| Class | Index Number | Name |
|---|---|---|
| 24S | | |

## ST. ANDREW'S JUNIOR COLLEGE
## JC 2 2025
## Preliminary Examination

**PHYSICS, Higher 2**  **9749/01**

Paper 1 Multiple Choice  **19th September 2025**
**1 hour**

Additional Materials: Multiple Choice Answer Sheet

### READ THESE INSTRUCTIONS FIRST

Write in soft pencil..
Do not use staples, paper clips, glue or correction fluid.
Write your name, index number and Civics Group the Answer Sheet in the spaces provided.

There are **thirty** questions in this paper. Answer **all** questions. For each question there are four possible answers **A, B, C** and **D**.
Choose the **one** you consider correct and record your choice in **soft pencil** on the separate Answer Sheet.

Each correct answer will score one mark. A mark will not be deducted for a wrong answer.
Any rough working should be done in this booklet.
The use of an approved scientific calculator is expected, where appropriate.

| For Examiner's Use | |
|---|---|
| Total | / 30 |

This document consists of **19** printed pages including this page.

2

## Data

| | |
|---|---|
| speed of light in free space | $c = 3.00 \times 10^8$ m s$^{-1}$ |
| permeability of free space | $\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$ |
| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}$ F m$^{-1}$ |
| | $= (1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ |
| elementary charge | $e = 1.60 \times 10^{-19}$ C |
| the Planck constant | $h = 6.63 \times 10^{-34}$ J s |
| unified atomic mass constant | $u = 1.66 \times 10^{-27}$ kg |
| rest mass of electron | $m_e = 9.11 \times 10^{-31}$ kg |
| rest mass of proton | $m_p = 1.67 \times 10^{-27}$ kg |
| molar gas constant | $R = 8.31$ J K$^{-1}$ mol$^{-1}$ |
| the Avogadro constant | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| the Boltzmann constant | $k = 1.38 \times 10^{-23}$ J K$^{-1}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ |
| acceleration of free fall | $g = 9.81$ m s$^{-2}$ |

## Formulae

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| work done on/by a gas | $W = p\,\Delta V$ |
| hydrostatic pressure | $p = \rho g h$ |
| gravitational potential | $\phi = -\dfrac{Gm}{r}$ |
| temperature | $T/K = T/{}^\circ C + 273.15$ |
| pressure of an ideal gas | $p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$ |
| mean translational kinetic energy of an ideal gas molecule | $E = \dfrac{3}{2}kT$ |
| displacement of particle in s.h.m. | $x = x_0 \sin \omega t$ |
| velocity of particle in s.h.m. | $v = v_0 \cos \omega t$ |
| | $v = \pm \omega \sqrt{x_0^2 - x^2}$ |
| electric current | $I = Anvq$ |
| resistors in series | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| electric potential | $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ |
| alternating current/voltage | $x = x_0 \sin \omega t$ |
| magnetic flux density due to a long straight wire | $B = \dfrac{\mu_0 I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil | $B = \dfrac{\mu_0 N I}{2r}$ |
| magnetic flux density due to a long solenoid | $B = \mu_0 n I$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \dfrac{\ln 2}{t_{1/2}}$ |

3

## Answer all questions.

1 The Clausius-Clapeyron equation for measuring relative vapour pressure of a gas $\dfrac{P}{P_o}$ , at a temperature T is as follows:

$$\frac{P}{P_o} = e^{-\frac{\Delta H}{R}\left(\frac{1}{T}-\frac{1}{T_o}\right)}$$

where $\Delta H$ is the enthalpy of vaporization, $R$ is the molar gas constant, $P$ and $P_o$ are the final and initial pressures and $T_o$ is the initial temperature of a gas.

Which of the following has the same units as $\Delta H$?

**A**    energy per mole

**B**    molar gas constant

**C**    temperature

**D**    no units

2 A student made a series of measurements of the diameter $d$ of a wire using four micrometer screw gauges A, B, C and D. The table shows the measurements taken.

If the actual diameter of the wire was 1.49 mm, which micrometer screw gauge produced a set of readings that could be described as accurate but not precise?

| micrometer screw gauge | Readings $d$ / mm | | | |
|---|---|---|---|---|
| A | 1.49 | 1.46 | 1.52 | 1.50 |
| B | 1.48 | 1.58 | 1.51 | 1.40 |
| C | 1.35 | 1.37 | 1.42 | 1.42 |
| D | 1.32 | 1.37 | 1.41 | 1.50 |

3   Two cars, initially next to each other and at rest, accelerate in the same straight line at different uniform rates. After 3 s, they are 36 m apart.
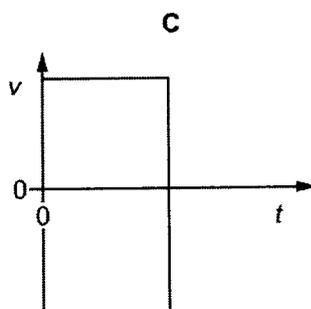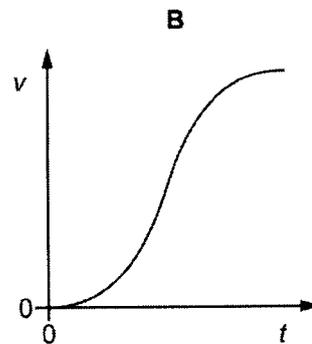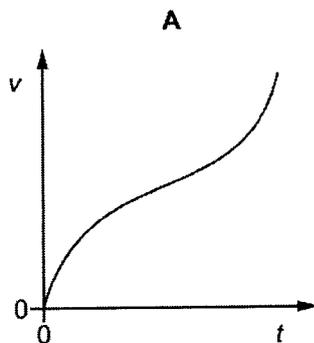
If they continue to accelerate at the same rate, how far apart will they be 5 s after they started?

A   60 m          B   96 m          C   100 m          D   256 m

4   A golf club hits a golf ball. The graph shows how the force $F$ on the ball varies with time $t$.
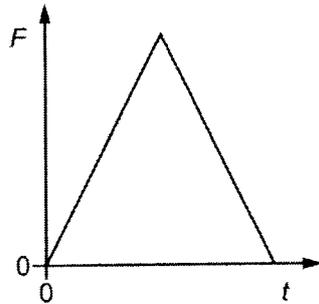


Which graph shows how the velocity $v$ of the ball varies with time $t$?

A



B



C



D
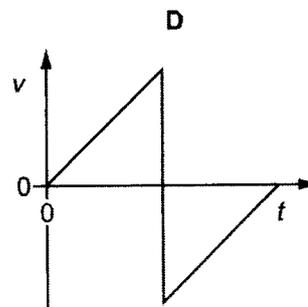
5   A stream of water from a hose travels horizontally at speed $v$. The stream strikes a brick wall and falls vertically down it without splashing.

The stream of water is a cylinder of cross-sectional area $A$. The water has density $\rho$.

Which expression is the force exerted on the wall by the water?

A   $\frac{1}{2}A\rho v^2$       B   $A\rho v^2$       C   $\frac{3}{2}A\rho v^2$       D   $2A\rho v^2$

6   Two train carriages each of mass 5000 kg roll toward one another on a horizontal frictionless track. One is travelling at a velocity of $u_1$ and the other at a velocity of $u_2$, as shown.
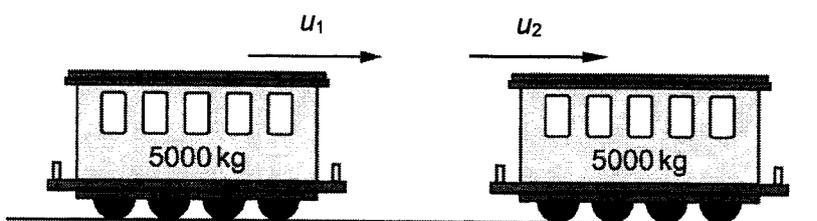


They collide and join together and have a final speed of 0.50 m s$^{-1}$ towards the right after the collision. During the collision, 11 250 J of kinetic energy was lost.

Taking rightward to be positive, what is $u_2$?

A   $-2.0$ m s$^{-1}$       B   $-1.0$ m s$^{-1}$       C   $1.0$ m s$^{-1}$       D   $2.0$ m s$^{-1}$

7  A block is moving along a horizontal frictionless surface. A constant force $F$ and a constant resistive force of 5.0 N act on the block as it is moving in the direction of the force $F$, as shown.

direction of movement

$F$ → [block] ← 5.0 N    frictionless surface
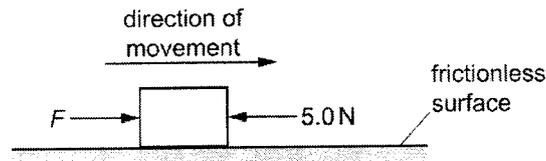
The graph shows the variation with time of the momentum of the block.

momentum / kg m s$^{-1}$

2.7
1.5
0        0.40
time / s
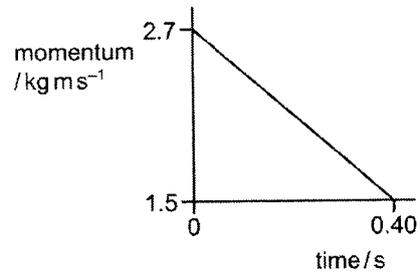
What is the magnitude of force $F$?

A    2.0 N            B    4.2 N            C    5.8 N            D    8.0 N

8  A climber is supported by a light rope on a vertical wall as shown.

P

$T$

18°

wall    →$R$

$W$
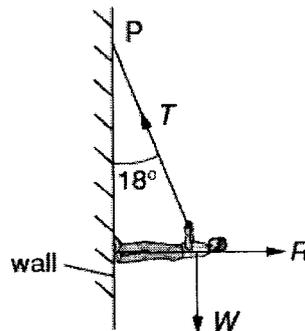
The weight $W$ of the climber is 520 N and the reaction force $R$ acts at right angles to the wall. The climber is in equilibrium.

Which row shows the value of the tension $T$ in the rope and $R$?

|   | $T$ / N | $R$ / N |
|---|---|---|
| A | 500 | 150 |
| B | 500 | 480 |
| C | 550 | 170 |
| D | 550 | 520 |

**9** On a fairground ride, passengers are rotated in a vertical circle at a constant angular speed. A passenger is shown in the diagram when he is at the side of the circle.
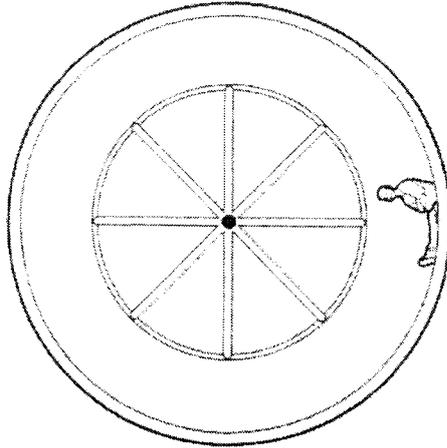


Which of the following diagrams best illustrates the forces acting on the passenger in this position?

**A**



**B**



**C**



**D**
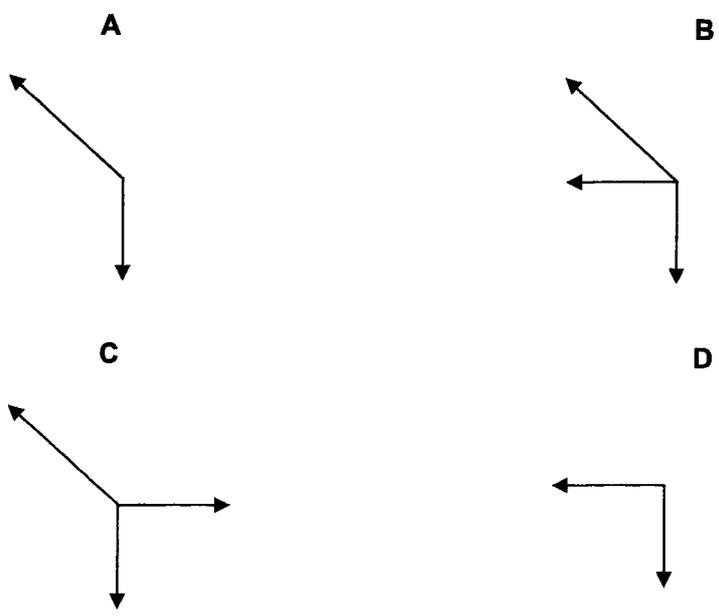
10   A small glass marble is moving in a horizontal circle round the inside surface of a smooth bowl. Its angular velocity is 8.0 rad s$^{-1}$ and the normal reaction $N$ acting on the marble is inclined at 35° to the vertical as shown.
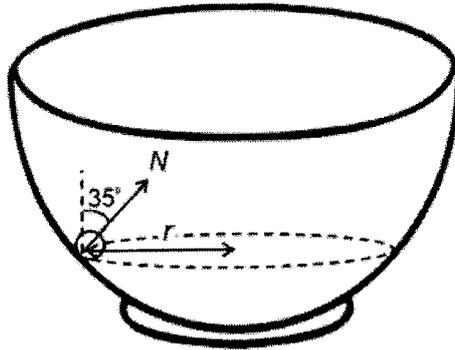
What is the radius $r$ of the horizontal circle?

A   0.050 m          B   0.070 m          C   0.090 m          D   0.11 m

11   Many highway entrance and exit roads are circular and designed for cars moving at 50 km h$^{-1}$.
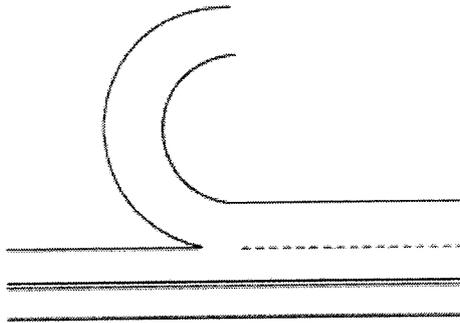
To design a similar road for a speed of 100 km h$^{-1}$ the engineers should increase the radius of the circular section by a factor of

A   $\sqrt{2}$          B   2          C   3          D   4

12    A mass *m* is situated in a uniform gravitational field.
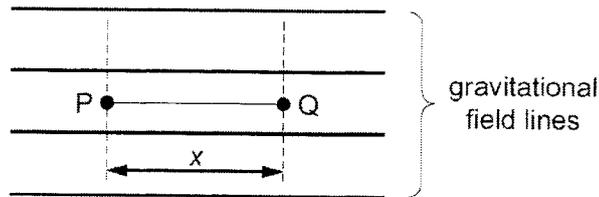


When the mass moves through a displacement *x*, from P to Q, it loses an amount of potential energy *E*.

Which row correctly specifies the magnitude and the direction of the acceleration due to gravity in this field?

| | magnitude | direction |
|---|---|---|
| A | $\dfrac{E}{mx}$ | → |
| B | $\dfrac{E}{mx}$ | ← |
| C | $\dfrac{E}{x}$ | → |
| D | $\dfrac{E}{x}$ | ← |

13    A fixed amount of an ideal gas has pressure *p* and volume *V*. The graph shows the variation of 1/*p* with *V* at a constant temperature.
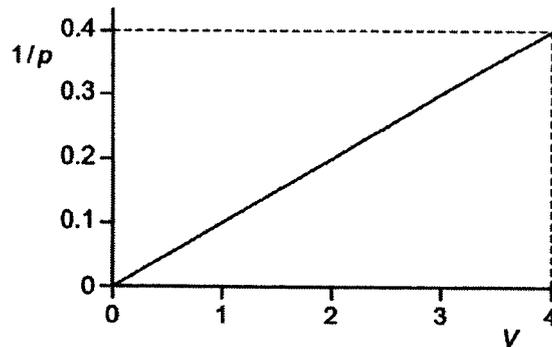


The amount of gas and the thermodynamic temperature are both halved. Which line will be produced?
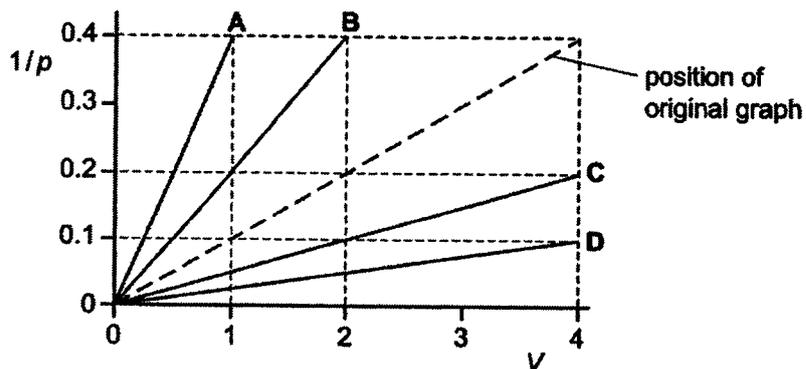
**14** The graphs below show how $pV$ varies with $p$, for a sample of nitrogen gas and oxygen gas at the temperature of a boiling liquid and at the temperature of the triple point of water in a constant volume gas thermometer.
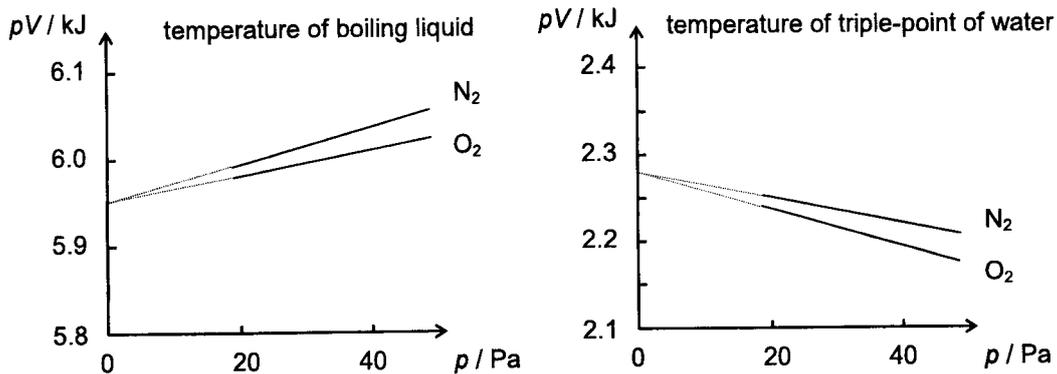


Which of the following is the probable thermodynamic temperature of the boiling liquid?

**A** 2.6 K **B** 13.5 K **C** 373 K **D** 714 K

**15** A particle of a mass of 90.0 g undergoes simple harmonic motion. The graph below shows the variation of its kinetic energy, $E_K$ with time, $t$.
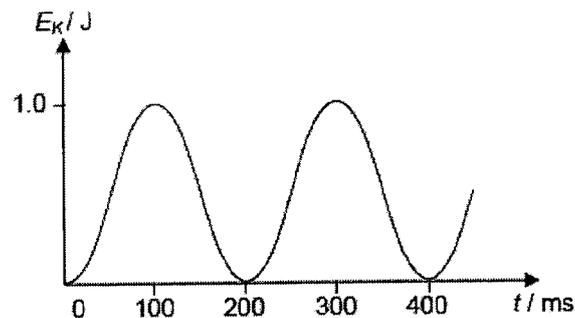


What is the maximum acceleration of the particle?

**A** $0.074 \text{ m s}^{-2}$ **B** $0.148 \text{ m s}^{-2}$ **C** $37 \text{ m s}^{-2}$ **D** $74 \text{ m s}^{-2}$

16   The graph shows the variation with time of the displacement X of an air particle as a continuous sound wave passes through the air.
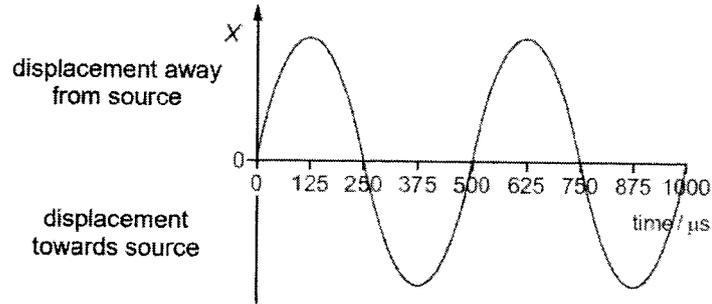


The speed of sound in the air is 330 m s⁻¹. All the graphs below have the same scales for the time axes as the graph above.

What is the displacement-time graph for another particle that is 0.04125 m away in the direction of the wave motion from this particle?
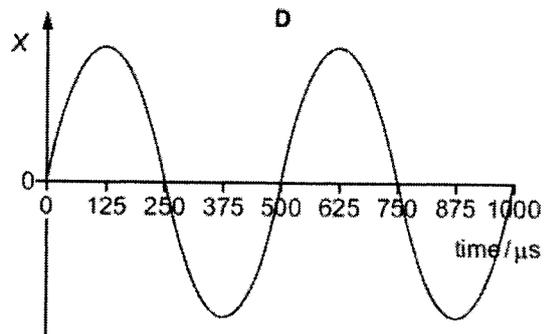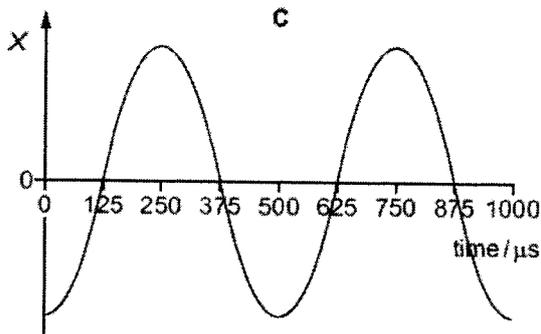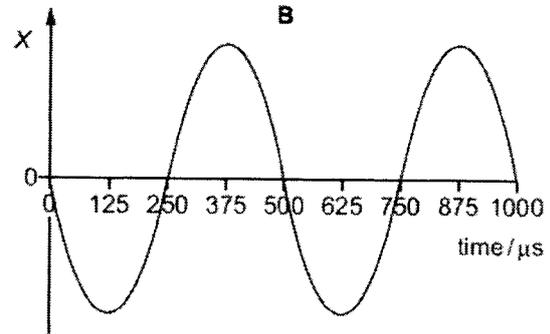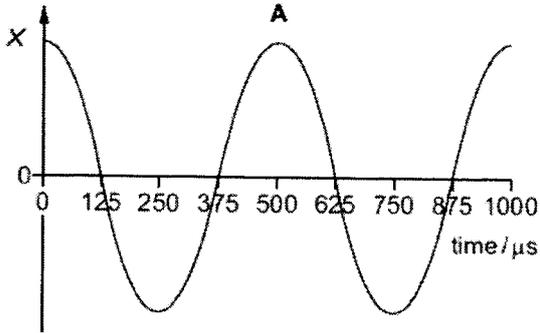
17 A student investigates the polarisation of microwaves. The microwaves from the transmitter are vertically polarised. A metal grille acts as a polarising filter when placed between the microwave transmitter and the receiver. The reading on the voltmeter is proportional to the intensity of microwaves transmitted through the grille.

When the transmission axis of the grille is vertical, the voltmeter reads 3.50 V.
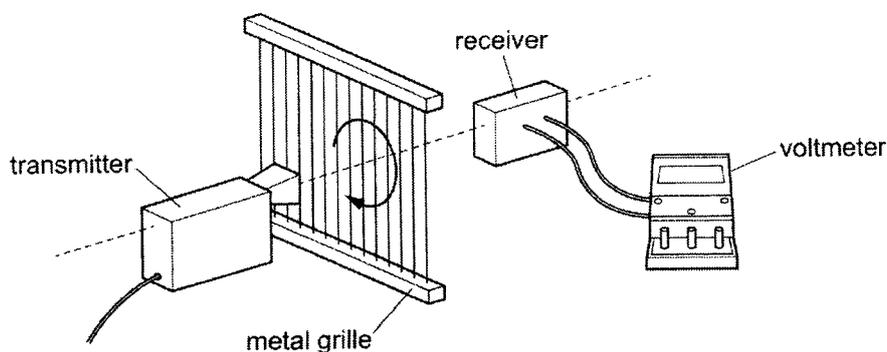


The grille is then rotated through an angle $\theta$. The voltmeter now reads 2.20 V.

What is $\theta$?

A   37.5°          B   39.0°          C   51.0°          D   52.5°

18 A parallel beam of light of wavelength 600 nm is incident normally on a diffraction grating. The grating has 500 lines per millimetre.
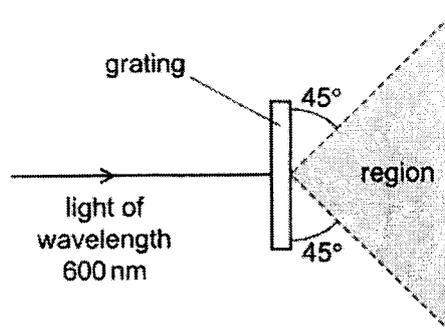


How many beams of coherent light emerge from the grating within the shaded region shown in the diagram?

A   2          B   3          C   4          D   5

**19** An electromagnetic wave is diffracted as it passes through a single slit. The width of the slit is larger than the wavelength of the wave.

Which change will decrease the amount of diffraction of the wave?

**A** Decrease the frequency of the wave.

**B** Decrease the time period of the wave.

**C** Decrease the width of the slit.

**D** Increase the wavelength of the wave.

**20** A conductor consists of three wires connected in series. The wires are all made of the same metal but have different cross-sectional areas. There is a current $I$ in the conductor.
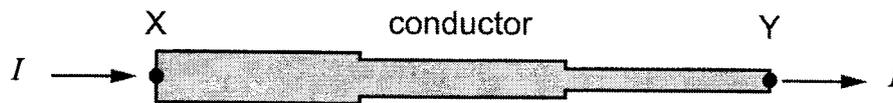


Point Y on the conductor is at zero potential. Which graph best shows the variation of potential $V$ with distance along the conductor?

**A**



**B**



**C**



**D**
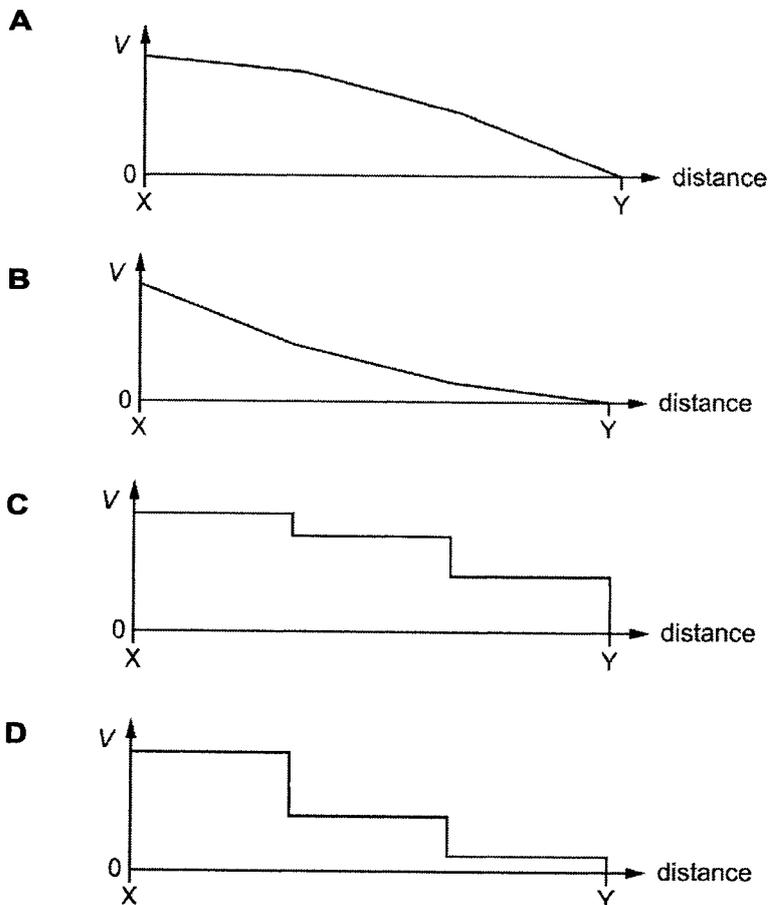
21  A circuit is needed which switches on a warning lamp when the temperature of a thermistor is too high.

Which of the following circuits is suitable?

**A**



**B**



**C**



**D**
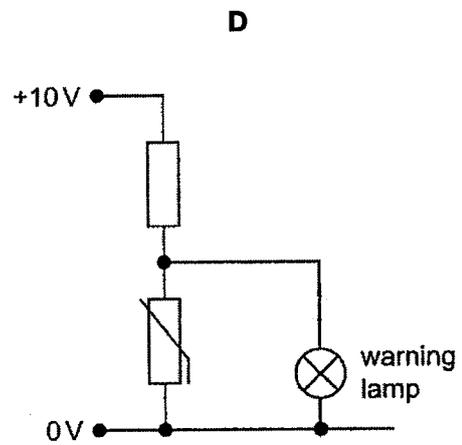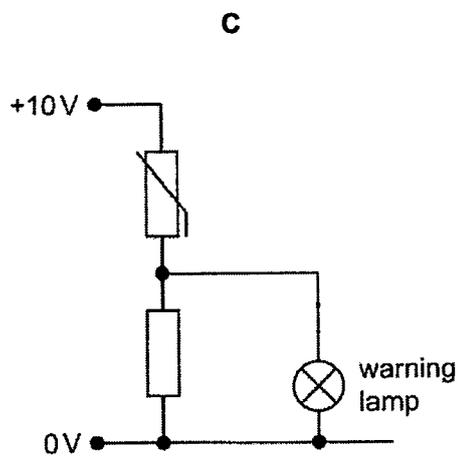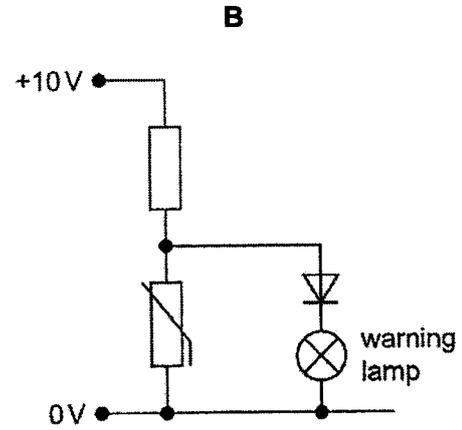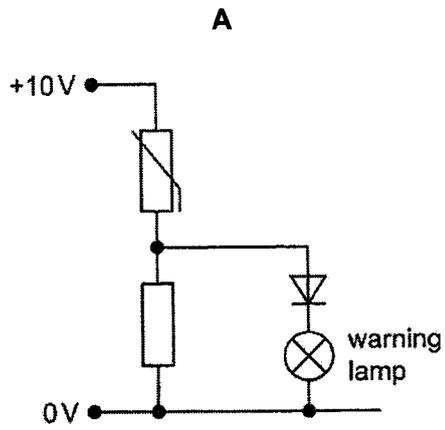
**22** Two charges +2Q and -Q are situated as shown below.

At which point can the resultant potential due to the two charges be zero?



**23** A wire carries a 7.00 A current along the x-axis and another wire carries a 6.00 A current along the y-axis, as shown below.
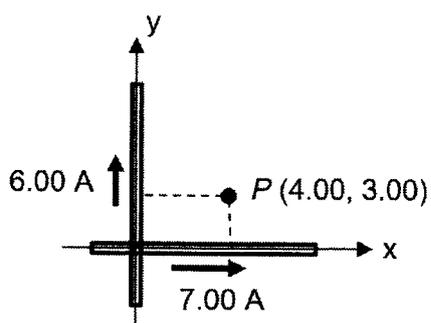


Which of the following shows the magnetic flux density at point P, located at x = 4.00 m, y = 3.00 m?

|   | Magnetic flux density / T | Direction |
|---|---------------------------|-----------|
| A | $1.67 \times 10^{-7}$ | out of page |
| B | $1.67 \times 10^{-7}$ | into page |
| C | $7.67 \times 10^{-7}$ | out of page |
| D | $7.67 \times 10^{-7}$ | into page |

24 The figure below shows a copper disc rotating steadily about its centre O in a uniform magnetic field between two bar magnets. The magnetic field is acting perpendicularly to the disc.
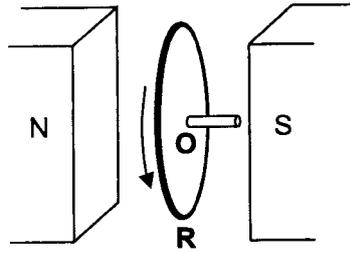


Which of the following graphs correctly shows the variation of the induced e.m.f. $\varepsilon$ between the centre O and a point R on the rim of the disc with time $t$?

A



B



C



D
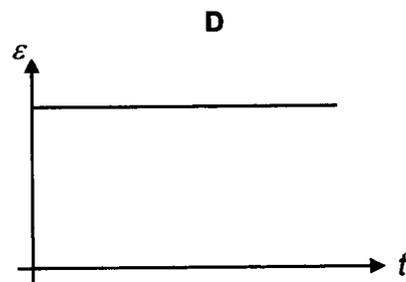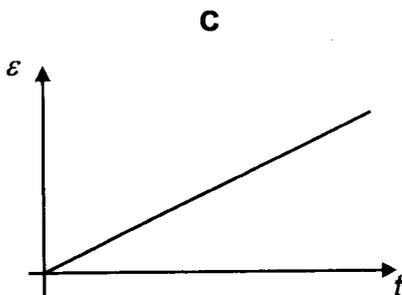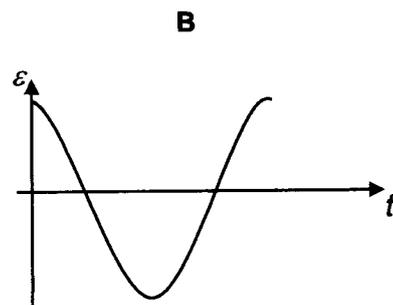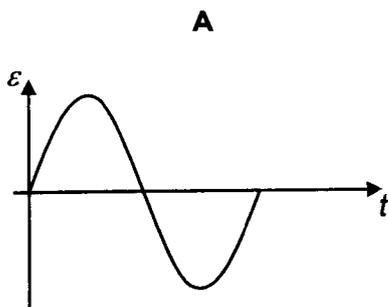
**25** A rigid conducting coil has 100 turns and a cross-sectional area of 8.0 x 10⁻³ m². It is freely suspended by a non-conducting cord. A uniform magnetic field is directed at right angles to the plane of the loop as shown in the figure.
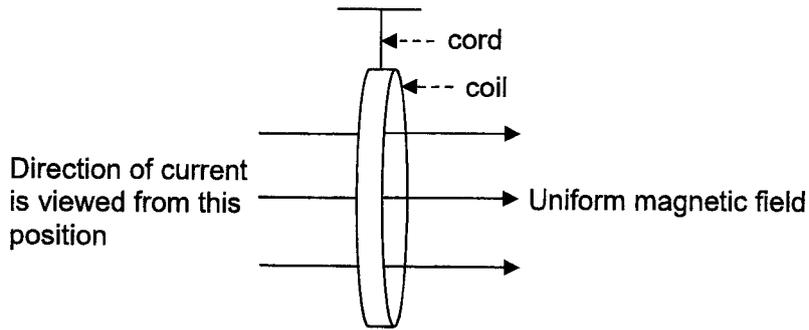


The magnetic flux density of the uniform magnetic field is changed steadily from 20 mT to 80 mT over a period of 4.0 s.

What is the direction of the induced current as viewed from the position indicated in the figure and the average e.m.f. induced in the coil during this time?

|   | Direction of induced current | Magnitude of induced e.m.f. / V |
|---|---|---|
| **A** | clockwise | $1.6 \times 10^{-2}$ |
| **B** | anti-clockwise | $1.6 \times 10^{-2}$ |
| **C** | clockwise | $1.2 \times 10^{-2}$ |
| **D** | anti-clockwise | $1.2 \times 10^{-2}$ |

**26** A generator produces a current of 60 A r.m.s. at a voltage of 120 V r.m.s. The voltage is stepped up to 4500 V r.m.s. by an ideal transformer and transmitted through a power line of total resistance 1.0 Ω.

What percentage of the power is lost in the transmission line?

**A** 0.048 %      **B** 0.036 %      **C** 0.024 %      **D** 0.018 %

27    A metal surface is illuminated with a beam of monochromatic electromagnetic radiation. By the photoelectric effect, photoelectrons may be emitted from the metal surface.

Which statement about the photoelectrons is correct?

A    No emission of photoelectrons occurs if the radiation is of a very low intensity.

B    Photoelectrons are emitted only if the wavelength of the radiation is greater than a minimum value.

C    The maximum speed of the photoelectrons emitted increases when the intensity of the radiation increases at constant frequency.

D    The rate of emission of photoelectrons decreases when the frequency of the radiation increases at constant intensity.

28    The following graph shows the spectrum of X-rays emitted from an X-ray tube.
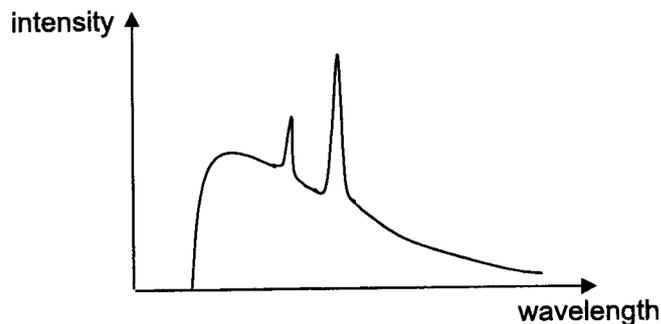


If the potential difference between the target and cathode is increased, which one of the following combinations represents a possible change in wavelength and intensity of the peaks?

|   | wavelength | intensity |
|---|---|---|
| A | remain the same | Increase |
| B | decrease | remain the same |
| C | remain the same | remain the same |
| D | decrease | increase |

**29** The rest-masses of deuteron $^2_1H$, proton and neutron are 2.0150u, 1.0086u and 1.0097u respectively. Which one of the following reactions takes place so that the deuteron may disintegrate to a proton and neutron?

   **A** Releasing a photon of energy 2 MeV.

   **B** Releasing a photon of energy 3 MeV.

   **C** Capturing a photon of energy 2 MeV.

   **D** Capturing a photon of energy 3 MeV.

**30** In a therapy unit, patients are given treatment from a certain radioactive source. This source has a half-life of 4 years. A particular treatment requires 10 minutes of irradiation when the source is first used.

How much time is required for this treatment, using the same source, 2 years later?

   **A** 7 minutes   **B** 12 minutes   **C** 14 minutes   **D** 20 minutes

**End of Paper**

| Class | Index Number | Name |
|---|---|---|
| 24S | | |

## ST. ANDREW'S JUNIOR COLLEGE
## JC 2 2025
### Preliminary Examination

**PHYSICS, Higher 2**  9749/02

Paper 2 Structured Questions

**3rd September 2025**
**2 hours**

Candidates answer on the Question Paper.
No additional materials are required.

### READ THESE INSTRUCTIONS FIRST

Write your name, index number and Civics Group on all the work you hand in.
Write in dark blue or black pen.
You may use a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Answer **all** questions.

At the end of the examination, fasten all your work securely together.
The number of marks is given in brackets [ ] at the end of each question or part question.

| For Examiner's Use | |
|---|---|
| 1 | / 12 |
| 2 | / 8 |
| 3 | / 7 |
| 4 | / 10 |
| 5 | / 10 |
| 6 | / 13 |
| 7 | / 20 |
| Total | / 80 |

This document consists of **23** printed pages including this page.

## Data

| | |
|---|---|
| speed of light in free space, | $c = 3.00 \times 10^8$ m s$^{-1}$ |
| permeability of free space, | $\mu_0 = 4\pi \times 10^{-7}$ H m$^{-1}$ |
| permittivity of free space, | $\varepsilon_0 = 8.85 \times 10^{-12}$ F m$^{-1}$ |
| | $= (1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ |
| elementary charge, | $e = 1.60 \times 10^{-19}$ C |
| the Planck constant, | $h = 6.63 \times 10^{-34}$ J s |
| unified atomic mass constant, | $u = 1.66 \times 10^{-27}$ kg |
| rest mass of electron, | $m_e = 9.11 \times 10^{-31}$ kg |
| rest mass of proton, | $m_p = 1.67 \times 10^{-27}$ kg |
| molar gas constant, | $R = 8.31$ J K$^{-1}$ mol$^{-1}$ |
| the Avogadro constant, | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| the Boltzmann constant, | $k = 1.38 \times 10^{-23}$ J K$^{-1}$ |
| gravitational constant, | $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ |
| acceleration of free fall, | $g = 9.81$ m s$^{-2}$ |

## Formulae

| | |
|---|---|
| uniformly accelerated motion, | $s = ut + \tfrac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| work done on/by a gas, | $W = p\,\Delta V$ |
| hydrostatic pressure, | $p = \rho g h$ |
| gravitational potential, | $\phi = -\dfrac{Gm}{r}$ |
| temperature, | $T/K = T/^{\circ}C + 273.15$ |
| pressure of an ideal gas, | $p = \dfrac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$ |
| mean translational kinetic energy of an ideal gas molecule, | $E = \dfrac{3}{2}kT$ |
| displacement of particle in s.h.m., | $x = x_0 \sin \omega t$ |
| velocity of particle in s.h.m., | $v = v_0 \cos \omega t$ |
| | $v = \pm \omega \sqrt{x_0^2 - x^2}$ |
| electric current | $I = Anvq$ |
| resistors in series, | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel, | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| electric potential, | $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ |
| alternating current/voltage, | $x = x_0 \sin \omega t$ |
| magnetic flux density due to a long straight wire, | $B = \dfrac{\mu_0 I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil, | $B = \dfrac{\mu_0 NI}{2r}$ |
| magnetic flux density due to a long solenoid, | $B = \mu_0 nI$ |
| radioactive decay, | $x = x_0 \exp(-\lambda t)$ |
| decay constant, | $\lambda = \dfrac{\ln 2}{t_{1/2}}$ |

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

**1**  A toy car with a rocket engine moves along a horizontal track, as shown in Fig. 1.1.
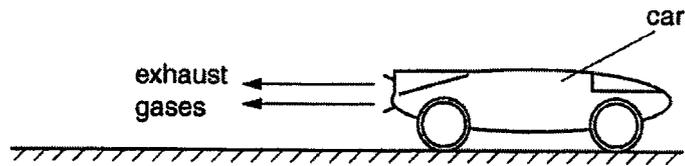


**Fig. 1.1**

The rocket engine produces a constant forward force of 4.6 N. The car loses mass continuously as exhaust gases are produced by the rocket.

**(a)**  Use momentum considerations to explain why the rocket produces a forward force on the car.

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.......................................................................................................................... [3]

**(b)**  The variation with time $t$ of the speed $v$ of the car is shown in Fig. 1.2.
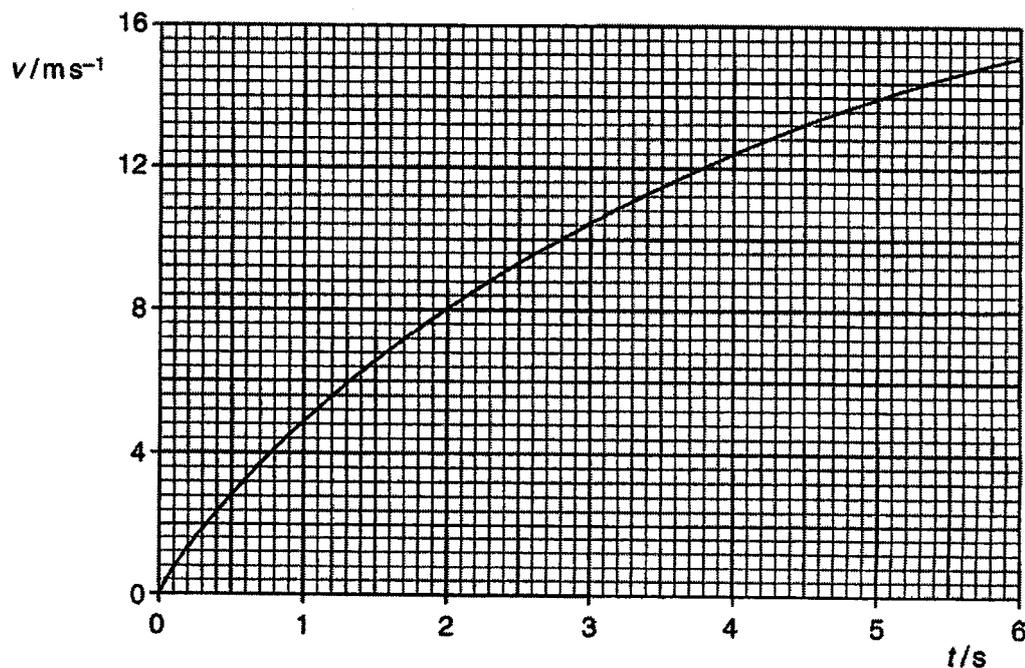


**Fig. 1.2**

At time $t$ = 2.0 s, the mass of the car is 440 g.

**(i)** For the time $t = 2.0$ s,

**1.** use Fig. 1.2 to determine the acceleration of the car,

acceleration = ........................ m s$^{-2}$ [2]

**2.** use your answer in **(i) part 1** to determine the magnitude of the resistive force acting on the car.

force = ........................ N [2]

**(ii)** Explain how it can be deduced that the resistive forces acting on the car increase with increase of speed.

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.................................................................................................................. [2]

**(c)** The toy car is now re-fuelled and then rotated so that it is pointing upwards.
It is suggested that the rocket engine produces sufficient force to propel the car vertically. By considering the acceleration of the car at time $t = 0$ in Fig. 1.2, comment on this suggestion.

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.................................................................................................................................

.................................................................................................................. [3]

**2**　**(a)**　State the principle of moments.

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**(b)**　A rigid uniform beam rests on a pivot at its centre, as shown in Fig. 2.1.
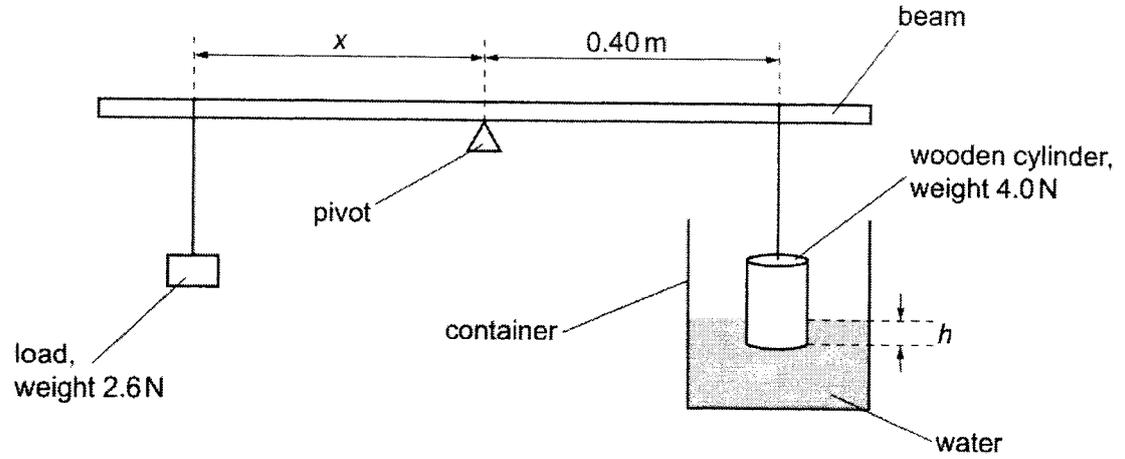


**Fig. 2.1** (not to scale)

A load of weight 2.6 N is suspended from the beam at distance $x$ from the pivot.

A wooden cylinder of weight 4.0 N is suspended from the beam at a distance of 0.40 m from the pivot on the opposite side of the pivot to the load. The cylinder rests in a container of water. The lower part of the cylinder is immersed in the water to depth $h$.

Initially, $h$ is equal to 0.10 m and $x$ is equal to 0.40 m. The system is in equilibrium.

**(i)**　Use the principle of moments to show that the upthrust $U$ exerted by the water on the cylinder is 1.4 N.

[2]

**(ii)** The density of the water is $1.0 \times 10^3$ kg m$^{-3}$.

Calculate the area $A$ of the circular cross-section of the cylinder.

$A =$ .............................. m$^2$ [2]

**(c)** More water is gradually added to the container in **(b)**, so that depth $h$ in Fig. 2.1 gradually increases. The length $x$ is continuously adjusted so that the system remains in equilibrium.

On Fig. 2.2, sketch the variation of $x$ with $h$. Use the space below for any working.
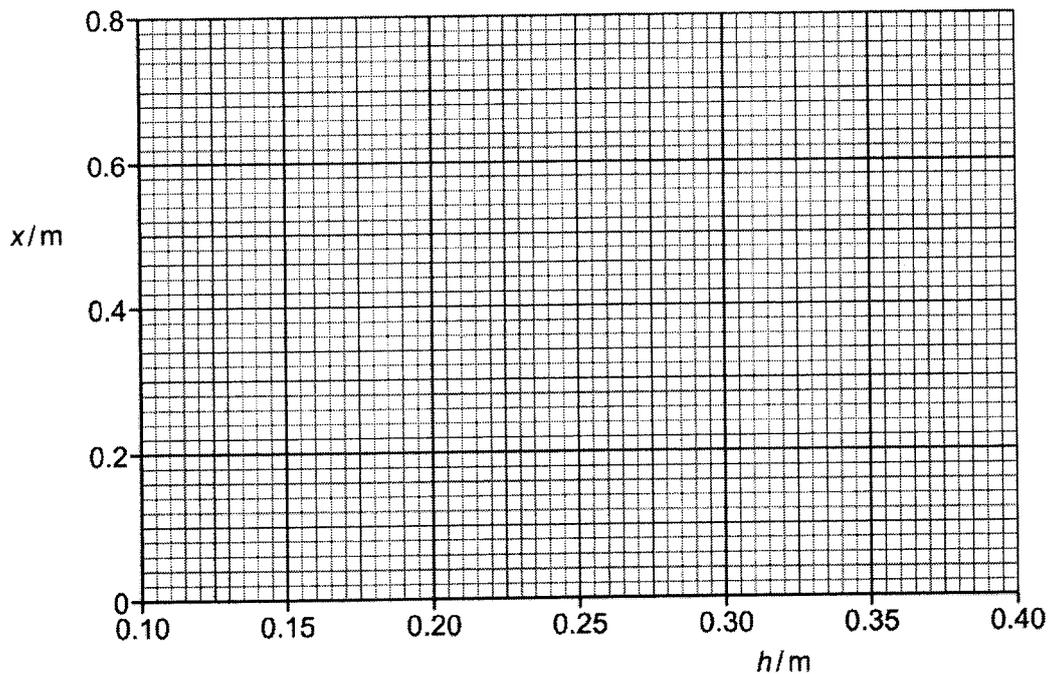


**Fig. 2.2**

[3]

**3** **(a)** A planet may be assumed to be a uniform sphere. It has gravitational potential $\Phi$ at distance $r$ from the centre of the planet. The variation with $1/r$ of $\Phi$ is shown in Fig. 3.1.
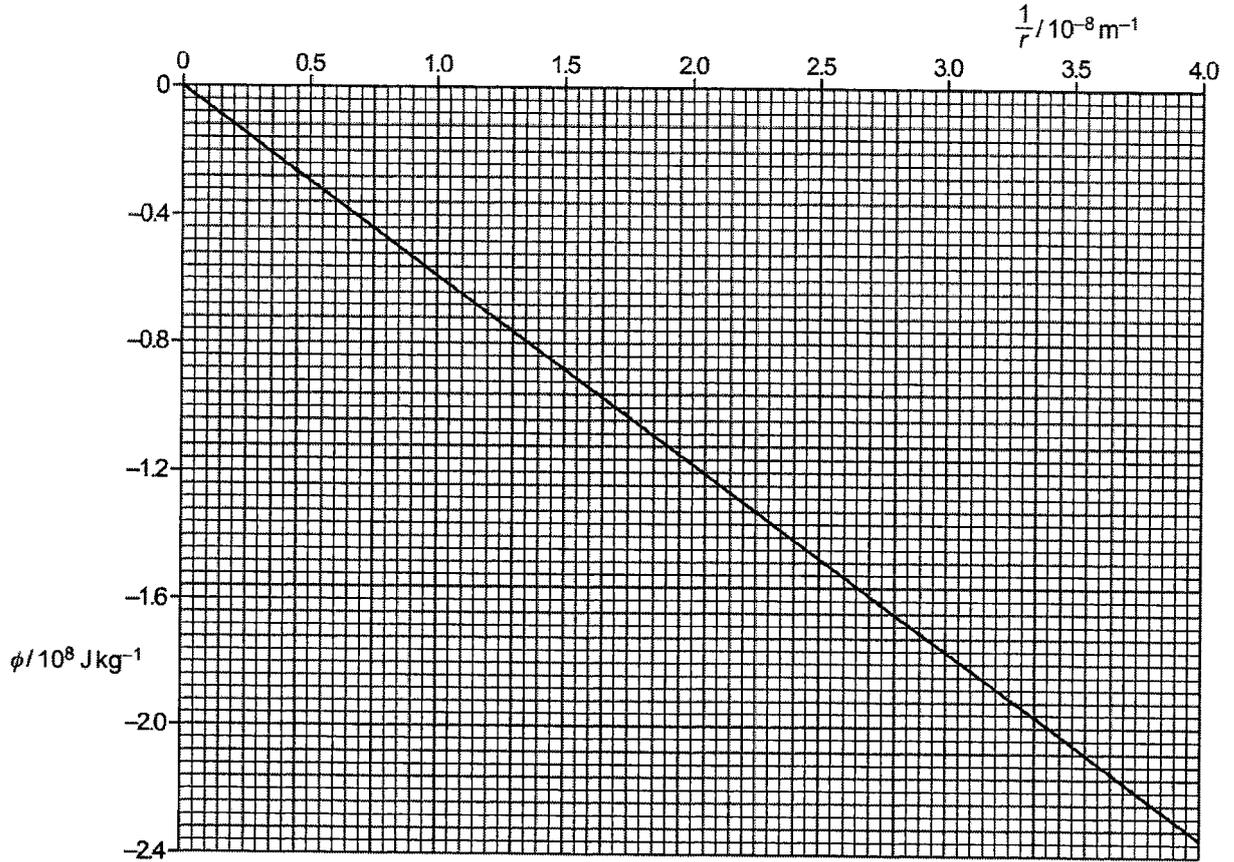


**Fig. 3.1**

**(i)** Show that the mass of the planet is $8.8 \times 10^{25}$ kg.

[2]

**(ii)** The period of rotation of the planet is 0.72 Earth days.

A satellite in orbit around the planet remains above the same point on the surface of the planet. The speed of the satellite is 8400 m s$^{-1}$. The mass of the satellite is 1200 kg.

Determine the additional energy required to move the satellite from its orbit to infinity.

energy required = .................................................... J [3]

**(b)** To move the satellite to a new, stable circular orbit closer to the planet, a short rocket thrust is required to begin the manoeuvre.

Explain the direction of this initial thrust.

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4    Fig. 4.1 shows a mass-spring system placed on a frictionless slope.
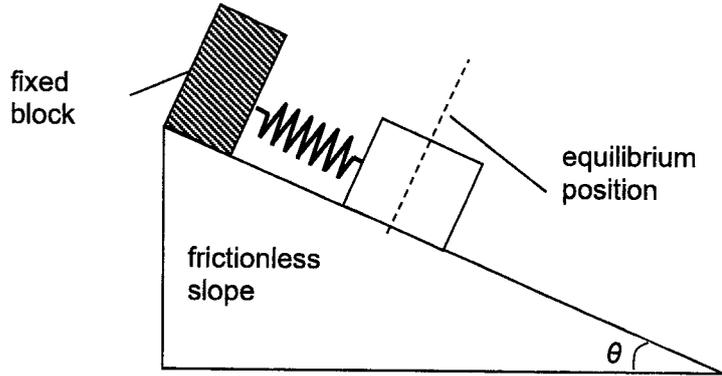


Fig. 4.1

The slope has an angle of $\theta$ from the horizontal. When a block of mass $m$ is hung, the spring stretches by an extension of $e$ and the mass remains in equilibrium.

The spring is further extended by $x$ downwards, along the slope, and released for the mass-spring system to oscillate. The spring constant is $k$.

(a)    Show that the acceleration $a$ of the block at the lowest point is given by $a = -\dfrac{k}{m}x$.

[3]

(b)    Explain how the expression in (a) shows the mass-spring system is oscillating in simple harmonic motion.

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.................................................................................................................... [2]

(c) The amplitude of oscillation of the mass-spring system is 3.0 cm.

Calculate the position of the mass from equilibrium when the speed of the mass is 25% of the maximum speed.

position = ........................ cm [2]

(d) A student removes the fixed block and attaches a variable frequency oscillator to the mass-spring system, as shown in Fig. 4.2.

Fig. 4.3 shows the variation of the amplitude of mass with the frequency of the oscillator.
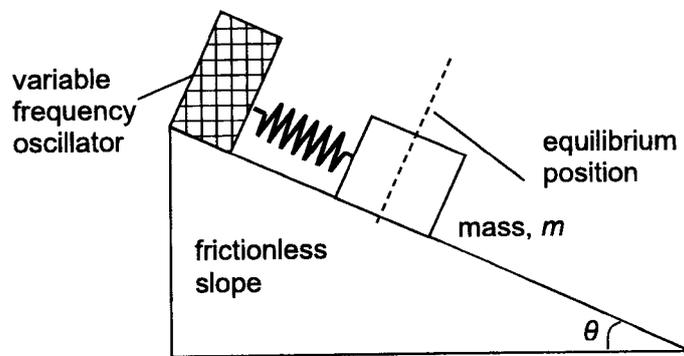


Fig. 4.2
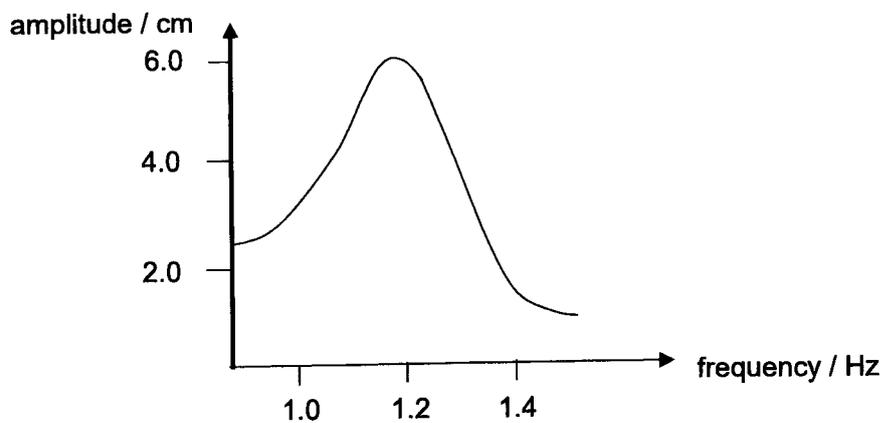


Fig. 4.3

(i) Explain the phenomenon illustrated in Fig. 4.3.

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................................................................................................................................

................................................................................................................................

.................................................................................................................... [2]

(ii) Calculate the magnitude of maximum acceleration of the mass.

acceleration = ......................... m s$^{-2}$ [1]

5  (a)  State Ohm's law.

..................................................................................................................................

..................................................................................................................................

.............................................................................................................. [1]

(b)  A battery of electromotive force (e.m.f.) 6.2 V and negligible internal resistance is connected in a circuit to a uniform resistance wire, a voltmeter, a fixed resistor and a switch, as shown in Fig. 5.1.
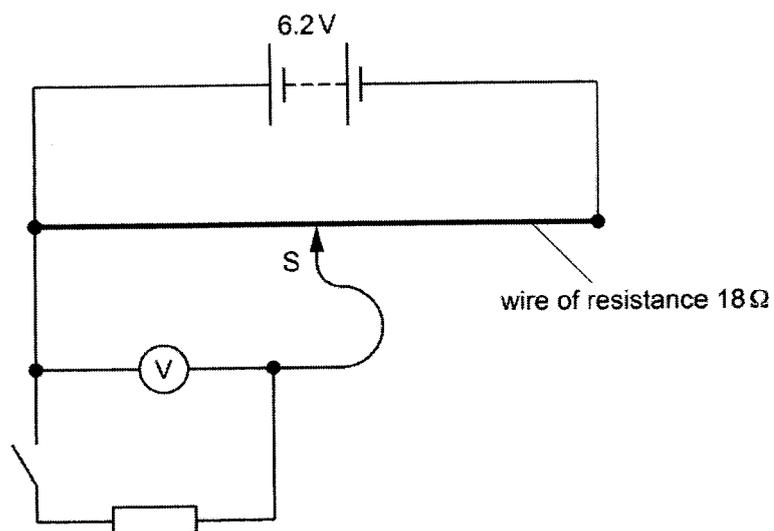


Fig. 5.1

The resistance wire has resistance 18 $\Omega$, length 0.94 m and cross-sectional area $7.2 \times 10^{-8} \, m^2$. The slider S is positioned half-way along the length of the wire.

(i)  Calculate the resistivity $\rho$ of the material of the resistance wire.

$\rho$ = .............................. $\Omega$ m [1]

**(ii)** The switch is now closed.

State whether there is an increase, decrease or no change to:

- the current in the battery

...................................................................................................

- the voltmeter reading.

...................................................................................................

[2]

**(iii)** The switch remains closed. The slider S is moved along the resistance wire so that the voltmeter reading is 3.1 V.

On Fig. 5.1, draw a cross (×) on the resistance wire to show a possible new position of the slider. [1]

**(c)** The circuit in **(b)** is altered by changing the battery for one of a different e.m.f. The switch is open.

A student records the following data for the resistance wire:

| | |
|---|---|
| current in the wire | 0.93 A |
| mean drift speed of charge carriers | $1.3 \times 10^{-3}\,\text{m s}^{-1}$ |
| number density of charge carriers | $9.0 \times 10^{28}\,\text{m}^{-3}$. |

**(i)** Determine the charge $q$ of a charge carrier in the wire suggested by this data.

$q =$ ................................ C [1]

**(ii)** With reference to the value of $q$, explain why the data recorded by the student cannot be correct.

...................................................................................................

...................................................................................................[1]

**(d)** A cell of electromotive force (e.m.f.) 1.8 V and internal resistance $r$ is connected in parallel with a resistor of resistance 6.0 Ω and a filament lamp, as shown in Fig. 5.2.
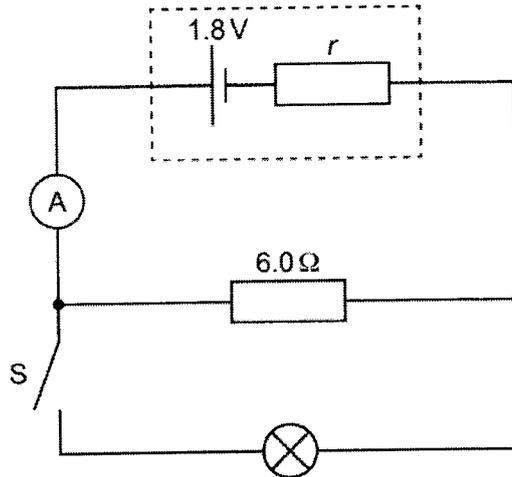


**Fig. 5.2**

Initially, the switch S is open.

At time $t_1$ switch S in Fig. 5.2 is closed. Fig. 5.3 shows the variation with time $t$ of the ammeter reading $I$.
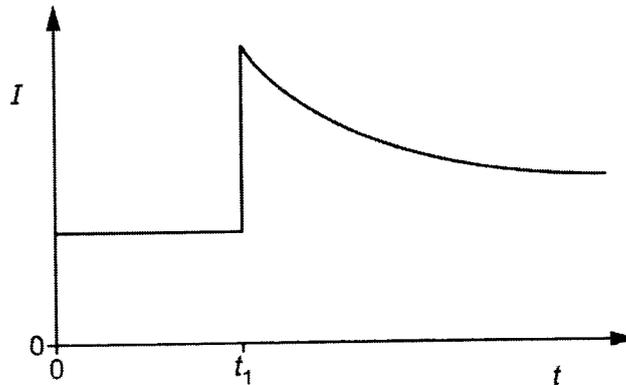


**Fig. 5.3**

By considering the effect of the lamp on the total resistance of the circuit, explain the variation of the ammeter reading shown in Fig. 5.3.

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...................................................................................................... [3]

**6** **(a)** In the fluorescent tube shown in Fig 6.1, electrons are accelerated from the filament and collide with a mercury atom, which is at its ground state.
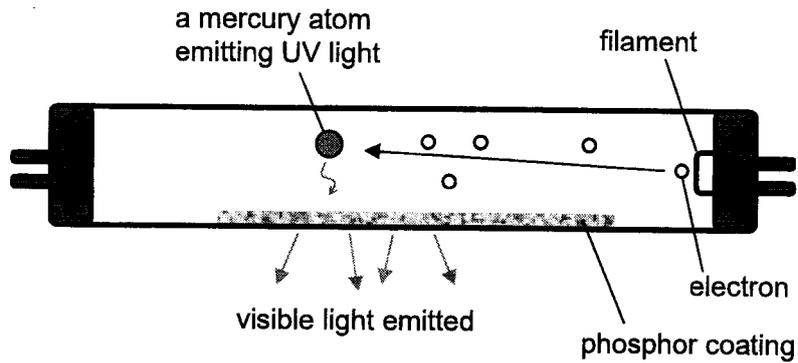


**Fig. 6.1**

Some of the energy levels of a mercury atom are represented in Fig. 6.2.

energy / eV

- — — — — — — — — — — — — — — — — — 0
———————————————— $-1.57$

———————————————— $-5.74$
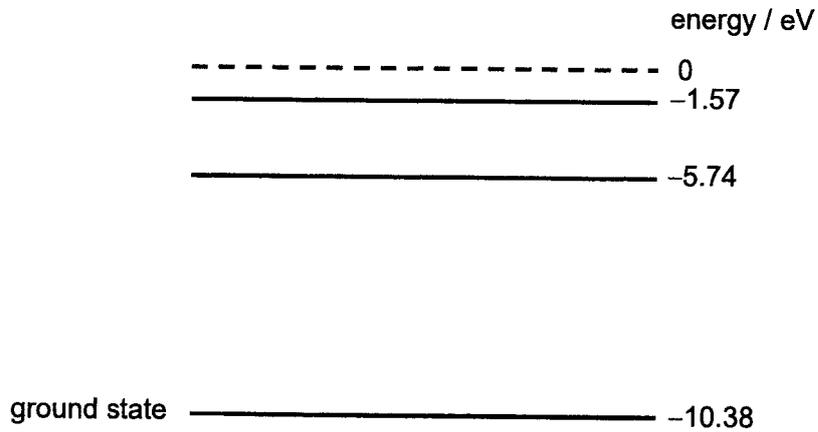
ground state ——————————————— $-10.38$

**Fig. 6.2** (not to scale)

**(i)** In one particular interaction, an electron with kinetic energy 10.0 eV collides with a mercury atom at its ground state.

Determine the longest wavelength of UV radiation that can be emitted due to this interaction.

wavelength =.................................m [2]

(ii) The UV photons emitted by the mercury atoms strike the phosphor coating on the inside of the fluorescent tube. The phosphor absorbs the UV photons and emits visible light by fluorescence.

Fig. 6.3 shows three energy levels $E_1$, $E_2$ and $E_3$ of an atom in the phosphor that are involved in the absorption of UV and emission of infrared and visible light.

On Fig. 6.3, draw arrows to indicate the following transitions:

(1) absorption of a UV photon
(2) emission of a red light photon
(3) emission of an infrared photon

Label the transitions clearly.

$E_3$ ─────────────────

$E_2$ ─────────────────

$E_1$ ─────────────────
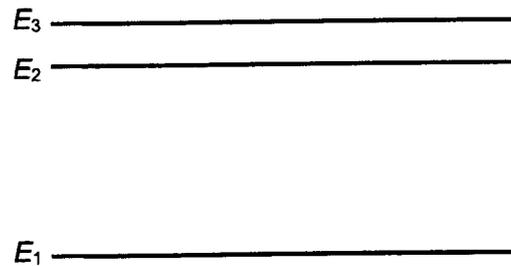
[1]

**Fig. 6.3**

(iii) Explain why the light emitted by the phosphor is of a longer wavelength than the UV light absorbed.

.........................................................................................................................

......................................................................................................................... [1]

(b) In an experiment to demonstrate the wave-particle duality of matter, UV light of wavelength 310 nm is incident on a polished sodium metal plate in a vacuum. The work function of sodium is 2.28 eV.

(i) Explain the energy transformation that occurs during photoelectric emission.

.........................................................................................................................

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......................................................................................................................... [2]

(ii) Calculate the maximum kinetic energy of the photoelectrons emitted from the sodium plate.

maximum kinetic energy = ........................... J [2]

**(c)** The emitted photoelectrons are directed as a beam towards a thin, polycrystalline graphite film. The electrons pass through the film and strike a fluorescent screen, producing a diffraction pattern as shown in Fig. 6.4 due to the wave-like properties of electron.

Assume that this diffraction pattern is formed only by the electrons possessing the maximum kinetic energy calculated in **(b)(ii)**.
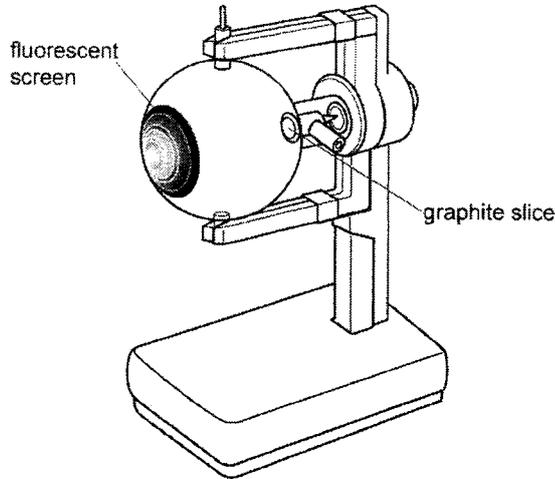


**Fig. 6.4**

**(i)** Determine the de Broglie wavelength of an electron with this maximum kinetic energy.

de Broglie wavelength = ................................. m [2]

**(ii)** Hence, explain why an observable diffraction pattern is formed.

...........................................................................................................................................

....................................................................................................................................... [1]

**(iii)** In reality, photoelectrons are emitted with a range of kinetic energies, from the maximum value calculated in **(b)(ii)** down to zero.

Explain how this range of energies affects the appearance of the diffraction pattern compared to the ideal one discussed in **(c)**.

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...........................................................................................................................................

....................................................................................................................................... [2]

7    Read the passage and answer the questions that follow.

In 1909, Robert Millikan and Harvey Fletcher developed an experiment to determine the fundamental charge of the electron. This was achieved by measuring the charge of oil drops in a known electric field. If each electron has the same charge, then the measured charge on the oil drops must be multiples of the same fundamental constant. Millikan received the Nobel Prize in Physics in 1923 for his precise measurement of this elementary electric charge and for his work on the photoelectric effect.

Fig. 7.1 shows the important features of the apparatus used by Millikan to measure the electron charge by observations on charged oil droplets.
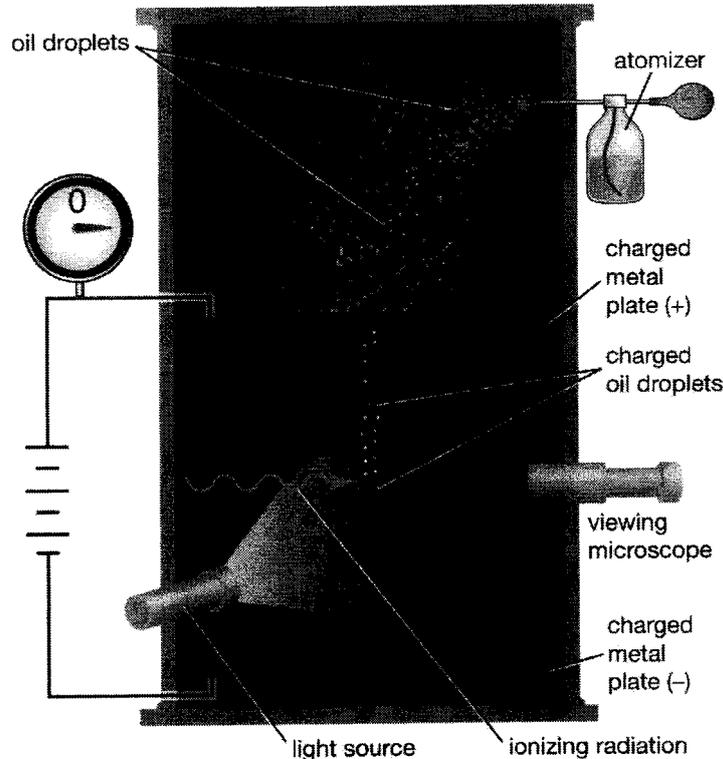


Fig. 7.1

In the apparatus, the viewing microscope is focused on the illuminated space under the hole through which oil droplets can enter. The atomizer introduces a mist of oil droplets through the hole in the top plate that is ionized by X-rays, making them negatively charged. When electric field is applied across the charged metal plates, the potential difference, $V$, between the plates can be adjusted until a particular oil droplet is suspended. The value $V$ that suspends that specific oil droplet can then be measured.

By repeating the experiment multiple times with differently sized oil droplets and recording the potential difference used, the charge of each oil droplet can be determined as small integer multiples of a certain base value of electronic charge. It is proposed that this base value is the elementary electric charge $e$.

In this experiment, the mass of the oil droplet is not measured directly using a scale. Instead, it is calculated after the electric field is removed, causing the oil droplets to fall. They quickly reach a terminal velocity which may be measured using a microscope and stopwatch. The weight of an oil droplet is found by timing its fall at terminal speed over a standard distance, when the potential difference across the plates is zero.

Fig. 7.2 shows the relationship between the weight $W$ of oil droplets and the time $T$ taken by the oil droplets to fall 1.00 mm in air.
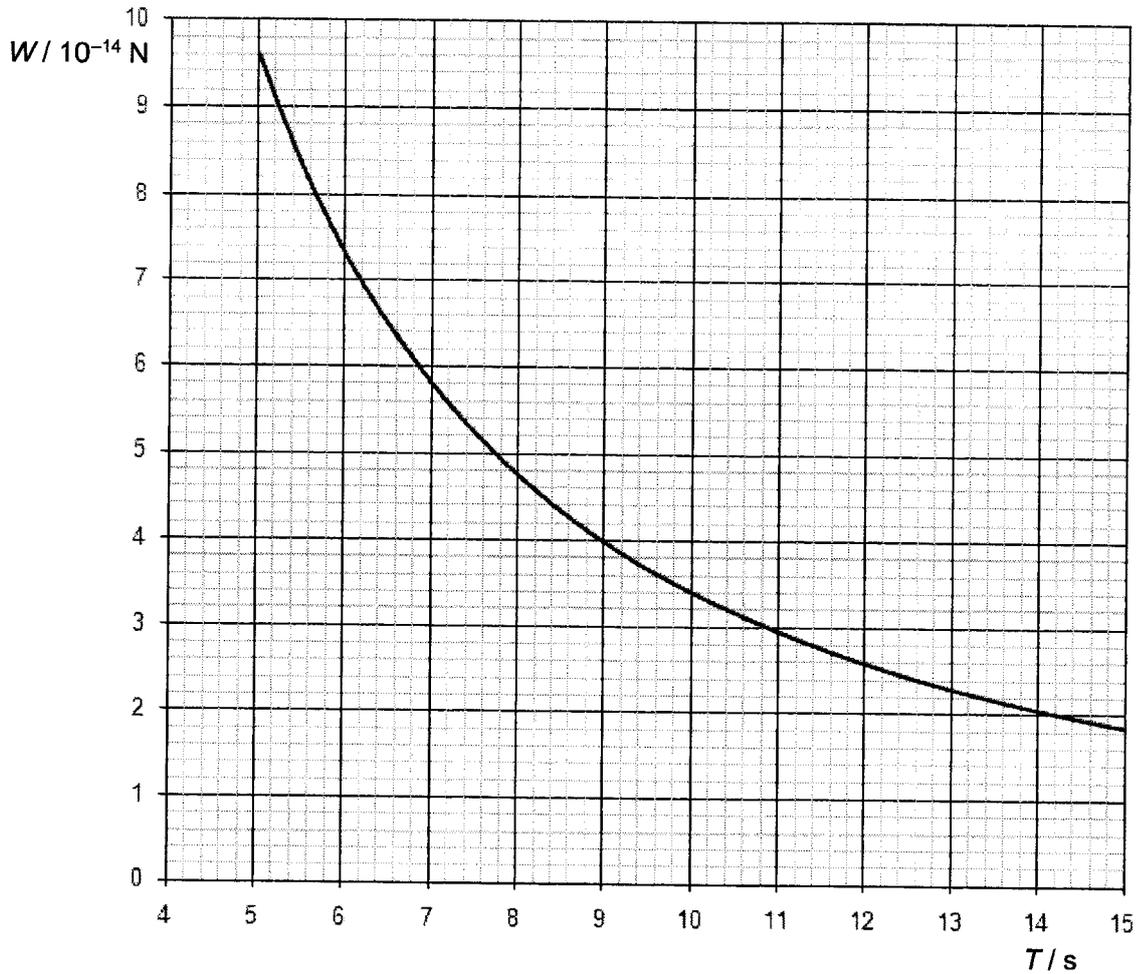


**Fig. 7.2**

The results shown in Fig. 7.3 were obtained with a Millikan apparatus.

For each oil droplet, the experimenter measured $V$ across the plates at which the droplet was observed to be stationary. The distance between the plates was 4.42 mm.

The experimenter also measured the time $T$ for the droplet to fall 1.00 mm in air at terminal speed after switching off the potential difference across the plates.

| $V / V$ | $T / s$ | $W / 10^{-14}$ N | $Q / 10^{-19}$ C |
|---|---|---|---|
| 770 | 11.2 | 2.9 | 1.66 |
| 230 | 10.0 | 3.4 | 6.53 |
| 1030 | 9.4 | 3.7 | 1.59 |
| 470 | 7.6 | | |
| 820 | 6.9 | 5.9 | 3.18 |
| 395 | 6.2 | 7.0 | 7.83 |

**Fig. 7.3**

20

At terminal velocity, the gravitational force is balanced by the drag force, $F_D$, which is given by the following equation,

$$F_D = 6\pi \eta \, r \, v$$

where $\eta$ is the coefficient of viscosity of the fluid and $r$, the radius of the oil droplet.

The coefficient of viscosity of air at room temperature is $1.8 \times 10^{-5}$ kg m$^{-1}$ s$^{-1}$.

**(a)** **(i)** Besides the elementary charge, state another fundamental constant that Millikan's oil drop experiment helped in determining its value.

..................................................................................................................................... [1]

**(ii)** Explain why the space housing the oil droplets between the metal plates should not be a vacuum.

.....................................................................................................................................

..................................................................................................................................... [1]

**(b)** **(i)** Compute the missing values in Fig. 7.3.

$W = $ ...................... $\times 10^{-14}$ N

$Q = $ ...................... $\times 10^{-19}$ C  [3]

**(ii)** When determining the value of $Q$ in **(b)(i)**, explain why it is reasonable to neglect the upthrust of the oil droplet.

.....................................................................................................................................

..................................................................................................................................... [1]

(iii) Using Fig. 7.3, determine, to four significant figures, the value of the elementary charge e from this experiment.

$e =$ .......................... $\times 10^{-19}$ C [2]

(c) (i) Measuring the terminal velocity of the droplet using the microscope and stopwatch can be difficult.

Suggest an instrument that can be used to make this measurement more easily.

................................................................................................................ [1]

(ii) Suggest why the oil droplets reach terminal velocity so quickly.

................................................................................................................

................................................................................................................ [1]

(iii) Calculate the radius of the oil droplet for the last row in Fig. 7.3.

radius = ........................... m [3]

**(d)** It is thought that, when the potential difference between the plates is zero, the weight $W$ of an oil droplet varies with time, $T$, of its fall (at terminal speed over a standard distance) according to the equation

$$W = aT^b \qquad \text{----------} \qquad (1)$$

where $a$ and $b$ are constants.

Some data from Fig. 7.2 are used to plot the graph of Fig. 7.4
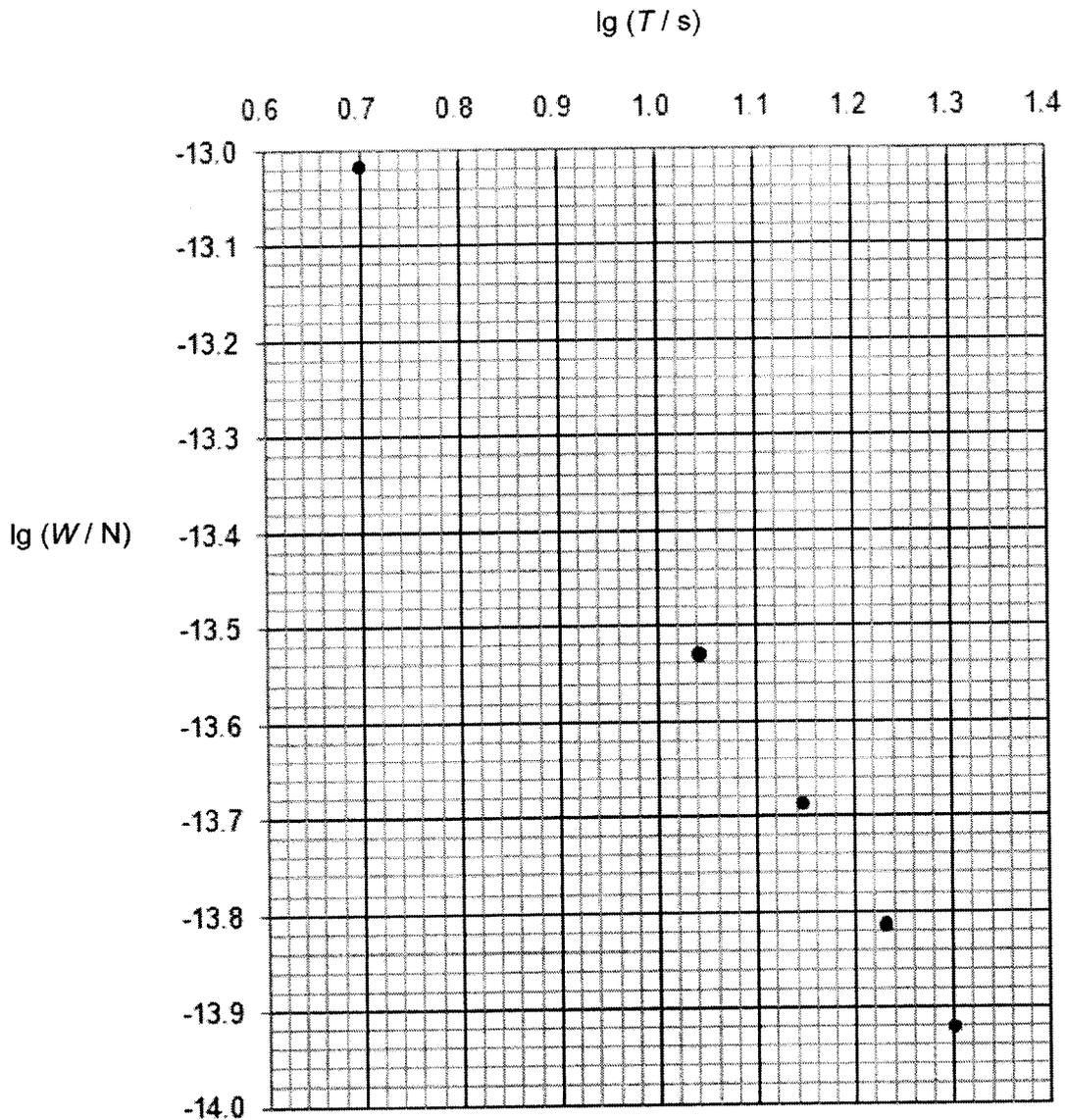


Fig, 7.4

(i) Use Fig. 7.2 to determine lg (W / N) for T = 8.0 s.

lg (W / N) = ..................................... [1]

(ii) On. Fig. 7.4,

1. plot the point corresponding to T = 8.0 s, [1]

2. draw the line of best fit for the points. [1]

(iii) Use the line drawn in (d)(ii) to determine the constant b in equation (1).

b = ............................. [2]

(iv) Deduce, from your value of b in (d)(iii), how the weight W of oil drop would depend on its terminal speed v.

[2]

**End of paper**

| Class | Index Number | Name |
|-------|--------------|------|
| 24S | | |

## ST. ANDREW'S JUNIOR COLLEGE
### JC 2 2025
### Preliminary Examination

**PHYSICS, Higher 2**  **9749/03**

Paper 3 Longer Structured Questions  **17<sup>th</sup> September 2025**
**2 hours**

Candidates answer on the Question Paper.
No Additional Materials are required.

**READ THESE INSTRUCTIONS FIRST**

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Do not use staples, paper clips, glue or correction fluid.

The use of an approved scientific calculator is expected, where appropriate.

Section **A**
Answer **all** questions.

Section **B**
Answer **one** question only.

You are advised to spend one and a half hours on Section A and half an hour on Section B.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

| For Examiner's Use | |
|--------------------|---|
| **Section A** | |
| 1 | / 10 |
| 2 | / 7 |
| 3 | / 15 |
| 4 | / 15 |
| 5 | / 13 |
| **Section B** | |
| 6 | / 20 |
| 7 | / 20 |
| **Total** | / 80 |

This document consists of **24** printed pages including this page.

2

## Data

| | |
|---|---|
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| permittivity of free space | $\varepsilon_0 = 8.85 \times 10^{-12}$ F m$^{-1}$ |
| | $= (1/(36\pi)) \times 10^{-9}$ F m$^{-1}$ |
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| the Planck constant | $h = 6.63 \times 10^{-34}$ J s |
| unified atomic mass constant | $u = 1.66 \times 10^{-27}$ kg |
| rest mass of electron | $m_e = 9.11 \times 10^{-31}$ kg |
| rest mass of proton | $m_p = 1.67 \times 10^{-27}$ kg |
| molar gas constant | $R = 8.31$ J K$^{-1}$ mol$^{-1}$ |
| the Avogadro constant | $N_A = 6.02 \times 10^{23}$ mol$^{-1}$ |
| the Boltzmann constant | $k = 1.38 \times 10^{-23}$ J K$^{-1}$ |
| gravitational constant | $G = 6.67 \times 10^{-11}$ N m$^2$ kg$^{-2}$ |
| acceleration of free fall | $g = 9.81$ m s$^{-2}$ |

## Formulae

| | |
|---|---|
| uniformly accelerated motion | $s = ut + \frac{1}{2}at^2$ |
| | $v^2 = u^2 + 2as$ |
| work done on/by a gas | $W = p\Delta V$ |
| hydrostatic pressure | $p = \rho g h$ |
| gravitational potential | $\phi = -\dfrac{Gm}{r}$ |
| temperature | $T/\text{K} = T/^\circ\text{C} + 273.15$ |
| pressure of an ideal gas | $p = \dfrac{1}{3}\dfrac{Nm}{v}\langle c^2 \rangle$ |
| mean translational kinetic energy of an ideal gas molecule | $E = \dfrac{3}{2}kT$ |
| displacement of particle in s.h.m. | $x = x_0 \sin \omega t$ |
| velocity of particle in s.h.m. | $v = v_0 \cos \omega t$ |
| | $v = \pm \omega \sqrt{x_0^2 - x^2}$ |
| electric current | $I = Anvq$ |
| resistors in series | $R = R_1 + R_2 + \ldots$ |
| resistors in parallel | $1/R = 1/R_1 + 1/R_2 + \ldots$ |
| electric potential | $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ |
| alternating current/voltage | $x = x_0 \sin \omega t$ |
| magnetic flux density due to a long straight wire | $B = \dfrac{\mu_0 I}{2\pi d}$ |
| magnetic flux density due to a flat circular coil | $B = \dfrac{\mu_0 NI}{2r}$ |
| magnetic flux density due to a long solenoid | $B = \mu_0 nI$ |
| radioactive decay | $x = x_0 \exp(-\lambda t)$ |
| decay constant | $\lambda = \dfrac{\ln 2}{t_{1/2}}$ |

## Section A

Answer **all** questions in the spaces provided

**1** **(a)** State what is meant by *parabolic motion*.

.................................................................................................................................

................................................................................................................... [2]

**(b)** A spring is used to launch a metal ball of mass $4.5 \times 10^{-2}$ kg up a ramp. The spring is compressed by $8.0 \times 10^{-2}$ m and held in equilibrium, as shown in Fig. 1.1.
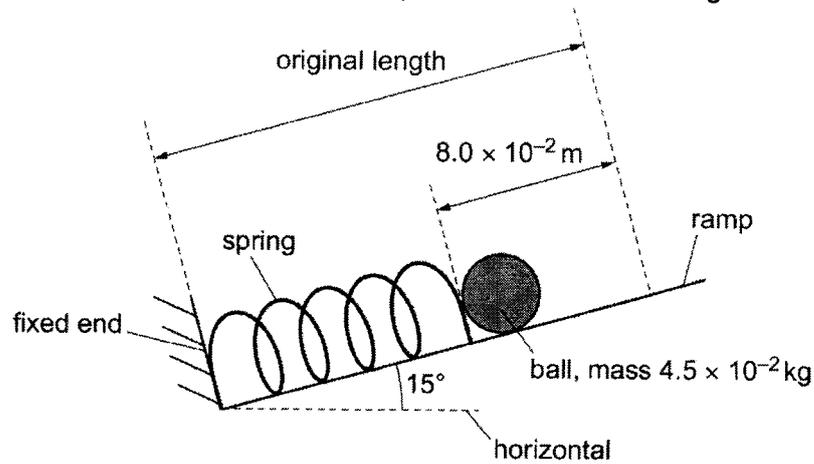


**Fig. 1.1**

The elastic potential energy stored in the spring at this compression is 0.24 J.
The ramp is at an angle of 15° to the horizontal.
The spring is released and expands quickly back to its original length.

**(i)** Calculate the average force the spring exerts on the ball during the expansion back to its original length.

average force = ........................ N [1]

**(ii)** The ball leaves the spring when the spring reaches its original length. Assume that all the elastic potential energy of the spring is transferred to the ball.

Calculate the speed of the ball as it leaves the spring.

speed = ........................ m s⁻¹ [2]

**(iii)** The ball travels up the slope as shown in Fig.1.2.
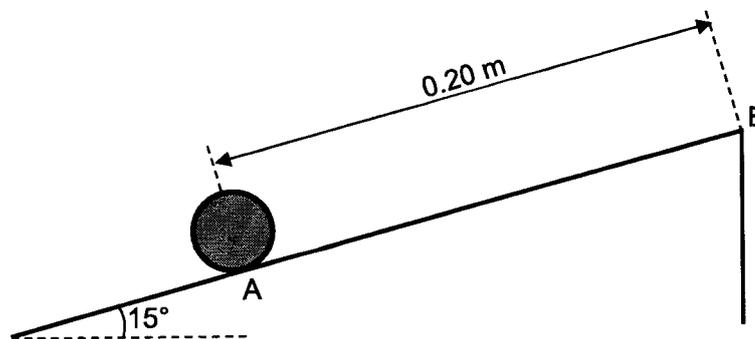


**Fig. 1.2**

At point A, the ball has a speed of 2.4 m s⁻¹. The ball will travel 0.20 m along the slope to reach point B, which is the end of the slope.

Show that the speed of the ball at point B is 2.2 m s⁻¹.

[1]

**(c)** The ball will leave the slope at point B. The height of the slope at B from the ground is 0.40 m, as shown in Fig. 1.3.
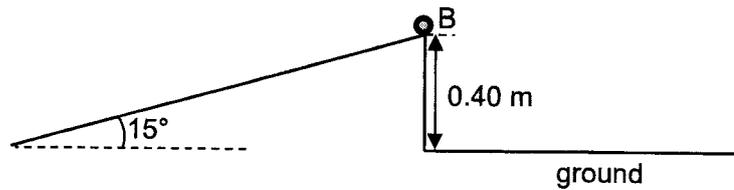


**Fig. 1.3**

**(i)** Determine the speed of the ball when it is at the maximum height.

speed = ........................ m s$^{-1}$ [1]

**(ii)** Determine the time just before the ball hits the ground.

time = ........................ s [2]

**(iii)** Determine the horizontal displacement travelled by the ball from B to the point just before hitting the ground.

horizontal displacement = ........................ m [1]

2 A binary star system consists of two stars X and Y that orbit around their common centre of gravity C. The orbits are circular. Both stars can be considered as point masses.

The mass of star X is $M$ and the mass of star Y is $2M$. The common centre of gravity is at a distance of $D$ from star Y, and at a distance of $2D$ from star X, as shown in Fig. 2.1.
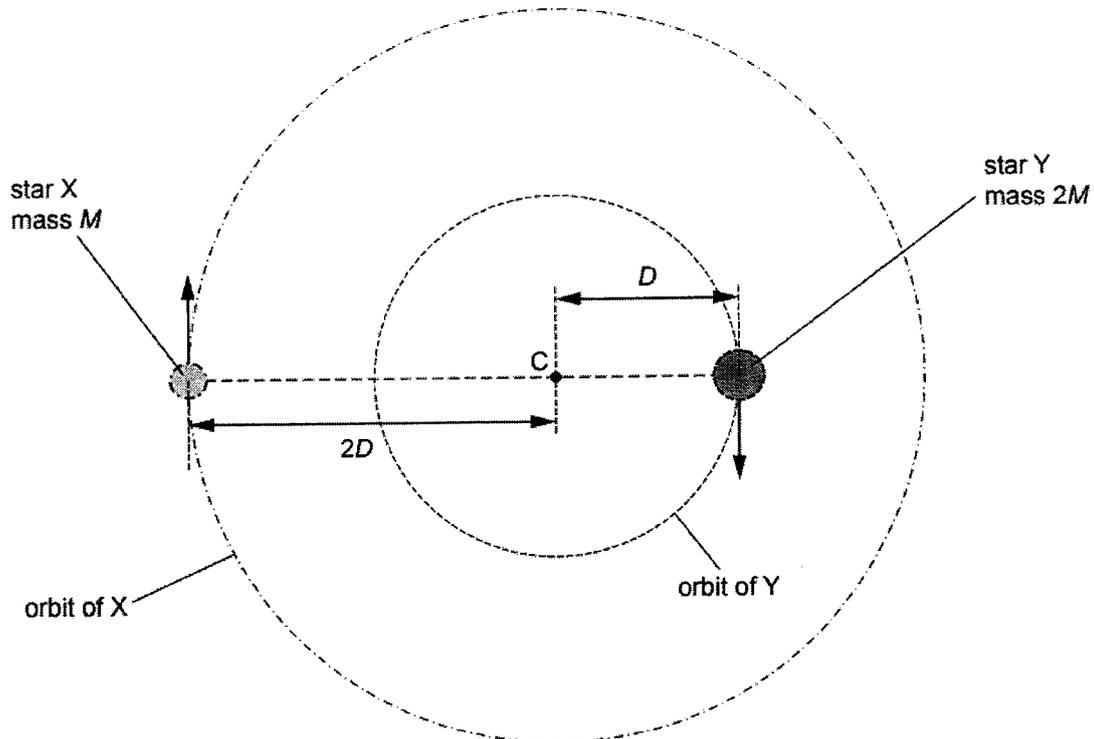


Fig. 2.1

(a) Star X orbits with angular velocity $\omega$. Show that the angular velocity of the orbit of star Y is also $\omega$.

[1]

**(b)** Deduce an expression, in terms of $G$, $M$ and $D$, for the total energy $E$ of the binary star system.

[4]

**(c)** The total energy $E$ of the binary star system is negative.

Explain the physical significance of this negative value.

...............................................................................................................

............................................................................................................... [1]

**(d)** Explain whether two identical electric charges could form a system in which the charges orbit around a common centre.

...............................................................................................................

............................................................................................................... [1]

3 (a) Two coherent sources X and Y of microwaves of frequency 2.5 × 10¹⁰ Hz are of a distance of 0.18 m apart in a vacuum, as shown in Fig. 3.1.
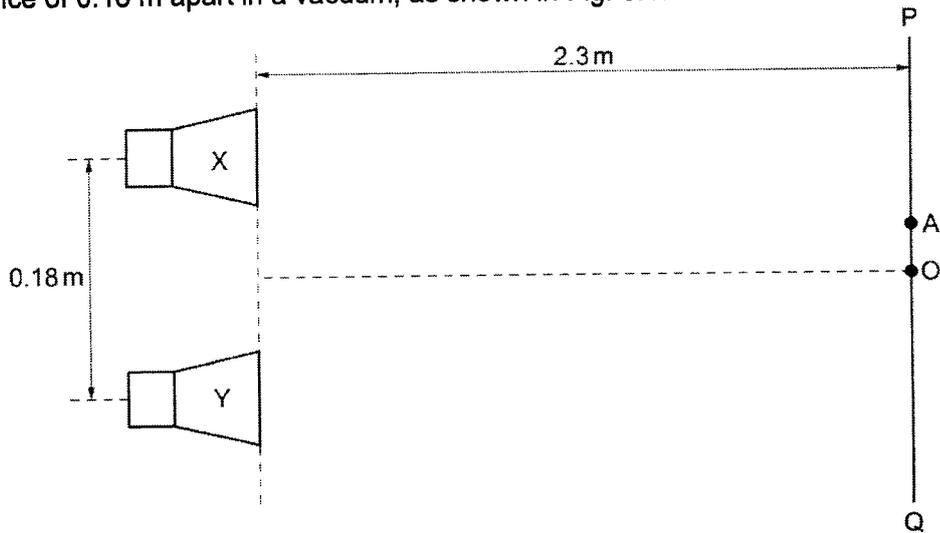


**Fig. 3.1**

There is a phase difference of **90°** between the waves emitted at the two sources.

A microwave detector moves along the line PQ, which is parallel to the line joining the two sources and 2.3 m away from it.

Point O is on the line PQ at a position that is equidistant from the two sources.
Point A is the position on the line PQ where the intensity of the microwaves is the greatest.

(i) Explain why the position of greatest intensity is **not** at point O.

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.......................................................................................................................... [2]

(ii) On Fig. 3.1, draw a cross (X) to show the position of the point on line PQ where the intensity minimum that is closest to point O occurs. Label this point B. [1]

(iii) Use the formula for the double-slit interference of light to calculate the distance between adjacent intensity maxima on the line PQ.

distance = ...................... m [2]

**(b)** A pipe is open at one end and closed at the other end with a piston. The piston can slide freely and is at a distance of 45 cm from the open end of the pipe, as shown in Fig. 3.2.
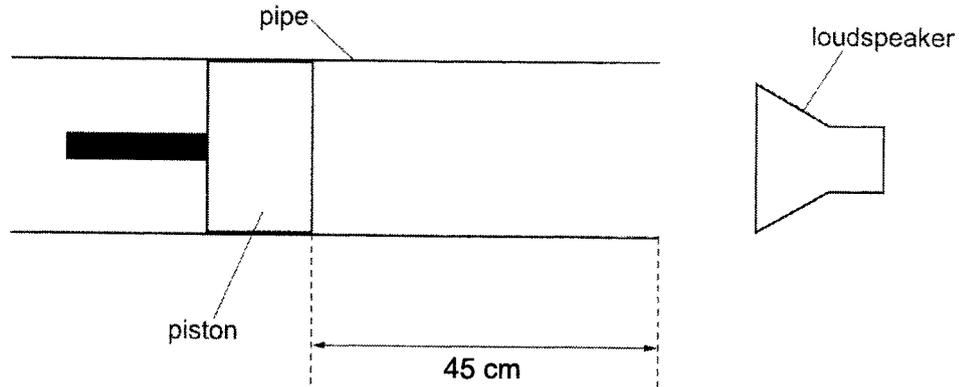


**Fig. 3.2**

A loudspeaker is positioned near the open end of the pipe. A loud sound is heard when the loudspeaker emits a sound wave of frequency 550 Hz. The speed of sound in the tube is measured to be 330 m s$^{-1}$.

**(i)** On Fig. 3.2, mark all the positions along the tube of

**1.** the displacement nodes (label these with the letter N),
**2.** the displacement antinodes (label these with the letter A). [2]

**(ii)** The frequency of the sound produced by the loudspeaker is gradually reduced.

Determine the lowest frequency at which a loud sound will be produced in the tube of length 45 cm.

frequency = ....................... Hz [2]

**(iii)** The piston is moved to the left. The frequency of the sound wave emitted by the loudspeaker is then changed so that a stationary wave is formed with the same number of antinodes as in **(b)(ii)**.

State and explain the change that is made to the frequency of the sound wave.

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.......................................................................................................... [2]

**(iv)** An alternative, more reliable, method of measuring the speed of sound shows that 330 m s$^{-1}$ is an underestimate. This underestimate cannot be attributed to the uncertainty in the measurement of either the frequency or the length of the pipe.

Suggest a reason that might have contributed to the underestimate.

............................................................................................................................................ [1]

**(c)** Two loudspeakers X and Y are connected to a signal generator and used to investigate interference. The loudspeakers emit sound waves of wavelength 0.16 m. The sound waves emitted from the two loudspeakers are in phase and have equal intensities.

The sound at point P is detected. Point P is 1.4 m from loudspeaker X and 1.8 m from loudspeaker Y, as shown in Fig. 3.3.
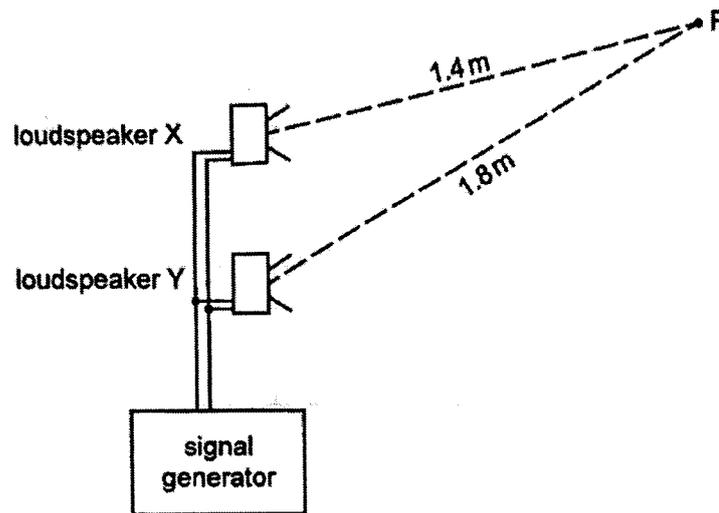


**Fig. 3.3**

The loudspeakers can be treated as point sources. The intensity at P of the sound from loudspeaker X is 4.5 × 10$^{-6}$ W m$^{-2}$.

Show that the resultant intensity at point P is 2.2 × 10$^{-7}$ W m$^{-2}$.

[3]

**4** **(a)** Two charged spheres of unequal sizes, carrying charges of +Q and -Q, are positioned as shown in Fig. 4.1 below.
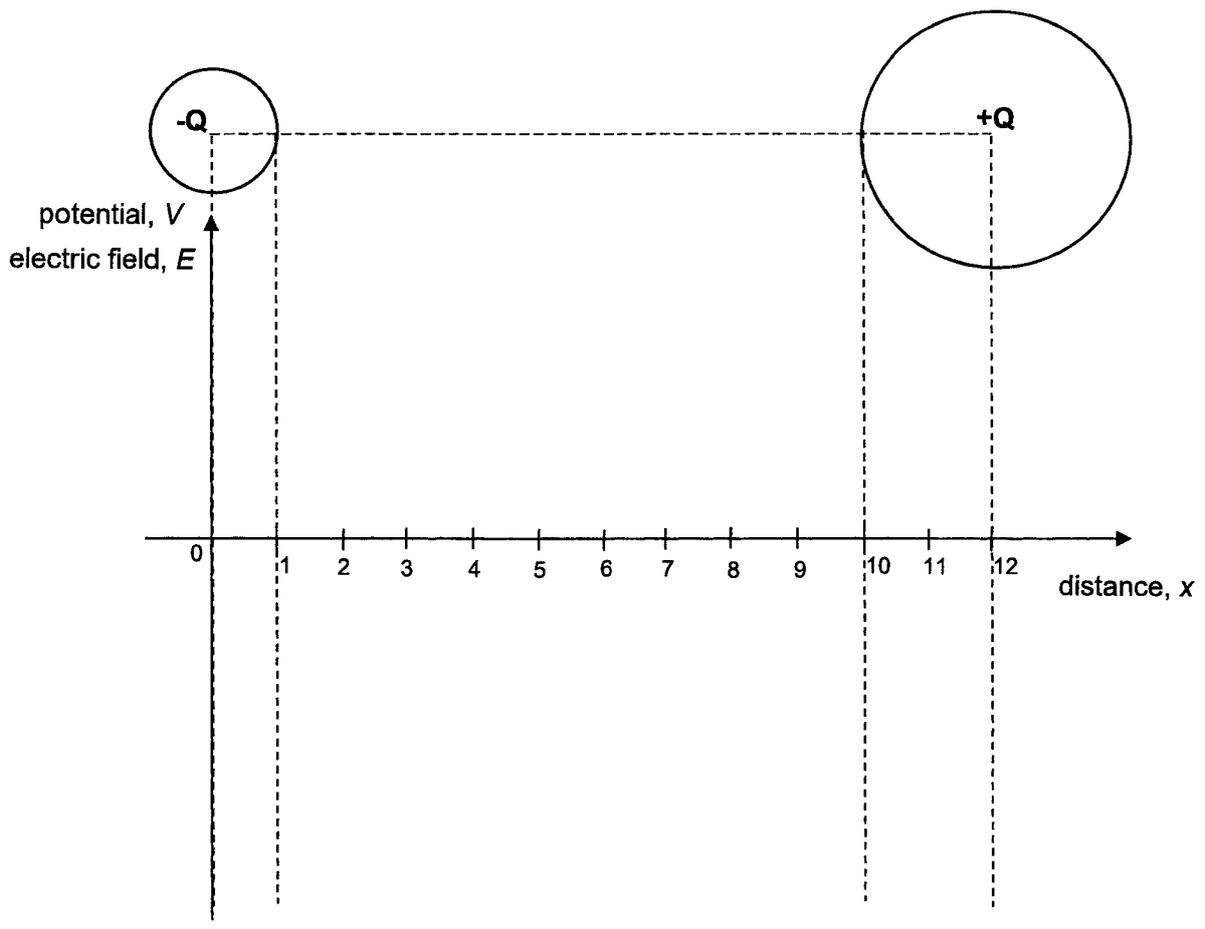


**Fig. 4.1**

**(i)** Draw the V-x graph of the two spheres on Fig. 4.1 that <u>spans from the centre of one sphere to the other</u>. Label the graph V. [3]

**(ii)** On the same figure, draw the E-x graph that spans the region <u>from 1 to 10 only</u>. Label the graph E and ensure that it is distinguishable from the graph in **(i)**.

Explain the position of either the turning point or the x-intercept of this graph.

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................................................................................................................... [4]

**(b)**  Two identical spherical drops of water, each carrying a charge of $+2.0 \times 10^{-10}$ C and with electric potential of 500 V on its surface, combine to form a single spherical drop.

Determine the approximate potential on the surface of the new drop formed.

potential = ................................. V [3]

**(c)**  Fig. 4.2 below below shows a simple current balance set-up. The midpoints of the rectangular wire rest on two knife edges at **A** and **B**, where **AB** = **CD** = 0.15 m. There is a current of 6.0 A which enters the wire via the knife edge at **B** in the direction of **BC** and exits at the knife edge at **A**. A separate current is supplied to the solenoid to create a field which has a flux density of 35 mT.
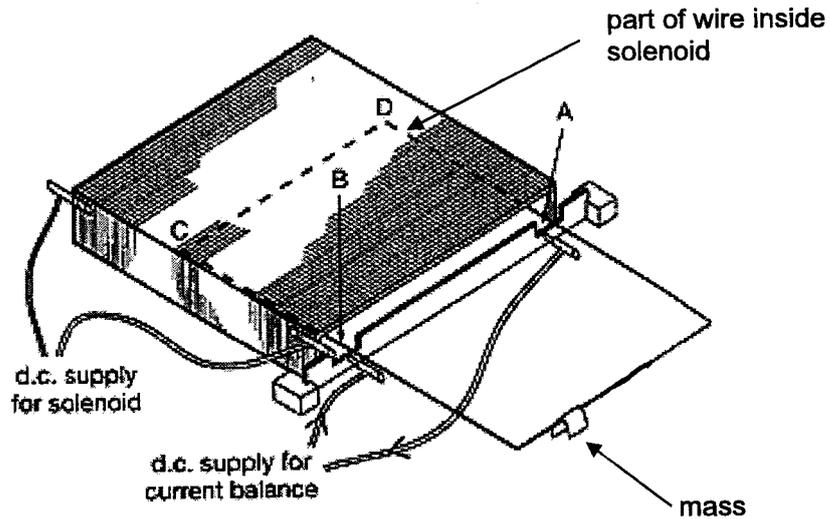


**Fig. 4.2**

**(i)**  Indicate, with *an arrow*, the direction of the magnetic field on Fig. 4.2 above.  [1]

**(ii)**  Calculate the force acting on the wire at **CD**.

force = ................................. N [1]

**(iii)** Determine the mass needed to be placed on the wire at the other end for the wire to be horizontally balanced.

mass = .................................. kg [1]

**(iv)** The laboratory environment has a background magnetic field in the horizontal direction that may interfere with the set-up.

Suggest and explain how the effect due to the background magnetic field can be reduced without using any additional apparatus.

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.................................................................................................................

........................................................................................................... [2]

5  (a)  Radioactive decay is both random and spontaneous.

(i)  State what is meant by random.

.................................................................................................................

.............................................................................................................[1]

(ii)  State what is meant by spontaneous.

.................................................................................................................

.............................................................................................................[1]

(iii)  State **one** piece of evidence for the random nature of decay.

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.............................................................................................................[1]

(b)  (i)  Describe the differences between nuclear fission and nuclear fusion.

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.................................................................................................................

.......................................................................................................... [3]

(ii)  Explain, with reference to the variation of binding energy per nucleon with nucleon number, why the processes of nuclear fission and nuclear fusion both result in a release of energy.

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.................................................................................................................

.............................................................................................................[2]

**(c)** Nuclei of an isotope of copper (Cu) each have 29 protons and 37 neutrons. This isotope is a $\beta^-$ emitter.

**(i)** State the nuclide notation in the form $^A_Z X$ for this nucleus of copper.

.......................................................................................................................[1]

**(ii)** The energy spectrum of the $\beta^-$ radiation emitted by a sample of this isotope is shown in Fig. 5.1.



number of $\beta^-$
particles

kinetic energy
of $\beta^-$ particle
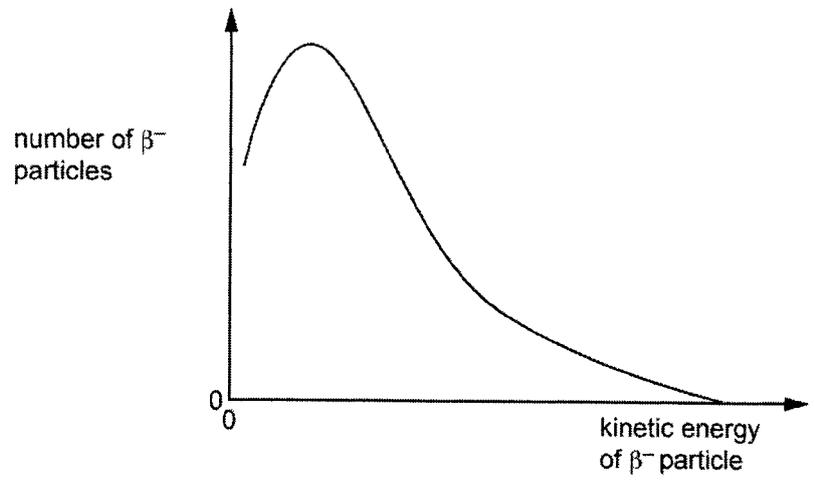
**Fig. 5.1**

Use Fig. 5.1 to explain why other particles apart from the $\beta^-$ particles must be emitted during this decay.

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............................................................................................................... [3]

**(iii)** In Fig. 5.1, sketch how the energy spectrum will look like if the beta decay were a two-body process. [1]

16

## Section B

Answer **one** question from this section in the spaces provided.

6  **(a)**  **(i)**  State the assumption of the kinetic theory of gases that explain why gas molecules could stay above ground.

...................................................................................................... [1]

**(ii)**  The pressure $P$ exerted by an ideal gas is given by the expression

$$P = \frac{1}{3}\rho <c^2>$$

where $\rho$ is the density of the gas and $<c^2>$ the mean square speed of the gas.

Starting with one gas molecule of mass, $m$, moving with speed $c_x$ in the x-direction in a cubic container with length $L$, show how the above expression can be derived. Define any symbols used.

[5]

**(b)** **(i)** Explain what is meant by *specific latent heat of vaporisation*.

.........................................................................................................................................

................................................................................................................................. [1]

**(ii)** A sample of ethanol of mass 0.35 kg is vaporised at its boiling point of 78 °C, under an atmospheric pressure of 1.0 x 10⁵ Pa.

Specific latent heat of vaporization = $0.95 \times 10^6$ J kg⁻¹
Density in liquid state = 790 kg m⁻³
Density in gaseous state = 1.6 kg m⁻³

**1.** Calculate the work done *by* the gas.

work done *by* gas = ................................. J [2]

**2.** Calculate the heat supplied into the system.

heat supplied into system = ................................. J [1]

**3.** Hence, calculate the increase in internal energy of the system.

increase in internal energy = ................................. J [2]

(c) A student determines the specific heat capacity of a liquid using the apparatus shown in Fig. 6.1 below.
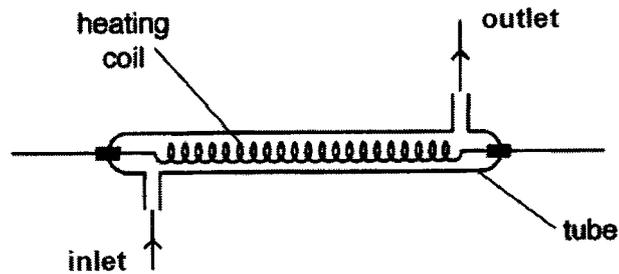


**Fig. 6.1**

The liquid flows through the tube at 0.15 kg min$^{-1}$, while the heater provides power at 25 W. The temperatures of the liquid at the inlet and outlet are 15 °C and 19 °C respectively. With the inlet and outlet temperatures unchanged, the flow rate increased to 0.23 kg min$^{-1}$ and the power of the heater increased to 37 W.

(i) Determine the rate of heat loss of the liquid.

rate of heat loss = ................................. W [2]

(ii) Explain why it is necessary for the inlet and outlet temperatures to remain unchanged.

...........................................................................................................................

........................................................................................................... [1]

**(d)** The Otto Thermodynamic Cycle shows the pressure-volume (*p-V*) processes of internal combustion engines such as those used in airplane and car engines.

The cycle uses the following processes

**A → B**   **Intake stroke**, gas is drawn into the cylinder at constant pressure.

**B → C**   **Compression stroke**, *adiabatic* compression of air in the cylinder back to the original volume with no fuel added.

**C → D**   **Rapid Combustion** at constant volume where pressure and temperature increase.

**D → E**   **Expansion (Power) stroke**, *adiabatic* expansion as the pressure decreases.

**E → B**   **Heat Rejection**, the ejection of spent, hot gases. The net volume change in this process is zero as the pressure adjusts back to the initial pressure.

**B → A**   **Exhaust stroke**, as the piston moves back into the cylinder, the volume of gas decreases at constant pressure back to the initial stage.

**(i)**   On the *p-V* axes below, complete the graph that represents the full Ideal Otto Cycle showing the processes **B → C → D → E → B** with the stages **C**, **D** and **E** clearly labelled. [3]

Pressure (*p*)

C

A                                                    B

0

Volume (*V*)
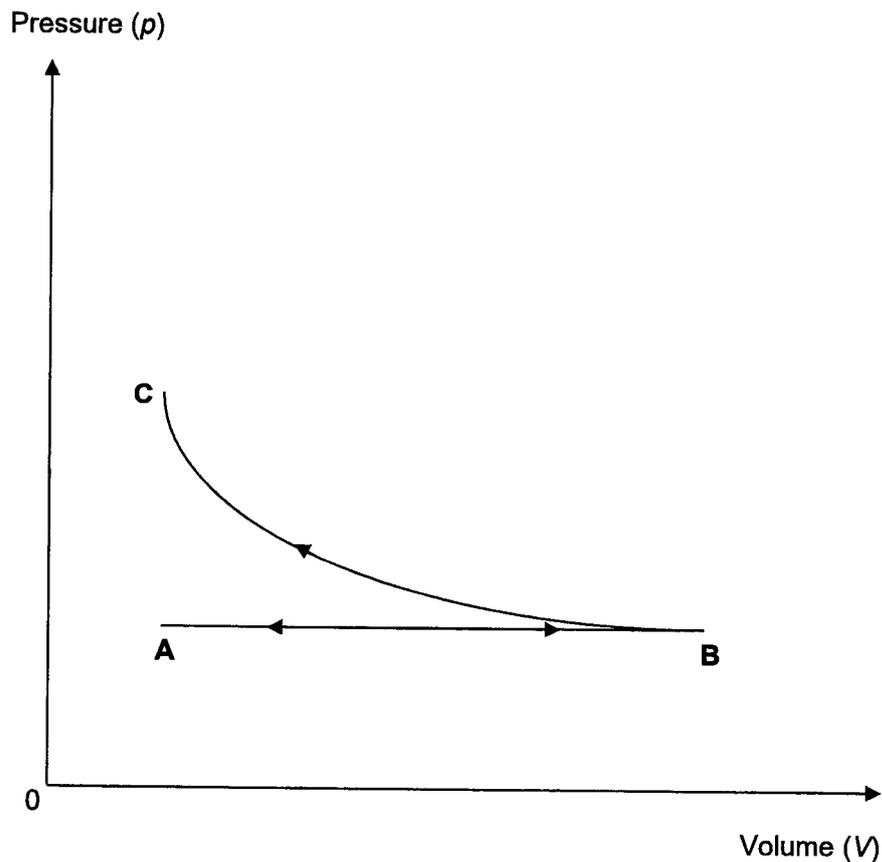
**Fig. 6.2**

**(ii)** Using a feature of the *p-V* diagram, describe how the power produced by the engine can be determined.

............................................................................................................

............................................................................................................ [1]

**(iii)** In reality, the *ideal* cycle does not occur due to energy losses within each process. Describe how the practical *p-V* diagram would differ from an ideal one.

............................................................................................................

............................................................................................................ [1]

7    (a)    The EZ-Link card is a "contactless" smartcard used for payments in Singapore, especially for transportation.

Fig. 7.1 shows part of the internal circuitry and wiring of an EZ-link card. The circuitry consists of a transmitter which is connected to 3 wire loops around the edges of the card. The transmitter requires electrical energy to communicate with an external device such as a card reader. However, there is no internal power source in the card. The area of the EZ-Link card is $4.00 \times 10^{-3}$ m$^2$.
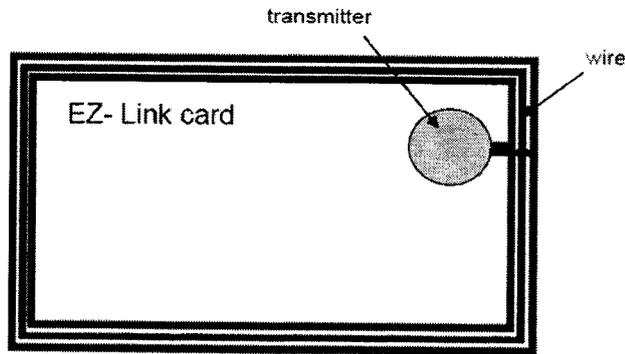


**Fig. 7.1**

Fig. 7.2 shows a card reader which produces a sinusoidal magnetic field of frequency $13.56 \times 10^6$ Hz.
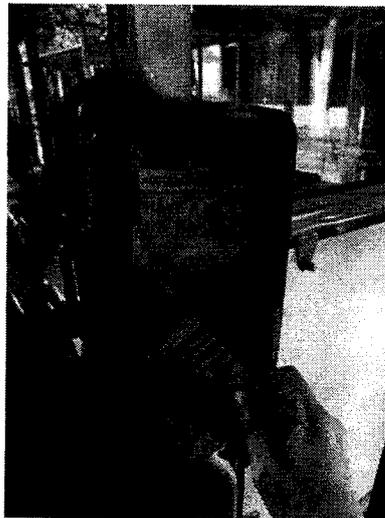


**Fig. 7.2**

(i)    State Faraday's Law and Lenz's Law.

Faraday's Law: ..........................................................................................................

..........................................................................................................................

..........................................................................................................................

Lenz's Law: ...............................................................................................................

.................................................................................................................... [2]

(ii) Using Faraday's Law, explain how electrical energy is generated to power the transmitter of the EZ-link card when it is tapped onto the card reader.

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................................................................................................ [3]

(iii) The card reader generates a magnetic field given by the equation $B = B_0 \sin(2\pi ft)$.

1. Calculate the magnitude of the peak e.m.f. generated in the card in terms of $B_0$. Show your working clearly.

peak e.m.f. = .................................. $B_0$ [3]

2. Calculate the peak magnetic flux density $B_0$ if the card needs a r.m.s.voltage of 10.0 mV to operate.

peak magnetic flux density $B_0$ = .................................. T [2]

**(iv)** The system is designed such that it can work if the card is tapped with either face. Explain briefly why this is possible.

..................................................................................................................

.............................................................................................................. [1]

**(b)** Explain what is meant by the *root-mean-square* (r.m.s) value of an alternating current.

..................................................................................................................

..................................................................................................................

.............................................................................................................. [1]

**(c)** A hair blower used in Singapore is rated at 240 V r.m.s., 1000 W. A student plans to bring the blower to the United States of America (USA), where the voltage is 120 V r.m.s..

**(i)** State one advantage of having alternating current from the mains rather than direct current.

..................................................................................................................

.............................................................................................................. [1]

**(ii)** It was suggested that the student needs to bring a transformer along to USA to operate the blower.

Determine the transformer's turns ratio $\dfrac{N_s}{N_p}$.

$\dfrac{N_s}{N_p} = $ ............................... [1]

(iii) The primary coil of the transformer is connected to the 120 V r.m.s. supply of the USA outlet. The secondary coil is connected to the blower.

Determine the r.m.s. primary current when the blower is operating at 1000 W.

State also any assumption you have made in your working.

r.m.s. current = ................................. A [2]

(iv) The transformer is non-ideal and electrical energy is converted to thermal energy in the windings of the transformer at a rate of 600 W.

1. Determine the r.m.s. secondary current.

secondary current = ................................. A [3]

2. Calculate the efficiency of the transformer.

efficiency = ................................. % [1]

**End of Paper**