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Answer **all** questions in the spaces provided.

1 (a) The table gives information about some fundamental particles.

Complete the table by filling in the missing information.

particle	quark structure	charge	strangeness	baryon number
	uud		0	
Sigma $^{+}$	uus	+ 1		
	$u\bar{d}$		0	0

(7 marks)

1 (b) Each of the particles in the table has an antiparticle.

1 (b) (i) Give **one** example of a baryon particle **and** its corresponding antiparticle.

particle .....

antiparticle .....

(1 mark)

1 (b) (ii) State the quark structure of an antibaryon.

.....

(1 mark)

1 (b) (iii) Give **one** property of an antiparticle that is the same for its corresponding particle and **one** property that is different.

Same .....

.....

Different .....

.....

(2 marks)

11

2 (a) State what is meant by the specific charge of a nucleus and give an appropriate unit for this quantity.

.....

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unit: .....

(2 marks)

2 (b) Nucleus X has the same nucleon number as nucleus Y. The specific charge of X is 1.25 times greater than that of Y.

2 (b) (i) Explain, in terms of protons and neutrons, why the specific charge of X is greater than that of Y.

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(2 marks)

2 (b) (ii) Nucleus X is $^{10}_{5}B$. Deduce the number of protons and the number of neutrons in nucleus Y.

number of protons .....

number of neutrons .....

(4 marks)

8

3 (a) Pair production can occur when a photon interacts with matter. Explain the process of pair production.

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(2 marks)

3 (b) Explain why pair production cannot take place if the frequency of the photon is below a certain value.

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(3 marks)

3 (c) Energy and momentum are conserved during pair production. State **two** other quantities that must also be conserved.

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(2 marks)

7

4 (a) When free electrons collide with atoms in their *ground state*, the atoms can be excited or ionised.

4 (a) (i) State what is meant by ground state.

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(1 mark)

4 (a) (ii) Explain the difference between excitation and ionisation.

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(3 marks)

4 (b) An atom can also become excited by the absorption of photons. Explain why only photons of certain frequencies cause excitation in a particular atom.

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(4 marks)

Question 4 continues on the next page

Do not write outside the box

4 (c) The ionisation energy of hydrogen is 13.6 eV. Calculate the minimum frequency necessary for a photon to cause the ionisation of a hydrogen atom. Give your answer to an appropriate number of significant figures.

answer .....Hz

(4 marks)

12

5 (a) A student is given a piece of metal wire and asked to investigate how the resistance of the wire changes between a temperature of 0 °C and 100 °C.

5 (a) (i) Draw a labelled diagram of a suitable arrangement that would enable the student to carry out the experiment.

(3 marks)

Do not write outside the box

5 (a) (ii) Describe the procedure the student would follow in order to obtain accurate and reliable measurements of the resistance of the wire at different temperatures between 0 °C and 100 °C.

The quality of written communication will be assessed in your answer.

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(6 marks)

Question 5 continues on the next page

5 (b) A certain metal has a *critical temperature* of –268 °C (5 K). Explain what is meant by critical temperature.

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(2 marks)

11

6 **X** and **Y** are two lamps. **X** is rated at 12 V 36 W and **Y** at 4.5 V 2.0 W.

6 (a) Calculate the current in each lamp when it is operated at its correct working voltage.

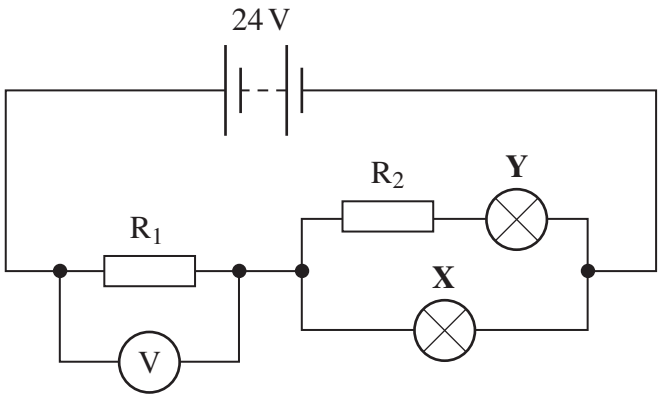
X ..... A

Y ..... A

(2 marks)

6 (b) The two lamps are connected in the circuit shown in **Figure 1**. The battery has an emf of 24 V and negligible internal resistance. The resistors, R_1 and R_2 are chosen so that the lamps are operating at their correct working voltage.

Figure 1



6 (b) (i) Calculate the pd across R_1.

answer V
(1 mark)

6 (b) (ii) Calculate the current in R_1.

answer ..... A
(1 mark)

6 (b) (iii) Calculate the resistance of R_1.

answer ..... Ω
(1 mark)

6 (b) (iv) Calculate the pd across R_2.

answer V
(1 mark)

6 (b) (v) Calculate the resistance of R_2.

answer ..... Ω
(1 mark)

Question 6 continues on the next page

6 (c) The filament of the lamp in **X** breaks and the lamp no longer conducts. It is observed that the voltmeter reading decreases and lamp **Y** glows more brightly.

6 (c) (i) Explain without calculation why the voltmeter reading decreases.

.....

.....

.....

(2 marks)

6 (c) (ii) Explain without calculation why the lamp **Y** glows more brightly.

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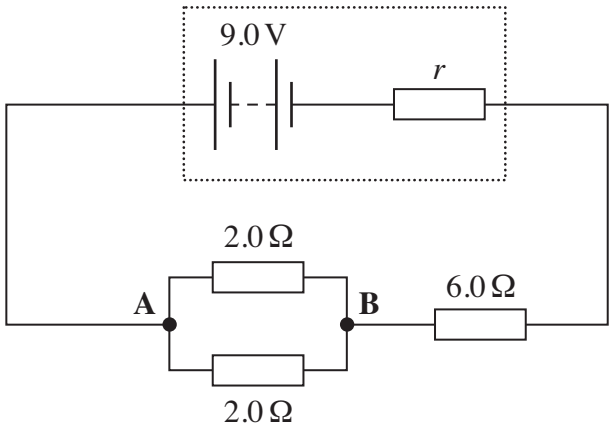
(2 marks)

11

7 A battery of emf 9.0 V and internal resistance, r, is connected in the circuit shown in **Figure 2**.

Figure 2



7 (a) The current in the battery is 1.0 A.

7 (a) (i) Calculate the pd between points **A** and **B** in the circuit.

answer = ... V
(2 marks)

7 (a) (ii) Calculate the internal resistance, *r*.

answer = ... Ω
(2 marks)

7 (a) (iii) Calculate the **total** energy transformed by the battery in 5.0 minutes.

answer = ... J
(2 marks)

7 (a) (iv) Calculate the percentage of the energy calculated in part (iii) that is dissipated in the battery in 5.0 minutes.

answer ..... %
(2 marks)

Question 7 continues on the next page

7 (b) State and explain **one** reason why it is an advantage for a rechargeable battery to have a low internal resistance.

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(2 marks)

10

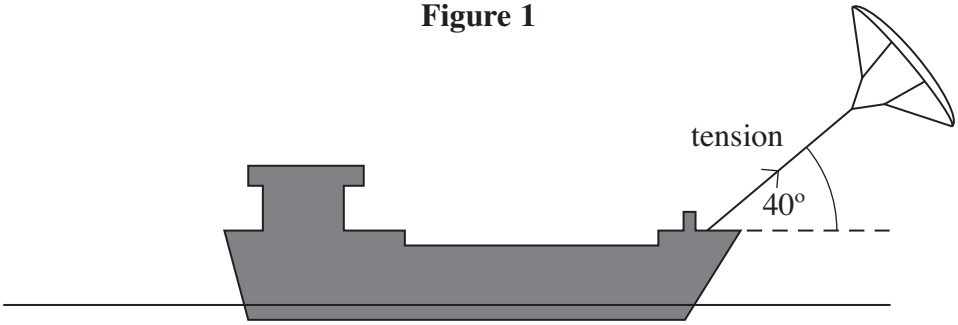
END OF QUESTIONS

Do not write outside the box

Answer **all** questions in the spaces provided.

1 Sail systems are being developed to reduce the running costs of cargo ships. The sail and ship's engines work together to power the ship. One of these sails is shown in **Figure 1** pulling at an angle of 40° to the horizontal.

Figure 1



1 (a) The average tension in the cable is 170 kN.
Show that, when the ship travels 1.0 km, the work done by the sail on the ship is 1.3×10^8 J.

(2 marks)

1 (b) With the sail and the engines operating, the ship is travelling at a steady speed of 7.0 m s^{-1}.

1 (b) (i) Calculate the power developed by the sail.

answer = ... W
(2 marks)

Do not write outside the box

1 (b) (ii) Calculate the percentage of the ship's power requirement that is provided by the wind when the ship is travelling at this speed.
The power output of the engines is 2.1 MW.

answer = ... %
(2 marks)

1 (c) The angle of the cable to the horizontal is one of the factors that affects the horizontal force exerted by the sail on the ship. State **two** other factors that would affect this force.

Factor 1 .....

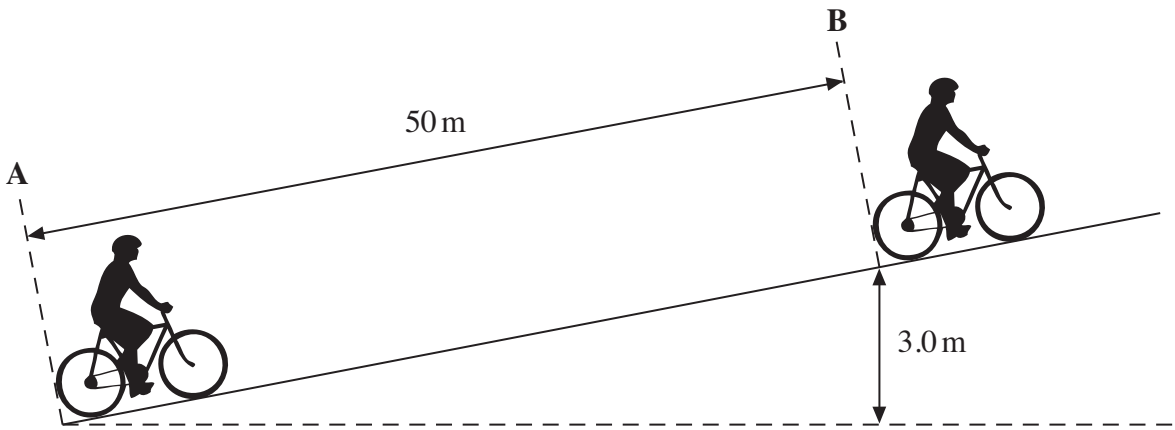
Factor 2 .....
(2 marks)

8

Turn over for the next question

2 An 'E-bike' is a bicycle that is assisted by an electric motor. **Figure 2** shows an E-bike and rider with a total mass of 83 kg moving up an incline.

Figure 2



2 (a) (i) The cyclist begins at rest at **A** and accelerates uniformly to a speed of 6.7 m s^{-1} at **B**. The distance between **A** and **B** is 50 m.
Calculate the time taken for the cyclist to travel this distance.

answer = ... s
(2 marks)

2 (a) (ii) Calculate the kinetic energy of the E-bike and rider when at **B**. Give your answer to an appropriate number of significant figures.

answer = ... J
(2 marks)

Do not write outside the box

2 (a) (iii) Calculate the gravitational potential energy gained by the E-bike and rider between **A** and **B**.

answer = ... J
(2 marks)

2 (b) Between **A** and **B**, the work done by the electric motor is 3700 J, and the work done by the cyclist pedalling is 5300 J.

2 (b) (i) Calculate the wasted energy as the cyclist travels from **A** to **B**.

answer = ... J
(2 marks)

2 (b) (ii) State **two** causes of this wasted energy.

Cause 1 .....

.....

Cause 2 .....

.....
(2 marks)

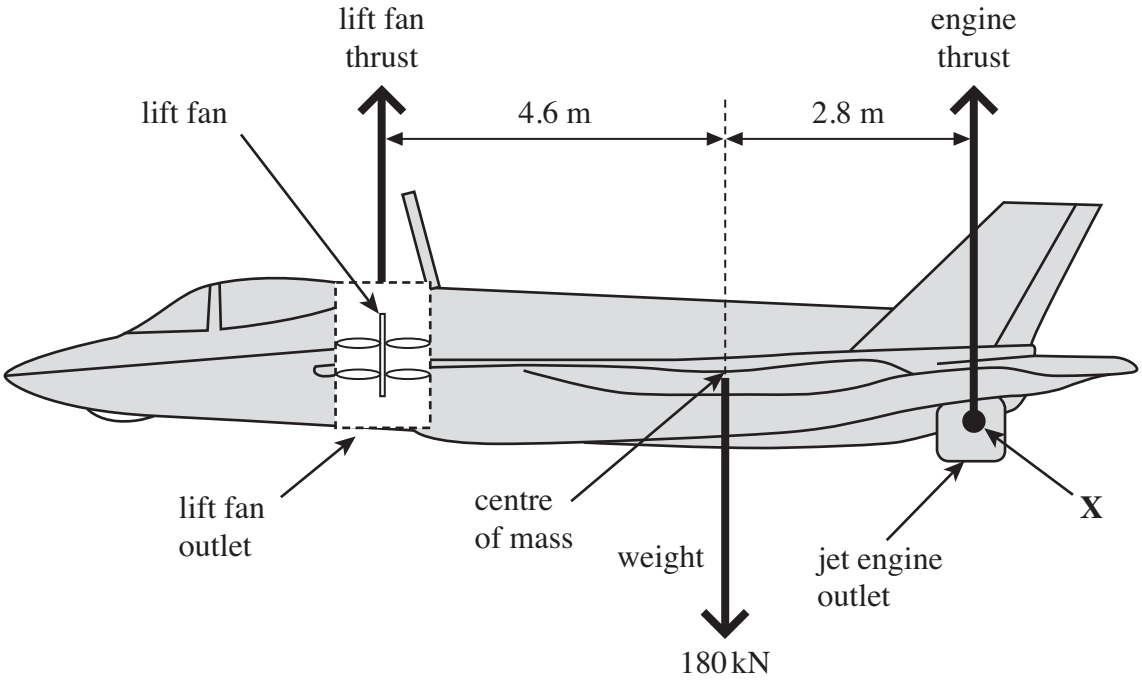
10

Turn over for the next question

Do not write outside the box

3 **Figure 3** shows an aircraft designed to take off and land vertically and also to hover without horizontal movement. In order to achieve this, upward lift is produced by directing the jet engine outlet downwards. The engine also drives a vertical lift fan near the front of the aircraft. The weight of the aircraft is 180 kN. The distance between the lift fan and the centre of mass is 4.6 m and the distance between the jet engine outlet and the centre of mass is 2.8 m.

Figure 3



3 (a) (i) Calculate the moment caused by the weight of the aircraft about the point **X**.

answer = ... N m
(2 marks)

3 (a) (ii) By taking moments about **X**, calculate the lift fan thrust if the aircraft is to remain horizontal when hovering.

answer = ... N
(3 marks)

3 (a) (iii) Calculate the engine thrust in **Figure 3**.

answer = ... N

(1 mark)

3 (b) Having taken off vertically, the jet engine outlet is turned so that the engine thrust acts horizontally. The aircraft accelerates horizontally to a maximum velocity. The forward thrust produced by the jet is 155 kN. The weight of the aircraft is 180 kN.

3 (b) (i) When the resultant horizontal force is 155 kN, calculate the horizontal acceleration of the aircraft.

answer = ... $m\,s^{-2}$

(2 marks)

3 (b) (ii) State and explain **one** characteristic of the aircraft that limits its maximum horizontal velocity.

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(2 marks)

Question 3 continues on the next page

3 (b) (iii) On the axes below, sketch the velocity-time graph for the horizontal motion of the aircraft as it accelerates from zero to its maximum horizontal velocity.

(2 marks)

3 (c) State how a velocity-time graph could be used to find the maximum acceleration.

.....

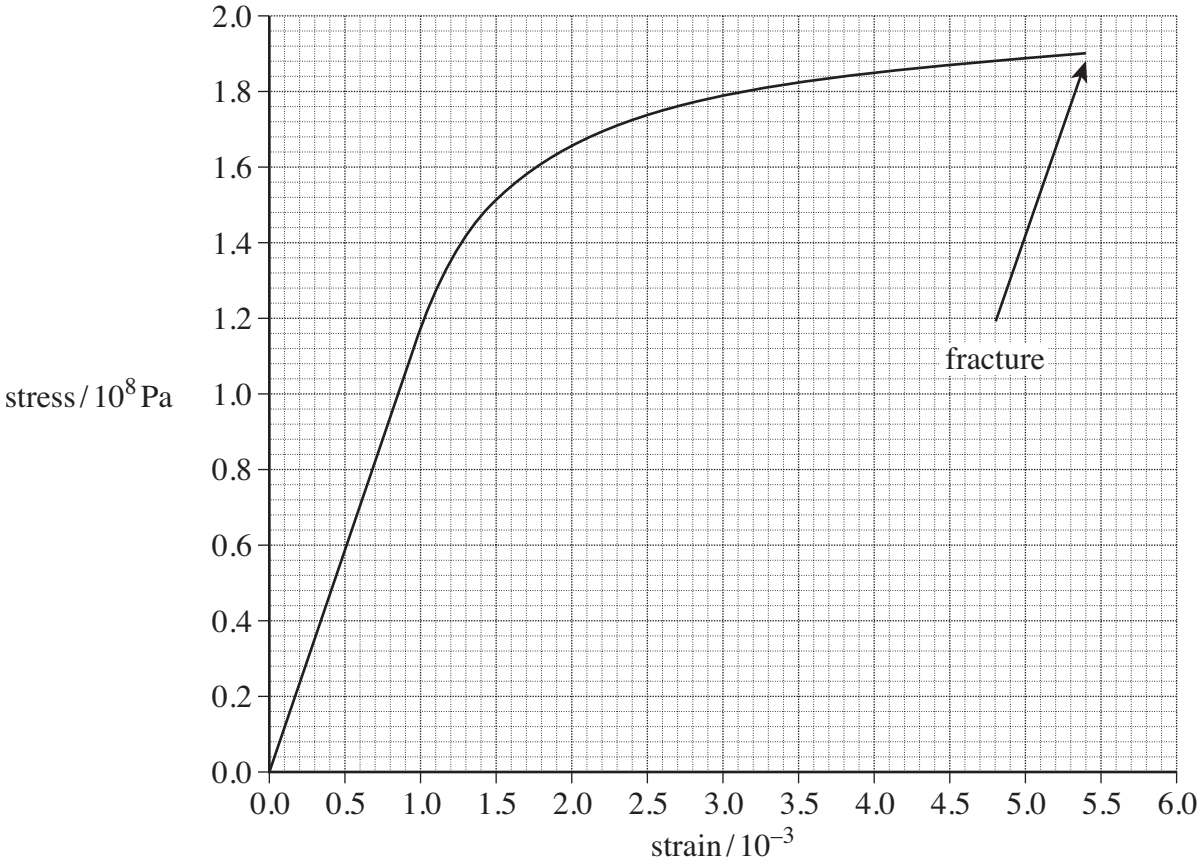
(1 mark)

13

Turn to page 10 for the next question

4 **Figure 4** shows a stress-strain graph for a copper wire.

Figure 4



4 (a) Define tensile strain.

.....

.....

(1 mark)

4 (b) State the breaking stress of this copper wire.

answer = ... Pa

(1 mark)

4 (c) Mark on **Figure 4** a point on the line where you consider plastic deformation may start. Label this point **A**.

(1 mark)

4 (d) Use the graph to calculate the Young modulus of copper. State an appropriate unit for your answer.

answer = ...

(3 marks)

4 (e) The area under the line in a stress-strain graph represents the work done per unit volume to stretch the wire.

4 (e) (i) Use the graph to find the work done per unit volume in stretching the wire to a strain of 3.0×10^{-3}.

answer = ... J m^{-3}

(2 marks)

4 (e) (ii) Calculate the work done to stretch a 0.015 kg sample of this wire to a strain of 3.0×10^{-3}.

The density of copper = 8960 kg m^{-3}.

answer = ... J

(2 marks)

4 (f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.

On **Figure 4** draw a line showing the possible variation of stress with strain for this material.

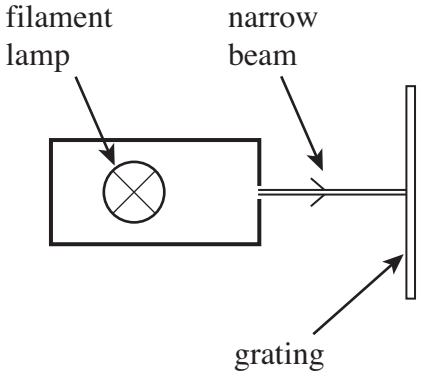
(2 marks)

12

Turn over for the next question

5 (a) In an experiment, a narrow beam of white light from a filament lamp is directed at normal incidence at a diffraction grating. Complete the diagram in **Figure 5** to show the light beams transmitted by the grating, showing the zero-order beam and the first-order beams.

Figure 5



(3 marks)

5 (b) Light from a star is passed through the grating.

Explain how the appearance of the first-order beam can be used to deduce **one** piece of information about the gases that make up the outer layers of the star.

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(2 marks)

5 (c) In an experiment, a laser is used with a diffraction grating of known number of lines per mm to measure the wavelength of the laser light.

5 (c) (i) Draw a labelled diagram of a suitable arrangement to carry out this experiment.

(2 marks)

5 (c) (ii) Describe the necessary procedure in order to obtain an accurate and reliable value for the wavelength of the laser light.
Your answer should include details of all the measurements and necessary calculations.
The quality of your written communication will be assessed in your answer.

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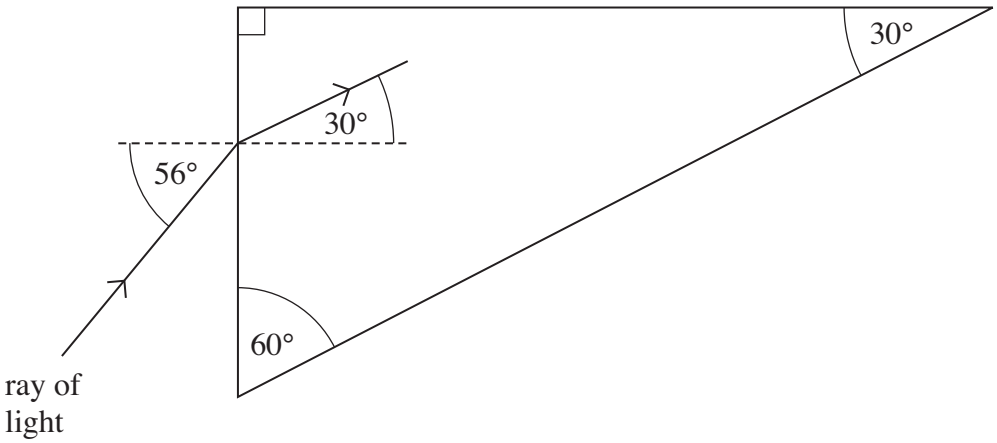
(6 marks)

13

6 **Figure 6** shows a glass prism. Light is directed into the prism at an angle of 56°. The path of the ray of light is shown as is it enters the prism.

Figure 6



6 (a) (i) Calculate the refractive index of the glass.

answer = ...

(2 marks)

6 (a) (ii) Calculate the critical angle for the glass-air boundary.

answer = ... degrees

(2 marks)

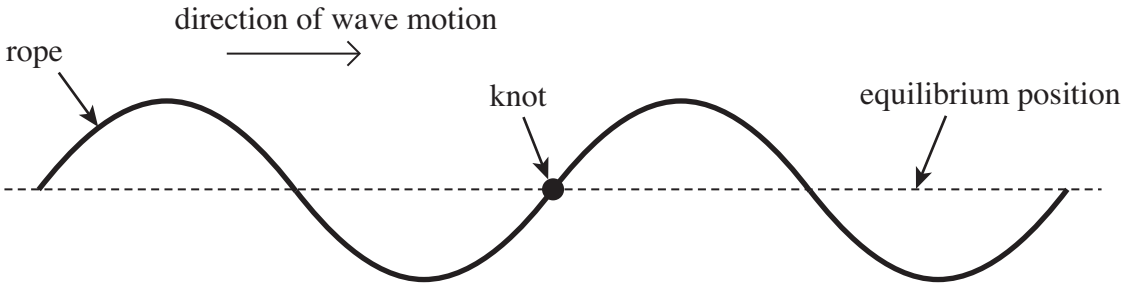
6 (b) On **Figure 6**, continue the path of the ray of light until it emerges from the prism.

(2 marks)

6

7 **Figure 7** shows a continuous progressive wave on a rope. There is a knot in the rope.

Figure 7



7 (a) Define the amplitude of a wave.

.....

.....

(2 marks)

7 (b) The wave travels to the right.
Describe how the **vertical** displacement of the knot varies over the next complete cycle.

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(3 marks)

7 (c) A continuous wave of the same amplitude and frequency moves along the rope from the right and passes through the first wave. The knot becomes motionless.
Explain how this could happen.

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(3 marks)

END OF QUESTIONS

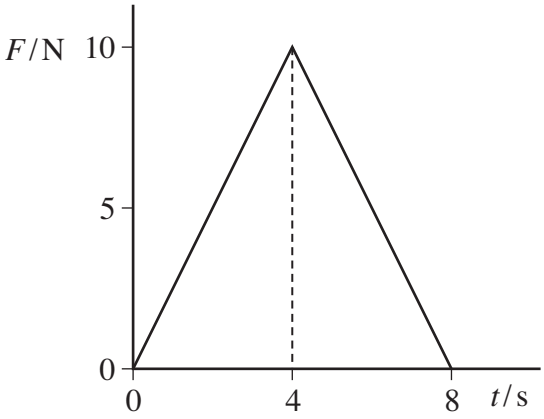
8

Multiple choice questions

Each of Questions **1** to **25** is followed by four responses, **A**, **B**, **C**, and **D**. For each question select the best response and mark its letter on the answer sheet.

You are advised to spend approximately **45 minutes** on this section.

1 A ball of mass 2.0 kg, initially at rest, is acted on by a force F which varies with time t as shown by the graph.



What is the velocity of the ball after 8.0 s?

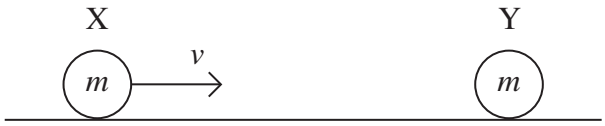
A $20\,\text{m s}^{-1}$

B $40\,\text{m s}^{-1}$

C $80\,\text{m s}^{-1}$

D $160\,\text{m s}^{-1}$

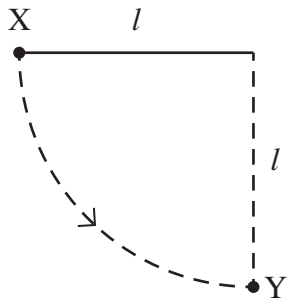
2 A body X moving with a velocity v makes an elastic collision with a stationary body Y of equal mass on a smooth horizontal surface.



Which line, **A** to **D**, in the table gives the velocities of the two bodies after the collision?

	velocity of X	**velocity of Y**
A	$\frac{v}{2}$	$-\frac{v}{2}$
B	$-\frac{v}{2}$	$\frac{v}{2}$
C	v	0
D	0	v

3 A ball of mass m, which is fixed to the end of a light string of length l, is released from rest at X.
It swings in a circular path, passing through the lowest point Y at speed v.



If the tension in the string at Y is T, which one of the following equations represents a correct application of Newton's laws of motion to the ball at Y?

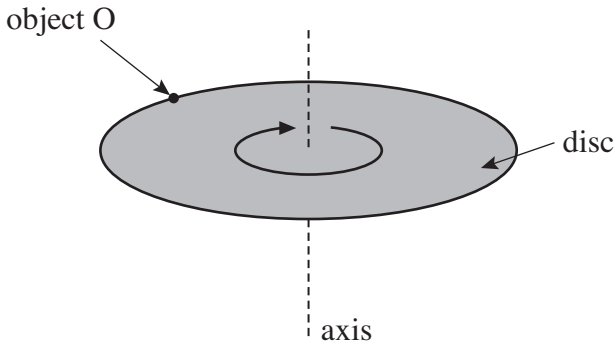
A $T = \frac{mv^2}{l} - mg$

B $mg - T = \frac{mv^2}{l}$

C $T - mg = \frac{mv^2}{l}$

D $T + \frac{mv^2}{l} = mg$

4 A disc of diameter D is turning at a steady angular speed at frequency f about an axis through its centre.



What is the centripetal force on a small object O of mass m on the perimeter of the disc?

A $2\pi mfD$

B $2\pi mf^2D$

C $2\pi^2mf^2D$

D $2\pi mf^2D^2$

5 What is the angular speed of a car wheel of diameter 0.400 m when the speed of the car is 108 km h^{-1}?

A 75 rad s^{-1}

B 150 rad s^{-1}

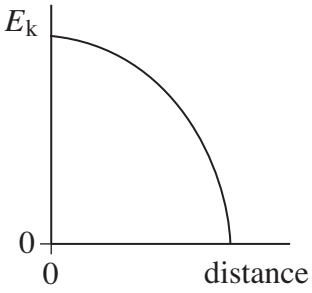
C 270 rad s^{-1}

D 540 rad s^{-1}

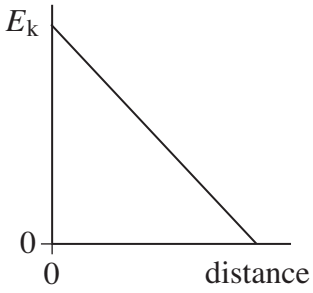
6 Which one of the following statements is true when an object performs simple harmonic motion about a central point O?

A The acceleration is always directed away from O.
B The acceleration and velocity are always in opposite directions.
C The acceleration and the displacement from O are always in the same direction.
D The graph of acceleration against displacement is a straight line.

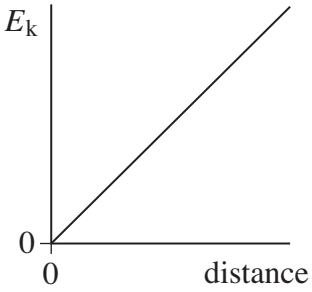
7 A body executes simple harmonic motion. Which one of the graphs, **A** to **D**, best shows the relationship between the kinetic energy, E_k, of the body and its distance from the centre of oscillation?



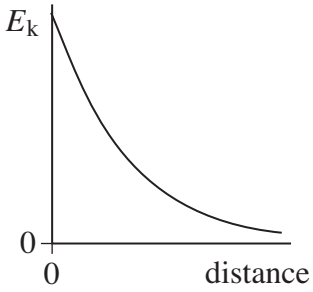
A



B



C



D

8 A mechanical system is oscillating at resonance with a constant amplitude. Which one of the following statements is **not** correct?

A The applied force prevents the amplitude from becoming too large.
B The frequency of the applied force is the same as the natural frequency of oscillation of the system.
C The total energy of the system is constant.
D The amplitude of oscillations depends on the amount of damping.

9 Which one of the following statements about Newton's law of gravitation is correct?

Newton's law of gravitation explains

A the origin of gravitational forces.
B why a falling satellite burns up when it enters the Earth's atmosphere.
C why projectiles maintain a uniform horizontal speed.
D how various factors affect the gravitational force between two particles.

10 If an electron and proton are separated by a distance of 5×10^{-11}m, what is the approximate gravitational force of attraction between them?

A 2×10^{-57}N

B 3×10^{-47}N

C 4×10^{-47}N

D 5×10^{-37}N

11 A spherical planet of uniform density ρ has radius R.

Which line, **A** to **D**, in the table gives correct expressions for the mass of the planet and the gravitational field strength at its surface?

	mass of planet	**gravitational field strength at surface**
A	$\frac{4\pi R^2\rho}{3}$	$\frac{4\pi GR\rho}{3}$
B	$\frac{4\pi R^3\rho}{3}$	$\frac{4\pi GR\rho}{3}$
C	$\frac{4\pi R^2\rho}{3}$	$\frac{4\pi G\rho}{3}$
D	$\frac{4\pi R^3\rho}{3}$	$\frac{4\pi G\rho}{3}$

12 The gravitational potential at the surface of the Earth, of radius R, is V. What is the gravitational potential at a point at a height R above the Earth's surface?

A $\frac{V}{4}$

B $\frac{V}{2}$

C V

D $2V$

13 A satellite is in orbit at a height h above the surface of a planet of mass M and radius R. What is the velocity of the satellite?

A $\sqrt{\frac{GM}{(R+h)}}$

B $\frac{\sqrt{GM\,(R+h)}}{R}$

C $\sqrt{\frac{GM\,(R+h)}{R}}$

D $\frac{\sqrt{GM}}{(R+h)}$

14 A repulsive force F acts between two positive point charges separated by a distance r. What will be the force between them if each charge is doubled and the distance between them is halved?

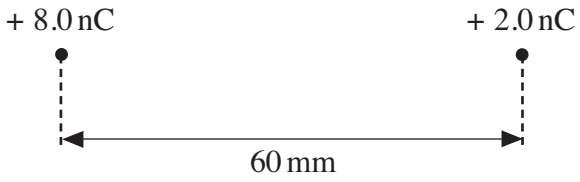
A F

B $2F$

C $4F$

D $16F$

15 The distance between two point charges of + 8.0 nC and + 2.0 nC is 60 mm.



At a point between the charges, on the line joining them, the resultant electric field strength is zero. How far is this point from the + 8.0 nC charge?

A 20 mm

B 25 mm

C 40 mm

D 45 mm

16 Which one of the following **cannot** be used as a unit for electric field strength?

A $J\,m^{-1}\,C^{-1}$

B $J\,A^{-1}\,s^{-1}\,m^{-1}$

C $N\,A^{-1}\,s^{-1}$

D $J\,C\,m^{-1}$

17 A capacitor stores a charge of 600 μC when charged to a potential difference (pd) of 6.0 V. What will be the pd across the plates if the charge stored increases by 50%?

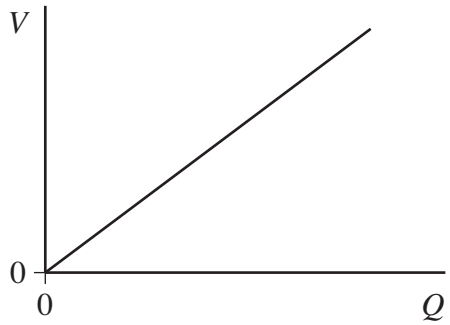
A 3.0 V

B 4.5 V

C 9.0 V

D 12.0 V

18 The graph shows the results of an experiment which was carried out to investigate the relationship between the charge Q stored by a capacitor and the pd V across it.



Which one of the following statements is **not** correct?

A The energy stored can be calculated by finding the area under the line.

B If a capacitor of smaller capacitance had been used the gradient of the graph would be steeper.

C If Q were doubled, the energy stored would be quadrupled.

D The gradient of the graph is equal to the capacitance of the capacitor.

19 A 10 μF capacitor is fully charged to a pd of 3.0 kV. The energy stored in the capacitor can be used to lift a load of 5.0 kg through a vertical height h. What is the approximate value of h?

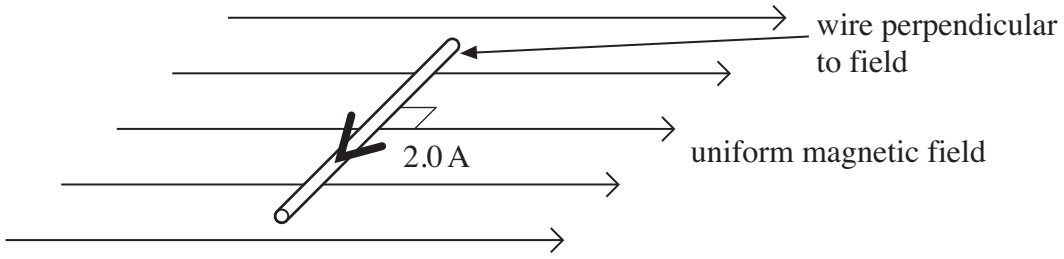
A 0.03 mm

B 0.9 mm

C 0.3 m

D 0.9 m

20 A horizontal straight wire of length 0.30 m carries a current of 2.0 A perpendicular to a horizontal uniform magnetic field of flux density 5.0×10^{-2} T. The wire 'floats' in equilibrium in the field.



What is the mass of the wire?

A 8.0×10^{-4} kg

B 3.1×10^{-3} kg

C 3.0×10^{-2} kg

D 8.2×10^{-1} kg

21 When a β particle moves at right angles through a uniform magnetic field it experiences a force F. An α particle moves at right angles through a magnetic field of twice the magnetic flux density with velocity one tenth the velocity of the β particle. What is the magnitude of the force on the α particle?

A $0.2\,F$
B $0.4\,F$
C $0.8\,F$
D $4.0\,F$

22 Charged particles, each of mass m and charge Q, travel at a constant speed in a circle of radius r in a uniform magnetic field of flux density B. Which expression gives the frequency of rotation of a particle in the beam?

A $\dfrac{BQ}{2\pi m}$

B $\dfrac{BQ}{m}$

C $\dfrac{BQ}{\pi m}$

D $\dfrac{2\pi BQ}{m}$

23 A 500 turn coil of cross-sectional area $4.0 \times 10^{-3}\,\text{m}^2$ is placed with its plane perpendicular to a magnetic field of flux density $7.5 \times 10^{-4}\,\text{T}$. What is the value of the flux linkage for this coil?

A $3.0 \times 10^{-6}\,\text{Wb turns}$
B $1.5 \times 10^{-3}\,\text{Wb turns}$
C $0.19\,\text{Wb turns}$
D $94\,\text{Wb turns}$

24 The output electromotive force (emf) of a simple ac generator can be increased by any of the four factors listed.

Which one of these factors should **not** be changed if the frequency of the output is to remain unaffected when the emf is increased?

A the area of the coil
B the number of turns on the coil
C the speed of rotation
D the strength of the magnetic field

25 Which one of the following would **not** reduce the energy losses in a transformer?

A using thinner wire for the windings
B using a laminated core instead of a solid core
C using a core made from iron instead of steel
D using a core that allows all the flux due to the primary coil to be linked to the secondary coil

END OF QUESTIONS

Do not write outside the box

Answer **all** questions.
You are advised to spend approximately **one hour** on this section.

1 (a) Define the electric potential at a point in an electric field.

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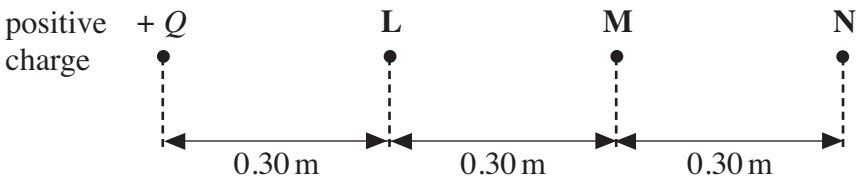
(3 marks)

1 (b) **Figure 1** shows part of the region around a small positive charge.

Figure 1



1 (b) (i) The electric potential at point **L** due to this charge is + 3.0 V. Calculate the magnitude Q of the charge. Express your answer to an appropriate number of significant figures.

answer = ... C

(3 marks)

1 (b) (ii) Show that the electric potential at point **N**, due to the charge, is +1.0 V.

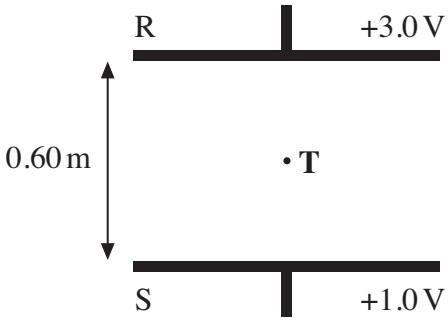
(1 mark)

1 (b) (iii) Show that the electric field strength at point **M**, which is mid-way between **L** and **N**, is 2.5 V m^{-1}.

(1 mark)

1 (c) R and S are two charged parallel plates, 0.60 m apart, as shown in **Figure 2**. They are at potentials of + 3.0 V and + 1.0 V respectively.

Figure 2



1 (c) (i) On **Figure 2**, sketch the electric field between R and S, showing its direction.

(2 marks)

1 (c) (ii) Point **T** is mid-way between R and S.
Calculate the electric field strength at **T**.

answer = ... V m^{-1}

(1 mark)

1 (c) (iii) Parts (b)(iii) and (c)(ii) both involve the electric field strength at a point mid-way between potentials of + 1.0 V and + 3.0 V. Explain why the magnitudes of these electric field strengths are different.

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(1 mark)

12

2 (a) Define the capacitance of a capacitor.

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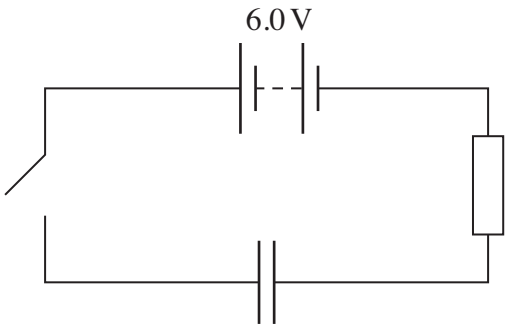
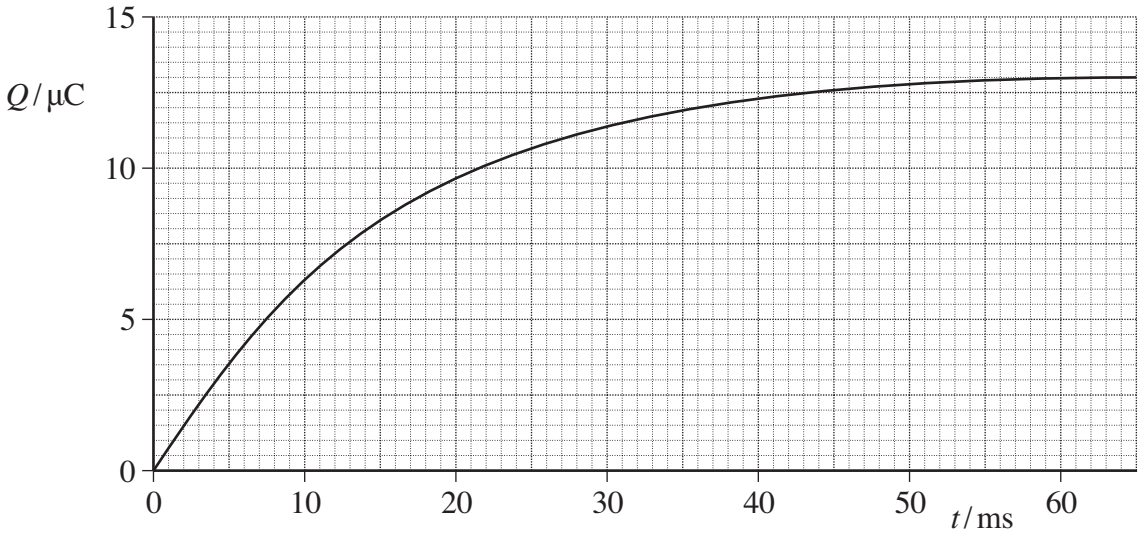
(2 marks)

2 (b) The circuit shown in **Figure 3** contains a battery, a resistor, a capacitor and a switch.

Figure 3



The switch in the circuit is closed at time $t = 0$. The graph shows how the charge Q stored by the capacitor varies with t.



2 (b) (i) When the capacitor is fully charged, the charge stored is 13.2 μC. The electromotive force (emf) of the battery is 6.0 V. Determine the capacitance of the capacitor.

answer = ... F

(2 marks)

Do not write outside the box

2 (b) (ii) The time constant for this circuit is the time taken for the charge stored to increase from 0 to 63% of its final value. Use the graph to find the time constant in milliseconds.

answer = ... ms

(2 marks)

2 (b) (iii) Hence calculate the resistance of the resistor.

answer = ... Ω

(1 mark)

2 (b) (iv) What physical quantity is represented by the gradient of the graph?

.....

.....

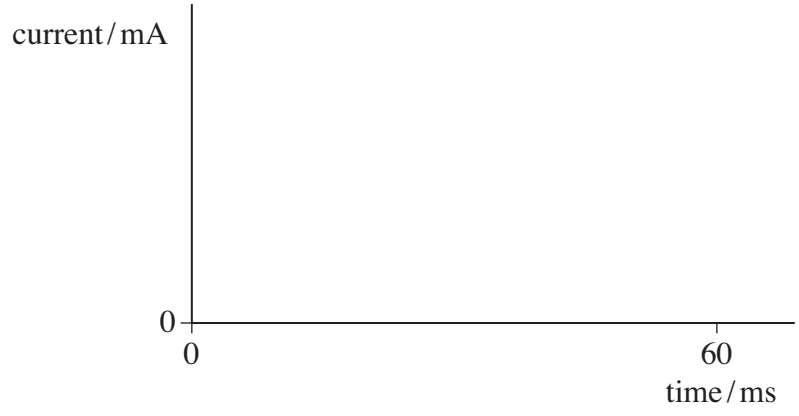
(1 mark)

2 (c) (i) Calculate the maximum value of the current, in mA, in this circuit during the charging process.

answer = ... mA

(1 mark)

2 (c) (ii) Sketch a graph on the outline axes to show how the current varies with time as the capacitor is charged. Mark the maximum value of the current on your graph.

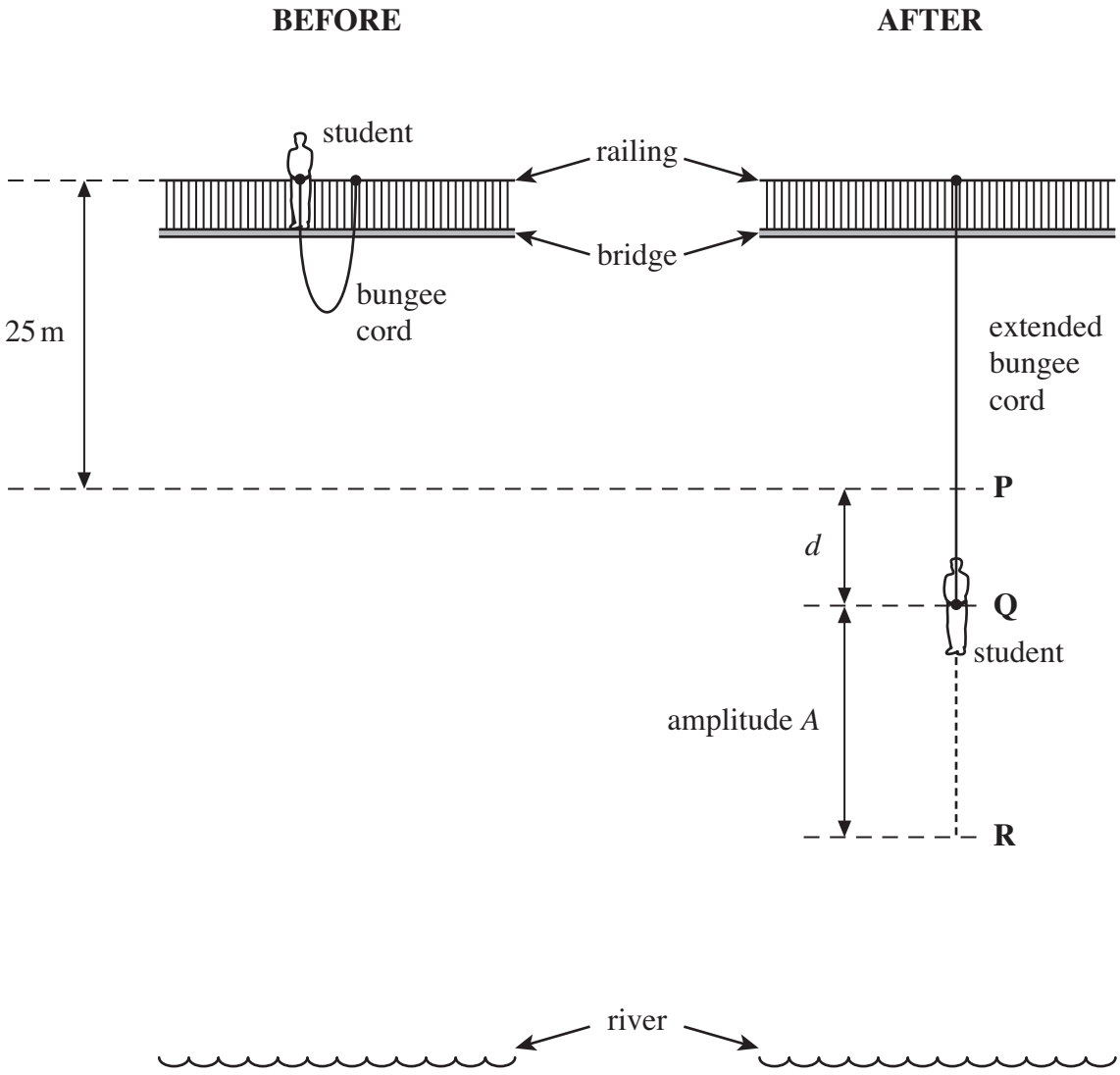


(2 marks)

11

3 The two diagrams in **Figure 4** show a student before and after she makes a bungee jump from a high bridge above a river. One end of the bungee cord, which is of unstretched length 25 m, is fixed to the top of a railing on the bridge. The other end of the cord is attached to the waist of the student, whose mass is 58 kg. After she jumps, the bungee cord goes into tension at point **P**. She comes to rest momentarily at point **R** and then oscillates about point **Q**, which is a distance *d* below **P**.

Figure 4



3 (a) (i) Assuming that the centre of mass of the student has fallen through a vertical distance of 25 m when she reaches point **P**, calculate her speed at **P**.
You may assume that air resistance is negligible.

answer = ... $m\,s^{-1}$

(2 marks)

3 (a) (ii) The bungee cord behaves like a spring of spring constant 54 $N\,m^{-1}$.
Calculate the distance d, from **P** to **Q**, assuming the cord obeys Hooke's law.

answer = ... m

(2 marks)

3 (b) As the student moves below **P**, she begins to move with simple harmonic motion for part of an oscillation.

3 (b) (i) If the arrangement can be assumed to act as a mass-spring system, calculate the time taken for one half of an oscillation.

answer = ... s

(2 marks)

3 (b) (ii) Use your answers from parts (a) and (b)(i) to show that the amplitude A, which is the distance from **Q** to **R**, is about 25 m.

(3 marks)

3 (c) Explain why, when the student rises above point **P**, her motion is no longer simple harmonic.

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(2 marks)

3 (d) (i) Where is the student when the stress in the bungee cord is a maximum?

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(1 mark)

3 (d) (ii) The bungee cord has a significant mass. Whereabouts along the bungee cord is the stress a maximum? Explain your answer.

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(2 marks)

14

Do not write outside the box

4 (a) A transformer operating on a 230 V mains supply provides a 12 V output. There are 1150 turns on the primary coil.

4 (a) (i) Calculate the number of turns on the secondary coil.

answer = ... turns
(1 mark)

4 (a) (ii) A number of identical lamps rated at 12 V, 24 W are connected in parallel across the secondary coil. The primary circuit of the transformer includes a 630 mA fuse. Calculate the maximum number of lamps that can be supplied by the transformer if its efficiency is 85%.

answer = ... lamps
(2 marks)

4 (a) (iii) The transformer circuit includes a fuse. Explain why this is necessary.

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(1 mark)

4 (a) (iv) Why is the fuse placed in the primary circuit rather than in the secondary circuit?

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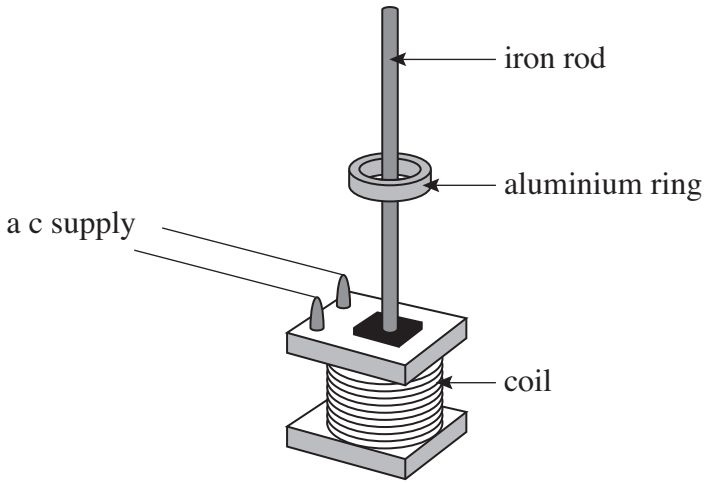
(1 mark)

Question 4 continues on the next page

Do not write outside the box

4 (b) **Figure 5** shows an experimental arrangement that can be used to demonstrate magnetic levitation. The iron rod is fixed vertically inside a large coil of wire. When the alternating current supply to the coil is switched on, the aluminium ring moves up the rod until it reaches a stable position 'floating' above the coil.

Figure 5



4 (b) (i) By reference to the laws of electromagnetic induction explain

- why a current will be induced in the ring,
- why the ring experiences a force that moves it upwards,
- why the ring reaches a stable position.

The quality of your written communication will be assessed in your answer.

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Do not write outside the box

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(6 marks)

4 (b) (ii) What would happen to the ring if the alternating current in the coil was increased without changing the frequency? Explain your answer.

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(2 marks)

13

END OF QUESTIONS

SECTION A

Answer ALL questions.

For questions 1–10, in Section A, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 The ionising properties of radiations determine their penetrating power.

Which of the following statements is correct?

☒ **A** α-particles are not very ionising so they are stopped by thin paper.

☒ **B** α-particles are very ionising so can only travel a few centimetres in air.

☒ **C** γ-radiation is very penetrating because it is very ionising.

☒ **D** γ-radiation is not very penetrating because it is very ionising.

(Total for Question 1 = 1 mark)

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2 A small satellite has a weight of 1200 N at the Earth's surface. It is launched into a circular orbit with radius equal to twice the radius of the Earth. The weight of the satellite in this orbit is

☒ **A** 0 N

☒ **B** 300 N

☒ **C** 600 N

☒ **D** 1200 N

(Total for Question 2 = 1 mark)

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3 A number of conditions must be met if the fusion of hydrogen nuclei is to occur. Which condition, in a sample of hydrogen, is **not** necessary for nuclear fusion to occur?

☒ **A** very high density

☒ **B** very high mass

☒ **C** very high pressure

☒ **D** very high temperature

(Total for Question 3 = 1 mark)

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4 New buildings in earthquake zones are often designed to be earthquake resistant. Such buildings incorporate mechanisms to reduce the transfer of kinetic energy from the ground to the building.

Which of the following would be the most important property of a material used in such a mechanism?

☒ **A** density

☒ **B** ductility

☒ **C** stiffness

☒ **D** strength

(Total for Question 4 = 1 mark)

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5 The molecules in a material may possess kinetic energy E_k and potential energy E_p.

The internal energy is equal to

☒ **A** ΣE_k

☒ **B** $\Sigma E_k - \Sigma E_p$

☒ **C** $\Sigma E_k + \Sigma E_p$

☒ **D** ΣE_p

(Total for Question 5 = 1 mark)

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6 Radioactive decay is sometimes described as being spontaneous. In this context spontaneous means

☒ **A** nothing can influence the decay.

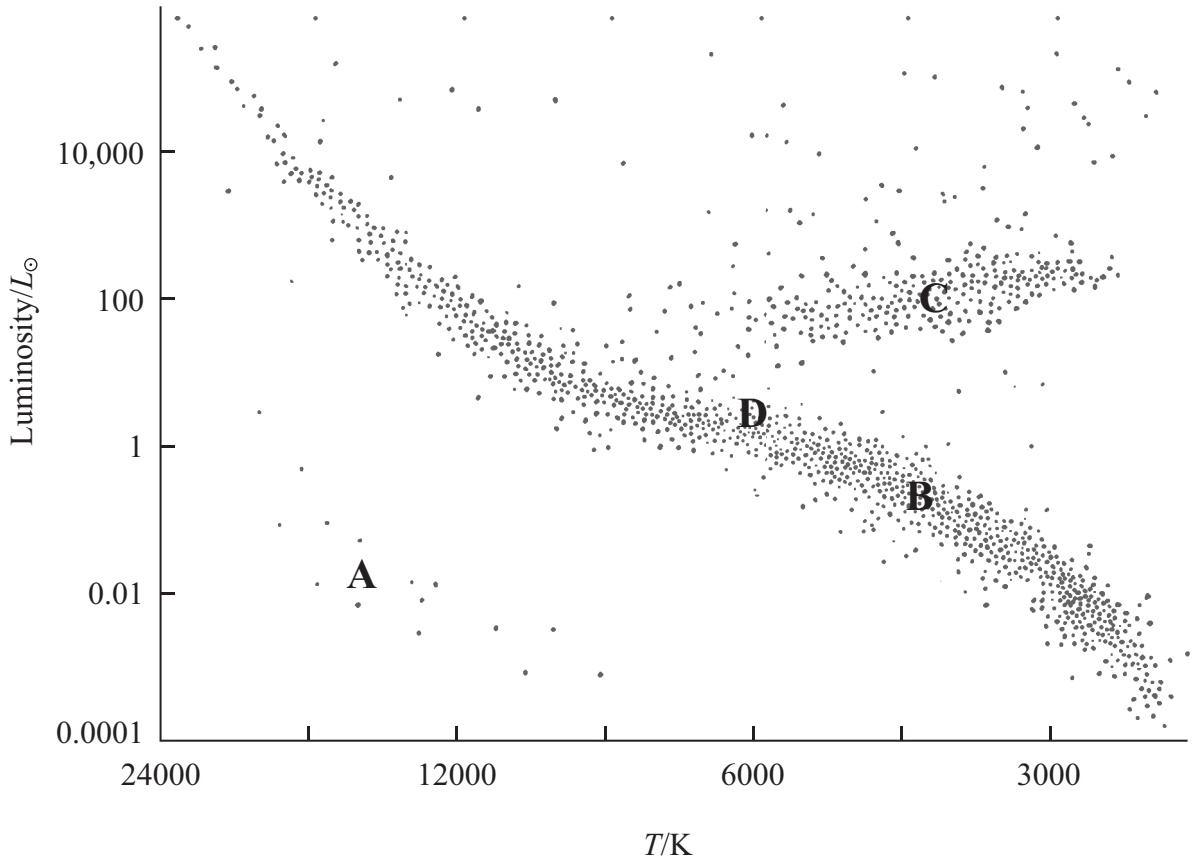
☒ **B** the decay is random.

☒ **C** the decay can be predicted.

☒ **D** the decay is exponential.

(Total for Question 6 = 1 mark)

Questions 7 and 8 refer to the Hertzsprung-Russell diagram below.



7 Which letter A, B, C or D represents the region on the diagram where a white dwarf star would be shown?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

(Total for Question 7 = 1 mark)

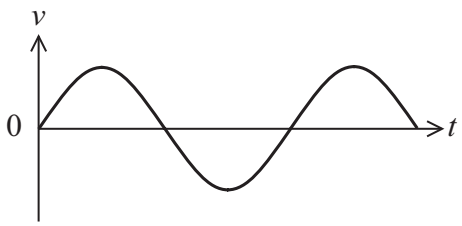
8 Which letter A, B, C or D represents the region on the diagram where our Sun would be shown?

- ☒ **A**
- ☒ **B**
- ☒ **C**
- ☒ **D**

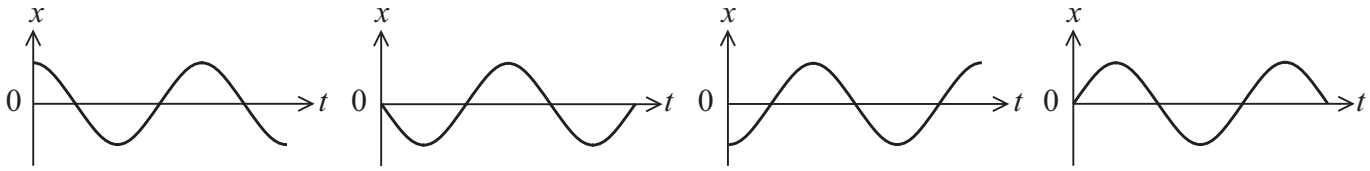
(Total for Question 8 = 1 mark)

Questions 9 and 10 refer to the diagram below.

The graph below shows how the velocity varies with time for an object undergoing simple harmonic motion.



9 Which graph shows the variation of displacement with time?



A **B** **C** **D**

☒ **A**

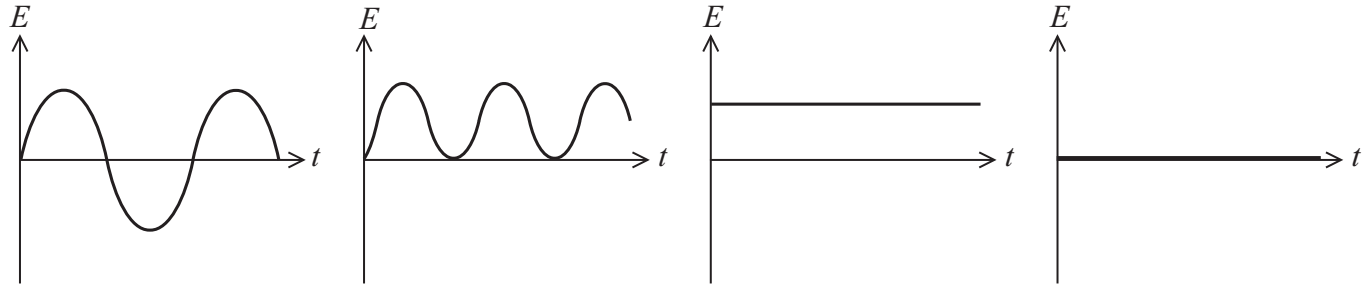
☒ **B**

☒ **C**

☒ **D**

(Total for Question 9 = 1 mark)

10 Which graph shows the variation of total energy with time?



A **B** **C** **D**

☒ **A**

☒ **B**

☒ **C**

☒ **D**

(Total for Question 10 = 1 mark)

TOTAL FOR SECTION A = 10 MARKS

SECTION B

Answer ALL questions in the spaces provided.

11 A student carries out an experiment to investigate how the volume occupied by a gas depends upon the temperature.

(a) What variables must the student control in this investigation?

(2)

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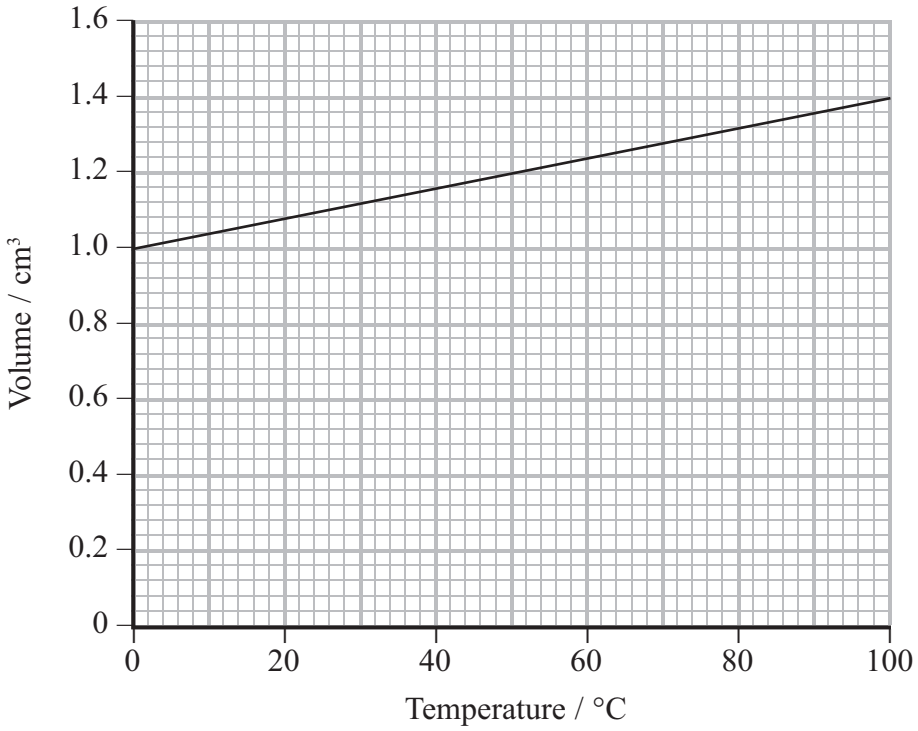
(b) The following graph is obtained.



Explain how graphs such as this provide evidence for an absolute zero of temperature.

(2)

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(Total for Question 11 = 4 marks)

12 All living organisms contain ^{12}C and radioactive ^{14}C. The concentration of ^{14}C in the organism is maintained whilst the organism is alive, but starts to fall once death has occurred.

(a) The count rate obtained from wood from an old Viking ship is 14.7 min^{-1} per gram of wood, after being corrected for background radiation. The corrected count rate from similar living wood is 16.5 min^{-1} per gram of wood.

Calculate the age of the ship in years.

^{14}C has a half life of 5700 years.

(4)

Age of ship = ... years

(b) The concentration of ^{14}C in living organisms might have been greater in the past.

Explain how this would affect the age that you have calculated.

(2)

(Total for Question 12 = 6 marks)

13 Betelgeuse is our nearest red giant. It has a luminosity of 4.49×10^{31} W and emits radiation with a peak energy emission occurring at a wavelength of 850 nm.

Show that Betelgeuse has a surface temperature of about 3000 K. Hence calculate the ratio of the radius of Betelgeuse, r_B to the radius of the Sun, r_S.

$$r_S = 6.95 \times 10^8 \text{ m}$$

(5)

$r_B/r_S =$ .....

(Total for Question 13 = 5 marks)

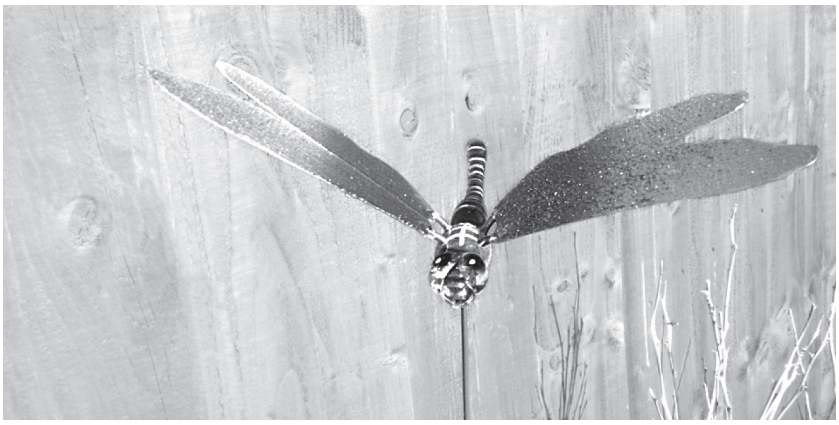
***14** Cepheid variable stars have long been seen as examples of standard candles. Recent measurements have indicated that the movement of the star through interstellar material might result in the formation of a layer of dust around the star. This affects how bright the star appears.

Explain how standard candles are used in astronomy, and suggest how the existence of a layer of dust around a Cepheid variable star might affect the conclusions drawn by astronomers.

(6)

(Total for Question 14 = 6 marks)

15 A garden ornament consists of a plastic dragonfly mounted on a stick. The dragonfly's wings are attached to the body with springs, and they flutter up and down in a gentle breeze.



(a) When the air is not moving and the wings are displaced through a small vertical distance, they oscillate. The time for 10 oscillations is recorded. This is repeated twice more.

Time / s		
t_1	t_2	t_3
6.2	6.6	6.9

(i) Calculate the frequency of oscillation of the wings.

(3)

Frequency = ...

(ii) The oscillation of the wings is thought to be simple harmonic motion.

State the conditions required for the oscillations to be simple harmonic.

(2)

(b) The amplitude of the wings' oscillation dies down after only a small number of oscillations.

Explain why this happens.

(2)

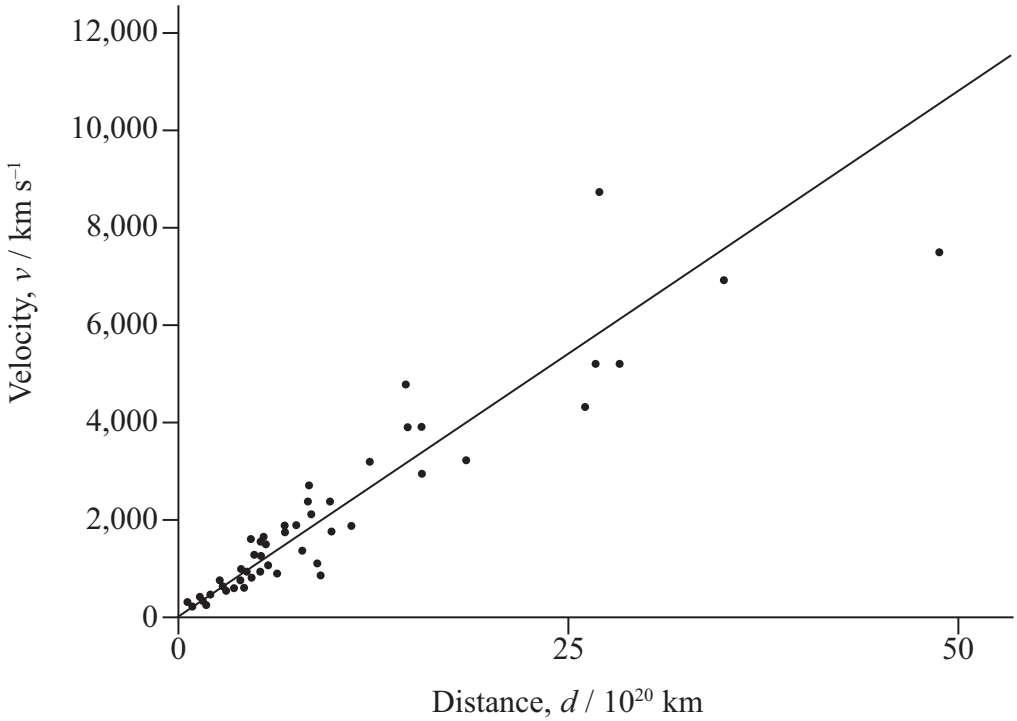
(c) In certain breezy conditions the wings are seen to oscillate with a very large amplitude.

Name this effect and state the condition for it to occur.

(2)

(Total for Question 15 = 9 marks)

16 The graph shows how the velocity varies with distance for a number of distant galaxies. All the galaxies are receding from Earth, and there appears to be a linear relationship between the velocity of recession and the distance to the galaxy.



(a) Use the graph to estimate an age for the Universe.

(4)

Age of the Universe = ...

*(b) Describe how astronomers would have determined the velocity of each galaxy.

(5)

*(c) Scientists are uncertain about the ultimate fate of the Universe.

Explain why.

(3)

(Total for Question 16 = 12 marks)

17 Communications satellites were first proposed in 1945 by the science fiction author Arthur C. Clarke. In an article published in the magazine Wireless World he asked whether rocket stations could give worldwide radio coverage.

In the article Clarke states:

"There are an infinite number of possible stable orbits, circular and elliptical, in which a rocket would remain if the initial conditions were correct. A velocity of 8 km s^{-1} applies only to the closest possible orbit, one just outside the atmosphere, and the period of revolution would be about 90 minutes. As the radius of the orbit increases the velocity decreases, since gravity is diminishing and less centrifugal force is needed to balance it."

(a) State what is meant in the article by the phrase "gravity is diminishing", and criticise the statement that "less centrifugal force is needed to balance (the satellite)".

(3)

(b) (i) By deriving an appropriate equation, show that the orbital speed of the satellite decreases as the radius of orbit increases.

(3)

(ii) By deriving an appropriate equation, show that the orbital period of a satellite increases as the orbital speed decreases.

(2)

(c) The period T of a satellite in a circular orbit is given by the equation

$$T = \sqrt{\frac{4\pi^2 r^3}{GM}}$$

where r is the radius of orbit and M is the mass of the Earth.

Calculate the period of a satellite in an orbit 4.0×10^5 m above the surface of the Earth.

mass of the Earth = 5.98×10^{24} kg

radius of the Earth = 6.36×10^6 m

(2)

Period of satellite = ...

(d) After a time the radius of the satellite's orbit will start to decrease due to the resistive forces acting on the satellite from the atmosphere. As this happens the satellite speeds up.

Describe the energy changes occurring as the radius of the orbit decreases.

(2)

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(Total for Question 17 = 12 marks)

18 Electrical power generated by nuclear fission makes an important contribution to world energy needs. However Rutherford, who is credited with the discovery and first splitting of the nuclear atom, later said:

"The energy produced by the breaking down of the atom is a very poor kind of thing. Anyone who expects a source of power from the transformation of these atoms is talking moonshine."

Rutherford carried out experiments that involved firing alpha particles at nitrogen atoms.

(a) (i) Complete the equation for the interaction between nitrogen and alpha particles.

(1)

$$^{14}_{7}\mathrm{N} + {}^{4}_{2}\alpha \rightarrow \ldots\ldots\mathrm{O} + \ldots\ldots{}^{1}\mathrm{p}$$

(ii) This interaction requires a small energy input. Other similar nuclear reactions may give an energy output of no more than 20 MeV, giving some justification to Rutherford's statement. Suggest why Rutherford's statement eventually turned out to be very inaccurate.

(1)

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(b) Uranium-235 is able to undergo fission when it absorbs a neutron to become uranium-236. The equation below shows a possible fission reaction.

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

Use the data in the table to show that the energy released by the fission of one uranium nucleus is about 170 MeV.

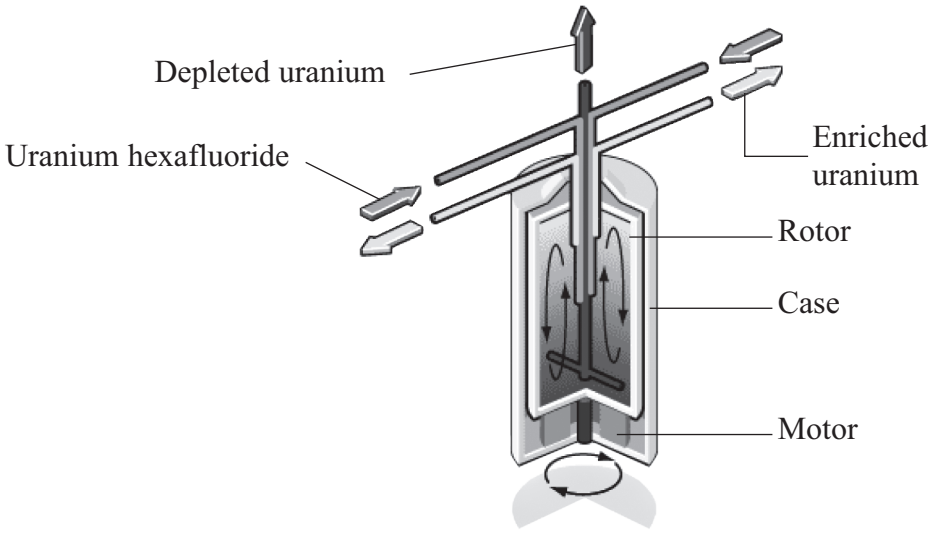
Isotope	Mass / 10^{-27} kg
^{235}U	390.29989
^{141}Ba	233.99404
^{92}Kr	152.64708
^{1}n	1.67493

(4)

(c) Naturally occurring uranium is more than 99% uranium-238. Fuel for a fission reactor requires at least 3% of the uranium to be uranium-235.

Uranium hexafluoride gas is used during the uranium enrichment process. It is fed into a centrifuge, and a rotating cylinder (rotor) sends the uranium-238 to the outside of the cylinder, where it can be drawn off, while the uranium-235 diffuses to the centre of the cylinder.

Gas centrifuge



(i) Give **one** similarity and **one** difference between the nuclei of uranium-238 and uranium-235.

(2)

Similarity .....

Difference .....

(ii) The rotor has a diameter of 30 cm and spins at a rate of 60,000 revolutions per minute.

Calculate the centripetal acceleration at the rim of the rotor.

(2)

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Centripetal acceleration = ...

(iii) The rotor is subjected to huge forces because of the high spin rate.

Give **two** mechanical properties essential for the material from which the rotor is made.

(2)

Property 1 .....

Property 2 .....

(d) The waste heat from some power stations is transferred to water.

The San Onofre Nuclear Generating Station in California has reactors with a total output power of 2200 MW. These reactors circulate sea water at an average mass flow rate of 7.0×10^4 kg s^{-1}. The water is heated to approximately 11 K above the input temperature as it flows through condensers, before being discharged back into the ocean.

Show that the rate at which energy is removed from the reactors is about 3000 MW, and hence estimate a value for the efficiency of the electrical power generation process.

specific heat capacity of the sea water = 3990 J kg^{-1} K^{-1}

(4)

Efficiency = ...

(Total for Question 18 = 16 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS

SECTION A

Answer ALL questions.

For questions 1–10, in Section A, select one answer from A to D and put a cross in the box ☒. If you change your mind, put a line through the box ☒ and then mark your new answer with a cross ☒.

1 A unit for magnetic flux is the

☒ **A** Wb

☒ **B** Wb m^2

☒ **C** T

☒ **D** T m^{-2}

(Total for Question 1 = 1 mark)

---

2 A body, initially at rest, explodes into two masses M_1 and M_2. These masses move apart with speeds v_1 and v_2 respectively.

The ratio v_1/v_2 is equal to

☒ **A** $\frac{M_1}{M_2}$

☒ **B** $\frac{M_2}{M_1}$

☒ **C** $\frac{\sqrt{M_1}}{\sqrt{M_2}}$

☒ **D** $\frac{\sqrt{M_2}}{\sqrt{M_1}}$

(Total for Question 2 = 1 mark)

---

3 Which of the following is a property of a uniform electric field?

☒ **A** A field that doesn't change over time.

☒ **B** A field that acts equally in all directions.

☒ **C** A field that only produces a force on moving charged particles.

☒ **D** A field that has the same strength at all points.

(Total for Question 3 = 1 mark)

---

4 A potential difference of 50 V is applied between two identical parallel aluminium plates. The plates are separated by a distance of 10 mm.

Which combination of potential difference and separation would double the electric field strength?

	Separation/mm	Potential difference/ V
☒ **A**	20	100
☒ **B**	20	25
☒ **C**	10	100
☒ **D**	10	25

(Total for Question 4 = 1 mark)

5 Which of the following is **not** a vector quantity?

☒ **A** electric field strength

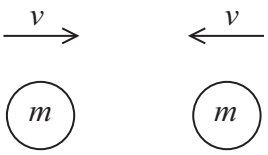
☒ **B** magnetic flux density

☒ **C** momentum

☒ **D** potential difference

(Total for Question 5 = 1 mark)

6 Two identical spheres of mass m are both travelling with a speed v towards each other.



The spheres collide head-on.

Which of the following statements **must** be true after the collision?

☒ **A** total momentum = $2mv$

☒ **B** total momentum = 0

☒ **C** total kinetic energy = mv^2

☒ **D** total kinetic energy = 0

(Total for Question 6 = 1 mark)

---

7 A cyclist travels along a straight horizontal road at a steady speed. A net force of 20 N is then applied for 6 s. The change in momentum of the cyclist is

☒ **A** 3.3 kg m s^{-1}

☒ **B** 26 kg m s^{-1}

☒ **C** 120 kg m s^{-1}

☒ **D** 720 kg m s^{-1}

(Total for Question 7 = 1 mark)

---

8 A conductor of length 50 mm carries a current of 3.0 A at 30° to a magnetic field of magnetic flux density 0.40 T.

The magnitude of the magnetic force acting on the conductor is

☒ **A** 0.030 N

☒ **B** 0.050 N

☒ **C** 30 N

☒ **D** 52 N

(Total for Question 8 = 1 mark)

---

9 An alpha particle and a beta particle both move into the same uniform magnetic field which is perpendicular to their direction of motion. The beta particle travels at 15 times the speed of the alpha particle.

The ratio of the force on the beta particle to the force on the alpha particle is

☒ **A** 3.7

☒ **B** 7.5

☒ **C** 30

☒ **D** 60

(Total for Question 9 = 1 mark)

10 The tubes of a linear accelerator (linac) get progressively longer down its length because

☒ **A** the accelerating particles become relativistic.

☒ **B** the frequency of the applied potential difference changes.

☒ **C** the accelerating particles must spend the same time in each tube.

☒ **D** the accelerating particles gain mass.

(Total for Question 10 = 1 mark)

TOTAL FOR SECTION A = 10 MARKS

SECTION B

Answer ALL questions in the spaces provided.

11 Early in the twentieth century physicists observed the scattering of alpha particles after they had passed through a thin gold foil. This scattering experiment provided evidence for the structure of the atom.

(a) State why it is necessary to remove the air from the apparatus that is used for this experiment.

(1)

.....

(b) From the results of such an experiment give **two** conclusions that can be deduced about the nucleus of an atom.

(2)

Conclusion 1 .....

.....

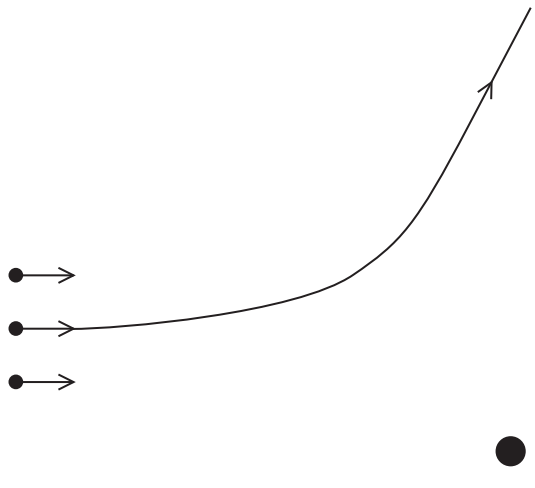
Conclusion 2 .....

.....

(c) The diagram shows three α-particles, all with the same kinetic energy. The path followed by one of the particles is shown.

Add to the diagram to show the paths followed by the other two particles.

(3)



(Total for Question 11 = 6 marks)

12 The electron in a hydrogen atom can be described by a stationary wave which is confined within the atom. This means that the de Broglie wavelength associated with it must be similar to the size of the atom which is of the order of 10^{-10} m.

(a) (i) Calculate the speed of an electron whose de Broglie wavelength is 1.00×10^{-10} m.

(3)

Speed = ...

(ii) Calculate the kinetic energy of this electron in electronvolts.

(3)

Kinetic energy = ... eV

(b) When β radiation was first discovered, it was suggested that there were electrons in the atomic nucleus, but it was soon realised that this was impossible because the energy of such an electron would be too great.

Suggest why an electron confined within a nucleus would have a much greater energy than the energy calculated in (a)(ii).

(2)

(Total for Question 12 = 8 marks)

13 The London Eye consists of a large vertical circle with 32 equally-spaced passenger cabins attached to it. The wheel rotates so that each cabin has a constant speed of 0.26 m s^{-1} and moves around a circle of radius 61 m.

(a) Calculate the time taken for each cabin to make one complete revolution.

(2)

.....

.....

Time = ...

(b) Calculate the centripetal force acting on each cabin.

mass of cabin = 9.7×10^3 kg

(2)

.....

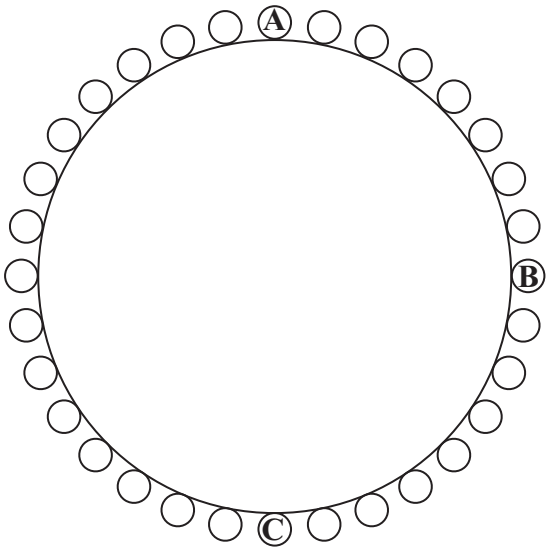
.....

.....

Centripetal force = ...

(c) (i) The diagram shows just the circle and the cabins.
Draw arrows to show the direction of the centripetal force acting on a person in a cabin when the person is at each of positions **A**, **B** and **C**.

(1)



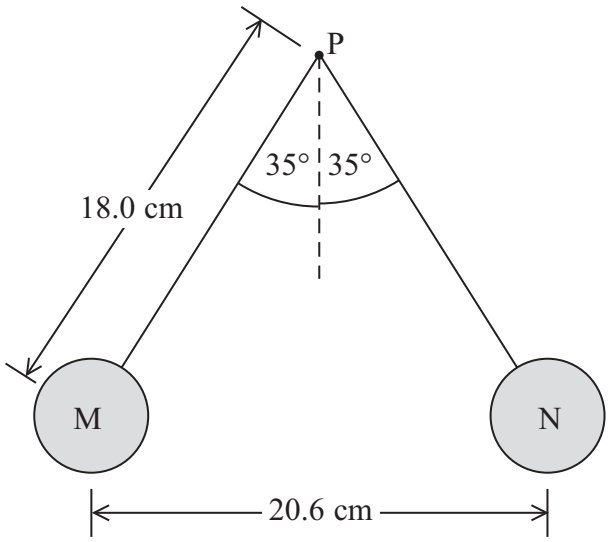
***(ii)** As the person in a cabin moves around the circle, the normal contact force between the person and the cabin varies.

State the position at which this force will be a maximum and the position at which it will be a minimum. Explain your answers.

(4)

(Total for Question 13 = 9 marks)

14 Two identical table tennis balls, M and N, are attached to non-conducting threads and suspended from a point P. The balls are each given the same positive charge and they hang as shown in the diagram. The mass of each ball is 2.7 g.



(a) Draw a free-body force diagram for ball M, label your diagram with the names of the forces.

(2)

(b) (i) Show that the tension in one of the threads is about 3×10^{-2} N.

(3)

(ii) Show that the electrostatic force between the balls is about 2×10^{-2} N.

(2)

(iii) Calculate the charge on each ball.

(3)

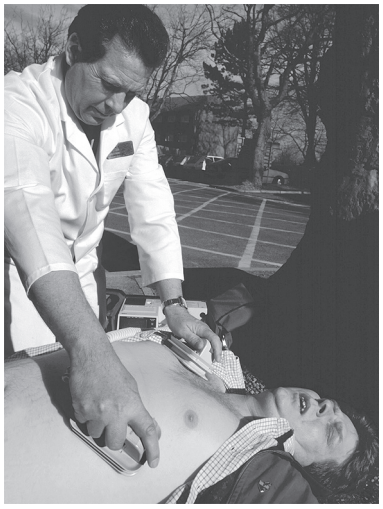
Charge = ...

(c) State and explain what would have happened if the charge given to ball M was greater than the charge given to ball N.

(2)

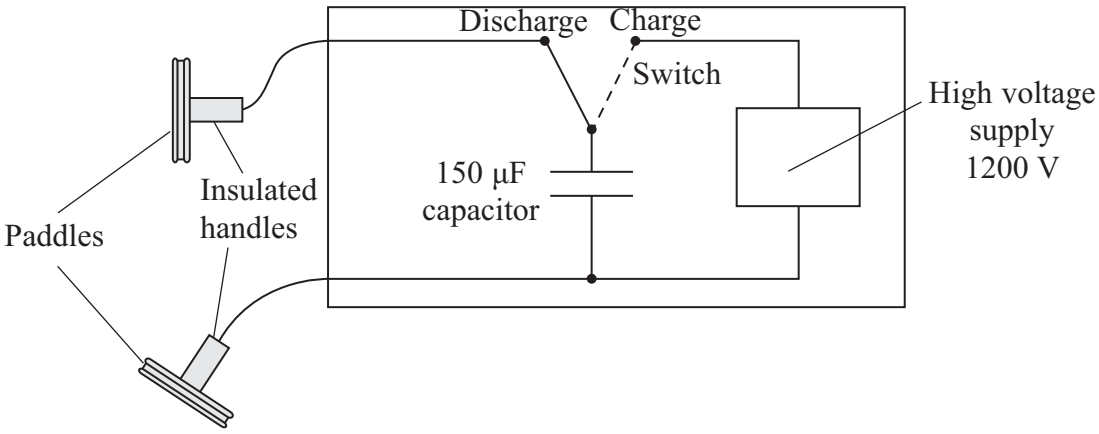
(Total for Question 14 = 12 marks)

15 A defibrillator is a machine that is used to correct an irregular heartbeat or to start the heart of someone who is in cardiac arrest.



The defibrillator passes a large current through the heart for a short time.

The machine includes a high voltage supply which is used to charge a capacitor. Two defibrillation 'paddles' are placed on the chest of the patient and the capacitor is discharged through the patient.



(a) The 150 μF capacitor is first connected across the 1200 V supply.

Calculate the charge on the capacitor.

(2)

.....

.....

Charge = ...

(b) Calculate the energy stored in the capacitor.

(2)

Energy stored = ...

(c) When the capacitor discharges there is an initial current of 14 A in the chest of the patient.

(i) Show that the electrical resistance of the body tissue between the paddles is about 90 Ω.

(1)

(ii) Calculate the time it will take for three quarters of the charge on the capacitor to discharge through the patient.

(3)

Time = ...

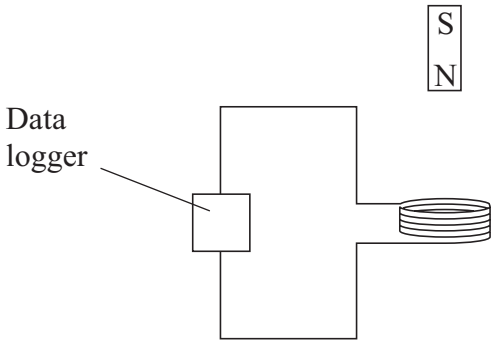
(iii) Body resistance varies from person to person. If the body resistance was lower, the initial current would be greater.

State how this lower body resistance affects the charge passed through the body from the defibrillator.

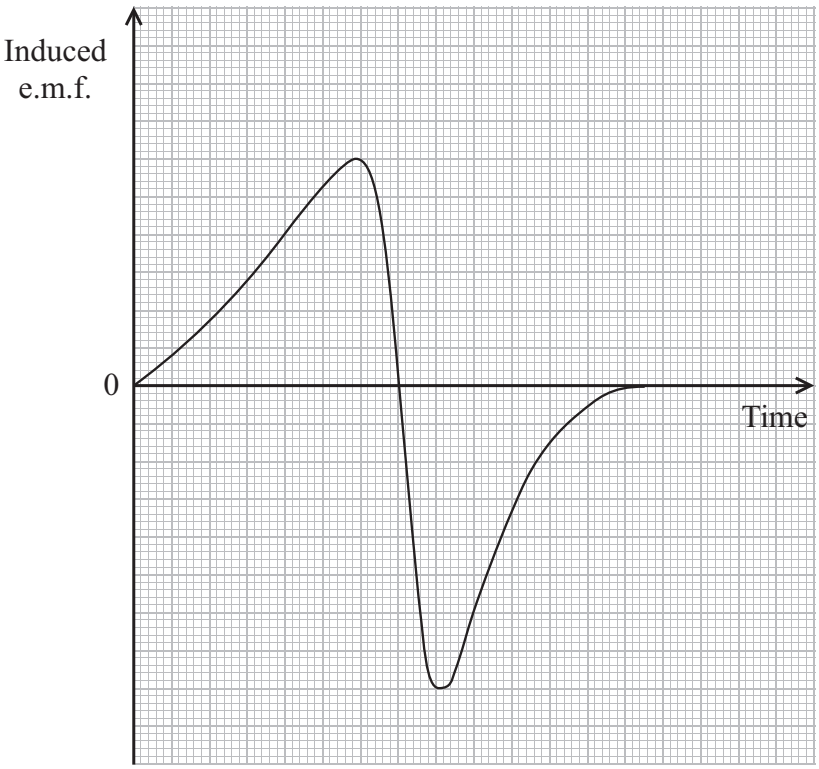
(1)

(Total for Question 15 = 9 marks)

16 A teacher demonstrates electromagnetic induction by dropping a bar magnet through a flat coil of wire connected to a data logger.



The data from the data logger is used to produce a graph of induced e.m.f. across the coil against time.

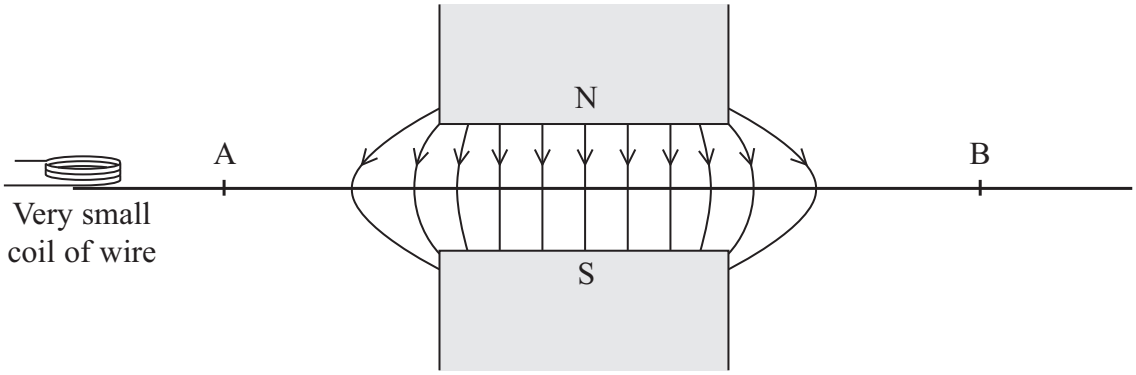


*(a) Explain the shape of the graph and the relative values on both axes.

(6)

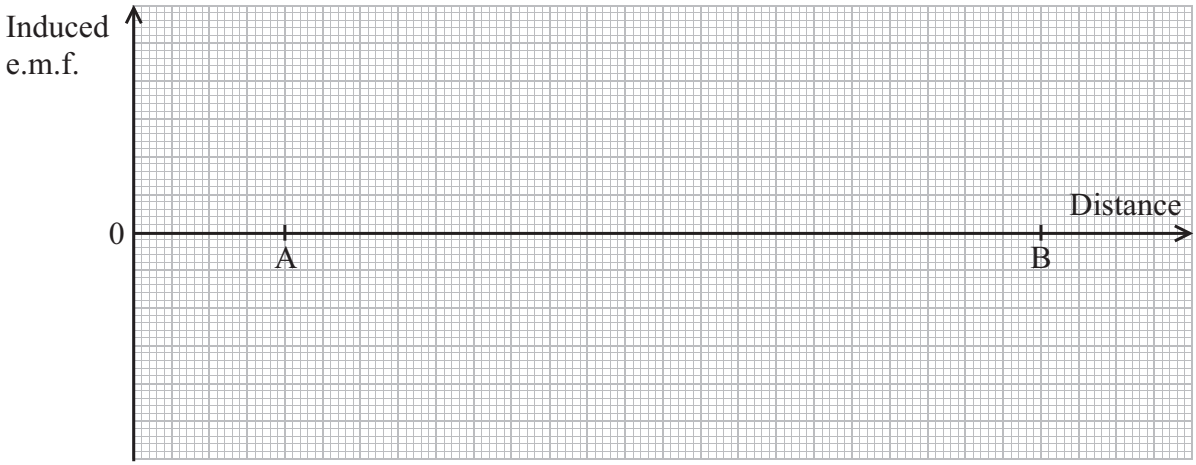
(b) The teacher then sets up another demonstration using a large U-shaped magnet and a very small coil of wire which is again connected to a data logger.

The north pole is vertically above the south pole and the coil is moved along the line AB which is midway between the poles. The magnetic field due to the U-shaped magnet has been drawn. The plane of the coil is horizontal.



Sketch a graph to show how the e.m.f. induced across the coil varies as the coil moves from A to B at a constant speed.

(4)



(Total for Question 16 = 10 marks)

17 In 2011 physicists at the Relativistic Heavy Ion Collider (RHIC) announced the creation of nuclei of anti-helium-4 which consists of anti-protons and anti-neutrons instead of protons and neutrons.

(a) 'Ordinary' helium-4 is written as $^{4}_{2}\text{He}$.

What do the numbers 4 and 2 represent?

(2)

(b) In the RHIC experiment, nuclei of gold $^{197}_{79}\text{Au}$ travelling at speeds greater than 2.99×10^{8} m s^{-1}, in opposite directions, collided, releasing energies of up to 200 GeV. After billions of collisions, 18 anti-helium nuclei had been detected.

(i) What is meant by 'relativistic' in the collider's name?

(1)

(ii) State why it is necessary to use very high energies in experiments such as these.

(1)

(iii) Show that the mass of a stationary anti-helium nucleus is about 4 GeV/c^2.

(4)

(iv) State why the small number of anti-helium nuclei produced only survive for a fraction of a second.

(1)

.....

.....

(v) A slow moving anti-helium nucleus meets a slow moving helium nucleus. If they were to combine to produce 2 high energy gamma rays, calculate the frequency of each gamma ray.

(2)

.....

.....

.....

.....

Frequency = ...

(c) There are two families of hadrons, called baryons and mesons. Baryons such as protons are made of three quarks.

(i) Describe the structure of a meson.

(1)

.....

.....

.....

(ii) Up quarks have a charge of +2/3e and down quarks a charge of –1/3e.
Describe the quark composition of anti-protons and anti-neutrons and use this to deduce the charge on each of these particles.

(4)

(Total for Question 17 = 16 marks)

TOTAL FOR SECTION B = 70 MARKS

TOTAL FOR PAPER = 80 MARKS