_e$$

$$^{15}_{7}N + ^{1}_{1}H \rightarrow ^{12}_{6}C + ^{4}_{2}He$$

Analyse the evidence that led to the discovery of the expansion of the Universe.

9 marks

- Analysis of the ratio of light elements in the early universe, led scientists to conclude that H:He were formed in a 3:1 ratio

- Which George Gamow was able to explain using an expanding universe model.
- Hubble observed the stellar spectra of spiral nebulae.
- Using luminosity-distance relationships, he found that the further away a galaxy was, the more red-shifted its spectral lines were, due to an optical doppler effect.
- This red-shifting occurred because these galaxies were receding from the observer, with a larger red-shift indicating a faster recession velocity. This was only possible if the universe was expanding.
- Additionally, Penzias and Wilson discovered cosmic microwave background radiation (CMBR).
- CMBR is a remnant of the photon decoupling era that occurred during the formation of the early universe
- and thus would not be present in a steady state or static universe model.
- Therefore, the combination of the evidence outlined above helped Hubble discover the expansion of the Universe.

Explain how stars are responsible for forming most of the elements on the periodic table.

8 marks

- New elements are formed through nuclear fusion reactions
- in a process called nucleosynthesis.
- During their lives on the main sequence, stars like the Sun form helium.
- Stars like the Sun form helium from hydrogen via a process called the proton-proton chain)
- whereas stars with 1.3 times the mass of the Sun form helium from hydrogen via a faster process called the Carbon-Nitrogen-Oxygen cycle.
- When main sequence stars become a red giant they form elements like carbon, nitrogen and oxygen.
- Larger stars form elements up to iron while they are giants.
- Elements heavier than iron are formed when giant stars explode as a supernova.

Explain the significance of the Geiger-Marsden experiment.

8 marks

- Diagram
- Explanation of diagram: alpha particles were fired at a thin sheet of gold foil. These alpha particles were detected after passing through the gold foil.
- 2 observations: most alpha particles pass through undeflected. Very few particles (1/8000) deflect through angles of greater than 90 degrees.
- These observations could not be explained by Thomson's plum pudding model of the atom (+ explain plum pudding model of atom)
- 2 inferences: the atom is made of mostly empty space. Most of the mass of the atom is located at the centre of the atom, in a small, dense and positively charged sphere
- Significance: GM experiment helped Rutherford create a new model of the atom, called the planetary model of the atom. This was an improvement upon the previous model of the atom by Thomson.

Analyse Chadwick's contributions to the model of the atom.

6 marks

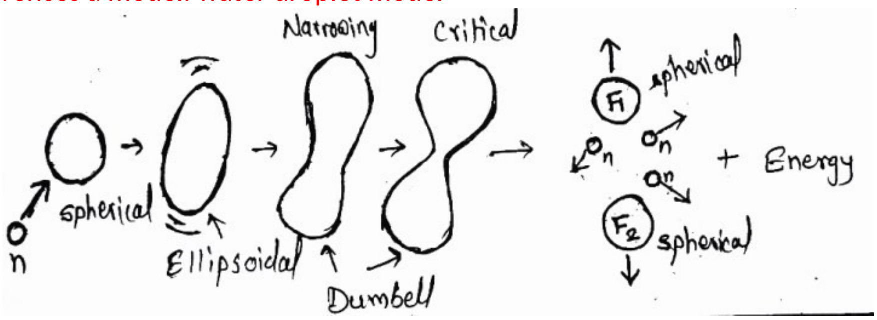
- Contributions: Chadwick discovered the neutron and changed the model of the atom so that the nucleus of atoms contained neutrons and protons.
- This is more detailed than the previous model of the atom, which said that the nucleus was positively charged.
- Diagram of experimental set up
- Explanation of method: alpha particles bombarded Beryllium and ejected an unknown radiation that was highly penetrating. This unknown radiation bombarded paraffin wax and ejected protons which could be detected.
- Explanation of the role of conservation of energy (with numbers)
- Explanation of the role of conservation of momentum

"Scientific progress typically builds on the successes and limitations of previous ideas"
Discuss this statement with reference to the work of Rutherford, Bohr and de Broglie in furthering our understanding of atomic structure.

9 marks

• Rutherford's alpha scattering experiments led him to propose that the mass of the atom was concentrated in a central small, dense and positively charged nucleus. Most of the rest of the atom was empty space, with negative electrons orbiting the nucleus in circular orbits. • Rutherford's model successfully explained the alpha scattering data and was thus an improvement of JJ Thompson's 'Plum pudding' model, which lacked a central nucleus. • However, it did not explain the hydrogen emission spectral lines, nor did it explain why the electrons did not spiral into the nucleus, emitting EMR as they did so, thus leading to the collapse of the atom. • Bohr built on Rutherford's ideas, by keeping the concept of a positive nucleus surrounded by orbiting electrons. He said electrons existed in stationary states where they are able to orbit the nucleus without emitting EMR. • He also explained the hydrogen spectral lines were due to electrons dropping from a higher stationary state to a lower one. • However, it lacked a mechanism for explaining why the stationary states existed. • De Broglie was able to explain why Bohr's stationary states existed. To do this, he considered the electron as a wave (and his equation of $\lambda = \frac{h}{mv}$ assigned electrons a tiny yet measurable wavelength), and not just as a particle. This led to the wave-particle model for matter. • In de Broglie's model, the electrons formed standing waves in their orbits, and as standing waves, they did not radiate energy, thus remaining stable. • Direct experimental evidence for de Broglie's ideas came from Davisson and Germer who observed electron diffraction, which is a defining property of waves.
Use a model to explain the process of nuclear fission and apply the concept of nuclear fission to controlled and uncontrolled chain reactions. 9 marks

- Define nuclear fission: the splitting of a larger nuclei into two or more smaller daughter nuclei
- Accompanied by the release of energy by $E=mc^2$
- References a model: water droplet model



- Uncontrolled chain reaction:
  - Neutron instigates nuclear fission, creating 3 more neutrons which each go on to instigate their own fission events at an exponential rate.
  - Large and often uncontrollable amounts of energy is released in the process much like in atomic bombs
- Controlled chain reaction
  - One neutron instigates one fission event each time
  - Energy is created and can be harnessed in nuclear reactors
  - Control rods made of cadmium and boron are used to absorb excess neutrons
  - Moderators such as heavy water and lead are used to slow neutrons to thermal speeds so that fission may be more efficiency instigated
- At least one nuclear equation
- At least one diagram

Explain the standard model of matter, with reference to the various classifications of fundamental particles.

9 marks

- The SM consists of two main groups of particles – fermions and bosons.
- Fermions are the building blocks of matter.
- Some (quarks) must bind together to form particles called hadrons (including protons and neutrons).
- Others, the leptons, can exist by themselves, such as the electron, muon, tau and neutrino particles. All of these fermions have mass and constitute our comprehension of “matter”.
- Bosons, instead, are “carrier” particles which interact with fermions to dictate fundamental forces of nature.
- There are two types of bosons:
- there are four vector bosons; the photon, gluon, W and Z bosons.
- These dictate the electromagnetic strong nuclear and weak nuclear forces – which are all vector quantities.
- There is one scalar boson, the Higgs Boson – which interacts with fermions to give them their mass. These are the classifications in the SM.

Explain the debate that surrounded the nature of cathode rays.

8 marks

- The essence of the debate was disagreement over the nature of cathode rays and whether they were waves or particles.
- 3 pieces of evidence for waves
- 3 pieces of evidence for particles
- The debate was eventually settled when Thomson showed that cathode rays could be deflected by electric fields, confirming that cathode rays are negatively charged particles.

Explain de Broglie's contribution to the model of the atom and the experimental evidence that supported him.

7 marks

- Matter wave hypothesis: **moving** particles have a wave-like nature
- Matter wave equation
- Significance of matter wave hypothesis: explained stable stationary states in Bohr's model of the atom which do not radiate energy (reference to Bohr's first postulate)
- Constructive interference creates standing waves which are stationary states where energy is not being emitted
- Only circumferences that were integer multiples of the wavelength of the electron could form these stationary states (equation or diagram)

- Derivation of quantised angular momentum expression from Bohr's postulates

$$L = mvr = \frac{hr}{\lambda} = \frac{hr}{\left[\frac{2\pi r}{n}\right]} = \frac{nh}{2\pi}$$

Experimental evidence:

- Davisson and Germer experiment or x-ray diffraction patterns

Analyse the evidence that suggests that there are other subatomic particles aside from protons, neutrons and electrons.

6 marks

- 2 marks each: observation + conclusion
- Beta decay: electron neutrinos were discovered after analysing the kinetic energy of beta particles
- Neutrons, although neutral, have a magnetic moment, which suggests that they are composed of smaller subatomic particles that are charged.
- Deep inelastic scattering experiments showed that protons and neutrons deflected electrons as if there were three point sources of mass within them.
- Other things to mention:
  - Cosmic ray experiments led to the discovery of the muon, mesons, kaon and lambda
  - The role of particle accelerators: studied high-energy collisions caused the discovery of new hadrons

Using examples, analyse the role of particle accelerators in validating theories. Reference the Standard Model of matter in your answer.

9 marks

- Particle accelerators collide particles and identify all the products and measure their properties such as mass, charge, energy and momentum.
- Particle accelerators have been used to discover many new particles and interactions that theorists have had to explain. The predictions of these new theories can then be tested using accelerators and colliders.
- For example, the electroweak theory predicted the existence and properties of the W and Z bosons, which were later confirmed experimentally in accelerators. These bosons now compose the SMM.
- Additionally, the Higgs Boson was predicted to be the boson responsible for the mass of elementary particles in the 20^{th} century. The Higgs Boson was finally discovered in 2012 via the use of the Large Hadron Collider, which is a synchrotron particle accelerator. The Higgs Boson is now integral to the SMM.
- Energies at which collisions occur can also give clues about the particles produced as the mass of the particles produced can never exceed the mass equivalent ($m=E/c^2$) of the energy put into the collision.
- For example, the second and third generation quarks in the SM had significantly larger masses than first generation quarks and were not available to be studied in nature.
- Thus, particle accelerators were necessary to create collisions with enough energy to create and validate the existence of these heavier elementary particles, via $E=mc^2$, so that they may be included in the SMM.
- Particle accelerators are also integral in supporting the idea that protons and neutrons are not fundamental particles found in the SMM. In 1969, inelastic scattering experiments between electrons and protons conducted using high-energy particle accelerators indicated there were tiny, scattering centres inside protons, which supported the existence of smaller, fundamental particles which made up the SMM. (These experiments were in some ways analogous to the early scattering experiments conducted by Rutherford that implied the existence of the nucleus.)
- Thus, particle accelerators are key in validating theories, such as the SMM.

The Large Hadron Collider (LHC) is the world's largest particle accelerator, operated by the European Organisation for Nuclear Research.

a) Describe the physics principles involved in the operation of particle accelerators like the LHC.

4 marks

b) What evidence have particle accelerators like the LHC contributed to the standard model of matter?

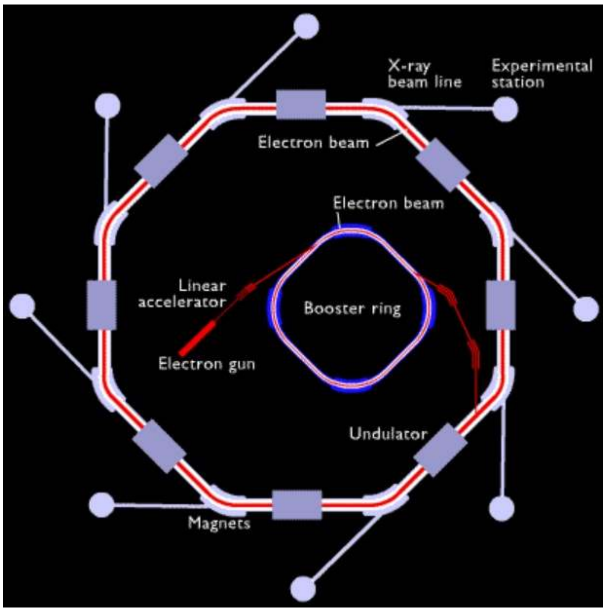
4 marks

The Large Hadron Collider (LHC) is the world's largest particle accelerator, operated by the European Organisation for Nuclear Research.

a) Describe the physics principles involved in the operation of particle accelerators like the LHC.

4 marks

- Diagram:



- Particle accelerators are designed to induce and observe high-speed particle interactions.
- A synchrotron uses electric fields to accelerate charged particles in a linear accelerator.
- The beam is then sent into a booster ring to increase in speed before being sent into the storage ring.
- Magnetic fields are used to deflect particles so that they undergo circular cyclic motion at a fixed radius.

b) What evidence have particle accelerators like the LHC contributed to the standard model of matter?

4 marks

- Particle accelerators have contributed the majority of the experimental evidence for the SM, as many aspects of the model are only observable in very specific high energy interactions.
- Accelerators confirm the behaviour of fundamental particles matches that predicted by the standard model.
- Further, components of the model are discovered and verified using accelerators.
- The Higgs boson was first observed in the LHC in 2012, and many other fundamental particles can only be studied using accelerators, thus highlighting their importance.