



CANDIDATE
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NUMBER

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9702/41

October/November 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Data

acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_o = \frac{f_s v}{v \pm v_s}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

gravitational potential	$\phi = -\frac{GM}{r}$
gravitational potential energy	$E_P = -\frac{GMm}{r}$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
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discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) (i) State what is indicated by the direction of the gravitational field line at a point in a gravitational field.

.....
 [1]

- (ii) Explain, with reference to gravitational field lines, why the gravitational field near the surface of the Earth is approximately constant for small changes in height.

.....

 [2]

- (b) A large isolated uniform sphere has mass M and radius R .

Point P lies on a straight line passing through the centre of the sphere, at a variable displacement x from the centre, as shown in Fig. 1.1.

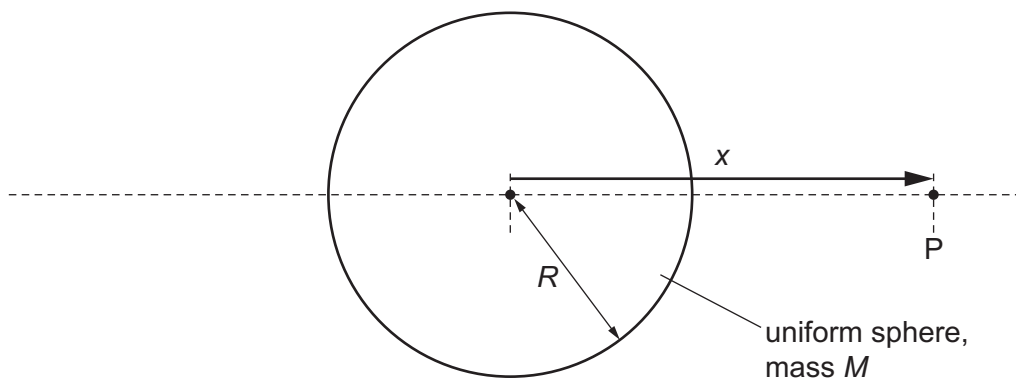


Fig. 1.1

Fig. 1.2 shows the variation with x of the gravitational field g at point P due to the sphere for the values of x for which P is inside the sphere.

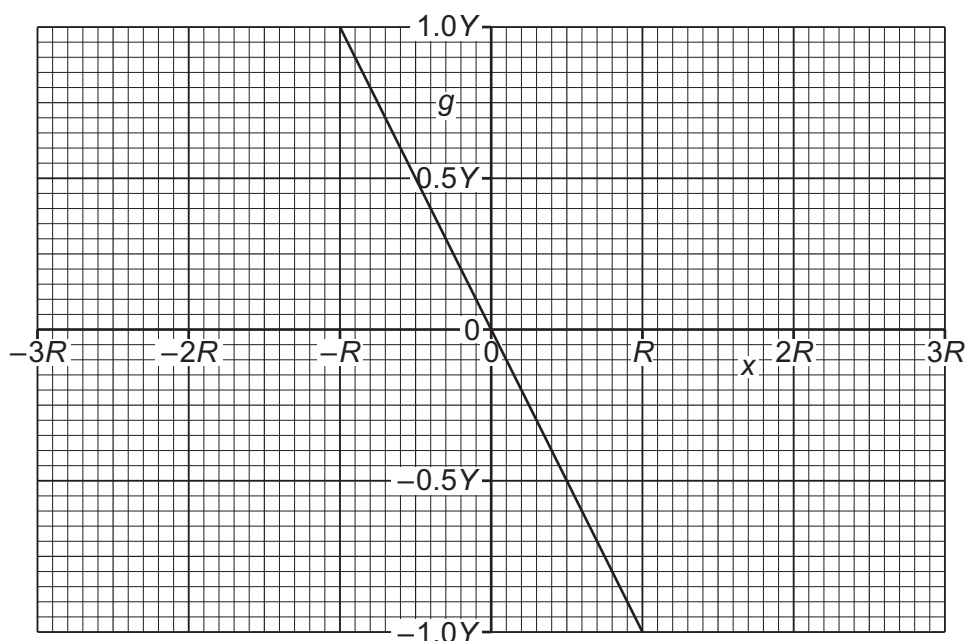


Fig. 1.2

The magnitude of the gravitational field at the surface of the sphere is Y .

- (i) Determine an expression for Y in terms of M and R . Identify any other symbols that you use.

[2]

- (ii) Explain why, at the surface of the sphere, g always has the opposite sign to x .

.....

 [2]

- (iii) Complete Fig. 1.2 to show the variation of g with x for values of x , up to $\pm 3R$, for which point P is outside the sphere. [3]

[Total: 10]

- 2 (a) Define specific heat capacity.

.....

.....

..... [2]

- (b) An ideal gas of mass 0.35 kg is heated at a constant pressure of $2.0 \times 10^5 \text{ Pa}$ so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 m^3 to 0.063 m^3 and the temperature increases by 56°C .

- (i) Show that the magnitude of the work done on the gas is 5000 J.

[1]

- (ii) Explain whether the work done on the gas is positive or negative.

.....

.....

..... [2]

- (iii) Determine the magnitude of the thermal energy q transferred to the gas.

$$q = \dots\dots\dots \text{ J [2]}$$

- (iv) Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

$$\text{specific heat capacity} = \dots\dots\dots \text{ unit } \dots\dots\dots [2]$$

- (c) The gas in (b) is now heated at constant volume rather than at constant pressure. The increase in internal energy of the gas is the same as in (b).

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in (b)(iv).

.....

.....

.....

.....

..... [3]

[Total: 12]

- 3 (a) The product pV for an ideal gas is given by

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

where p is the pressure of the gas and V is the volume of the gas.

- (i) State the meaning of the symbols N , m and $\langle c^2 \rangle$ in this equation.

N :

m :

$\langle c^2 \rangle$:

[3]

- (ii) Use the equation of state for an ideal gas to show that the average translational kinetic energy E_K of a molecule of the gas at thermodynamic temperature T is given by

$$E_K = \frac{3}{2} kT.$$

[2]

- (b) The surface of a star consists mainly of a gas that may be assumed to be ideal. The molecules of the gas have a root-mean-square (r.m.s.) speed of 9300 m s^{-1} .

The mass of a molecule of the gas is $3.34 \times 10^{-27} \text{ kg}$.

Determine, to three significant figures, the temperature of the surface of the star.

temperature = ... K [2]

- (c) The radiant flux intensity of the radiation from the star in (b) is $2.52 \times 10^{-8} \text{ W m}^{-2}$ when observed at a distance of $4.16 \times 10^{16} \text{ m}$ from the star.

(i) Calculate the luminosity of the star. Give a unit with your answer.

luminosity = ... unit [2]

(ii) Determine the radius of the star.

radius = ... m [2]

- (d) The gas at the surface of a star has a very high pressure.

Use the basic assumptions of the kinetic theory to suggest why, in practice, a gas at the surface of a star is unlikely to behave as an ideal gas.

.....

 [2]

[Total: 13]

- 4 A heavy metal sphere of mass 0.81 kg is suspended from a string. The sphere is undergoing small oscillations from side to side, as shown in Fig. 4.1.

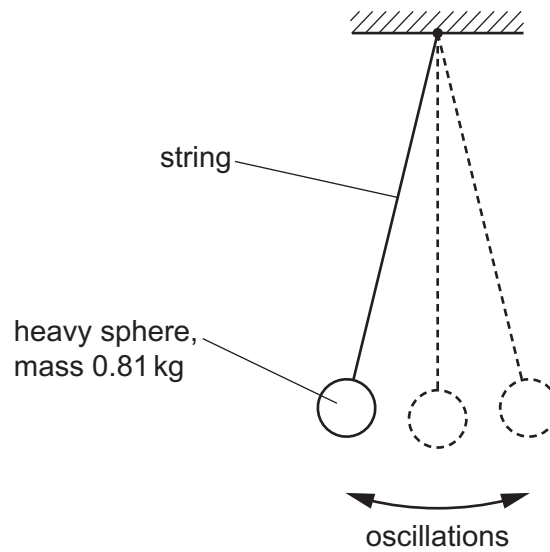


Fig. 4.1

The oscillations of the sphere may be considered to be simple harmonic with amplitude 0.036 m and period 3.0 s.

- (a) State what is meant by simple harmonic motion.

.....

.....

..... [2]

- (b) Calculate:

- (i) the angular frequency of the oscillations

angular frequency = ... rad s^{-1} [2]

(ii) the total energy of the oscillations.

total energy = ... J [2]

- (c) The suspended sphere is now lowered into water. The sphere is given a sideways displacement of $+0.036\text{ m}$ from its equilibrium position and is then released at time $t = 0$. The water causes the motion of the sphere to be critically damped.

On Fig. 4.2, sketch the variation of the displacement x of the sphere from its equilibrium position with t from $t = 0$ to $t = 6.0\text{ s}$.

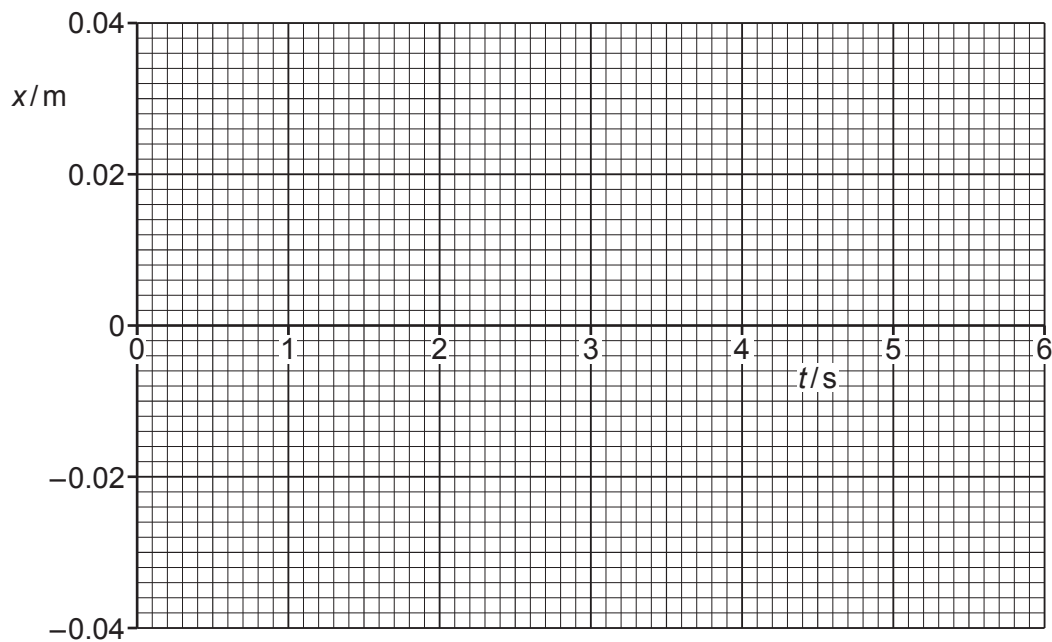


Fig. 4.2

[3]

[Total: 9]

- 5 (a) Define electric potential at a point.

.....

.....

..... [2]

- (b) Two isolated charged metal spheres X and Y are situated near to each other in a vacuum with their centres a distance of 24 m apart. Point P is at a variable distance x from the centre of sphere X on the line joining the centres of the spheres.

Fig. 5.1 shows the variation with x of the electric potential V due to the spheres at point P.

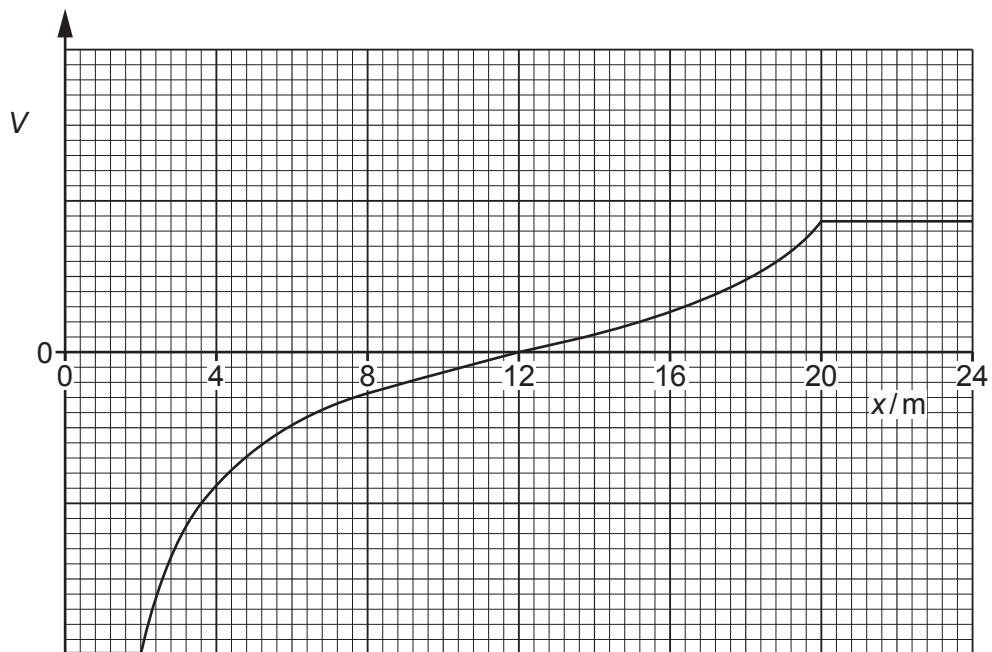


Fig. 5.1

State **three** conclusions that can be drawn about the spheres from Fig. 5.1. The conclusions may be qualitative or quantitative.

1

.....

2

.....

3

.....

[3]

- (c) A positively charged particle is placed at point P in (b), such that $x = 12\text{ m}$. The particle is released.

Describe and explain the subsequent motion of the particle.

.....

.....

.....

.....

..... [3]

[Total: 8]

- 6 (a) Define magnetic flux density.

.....

.....

.....

..... [2]

- (b) Electrons are moving in a vacuum with speed $1.7 \times 10^7 \text{ ms}^{-1}$. The electrons enter a uniform magnetic field of flux density 4.8 mT . Fig. 6.1 shows the path of the electrons.

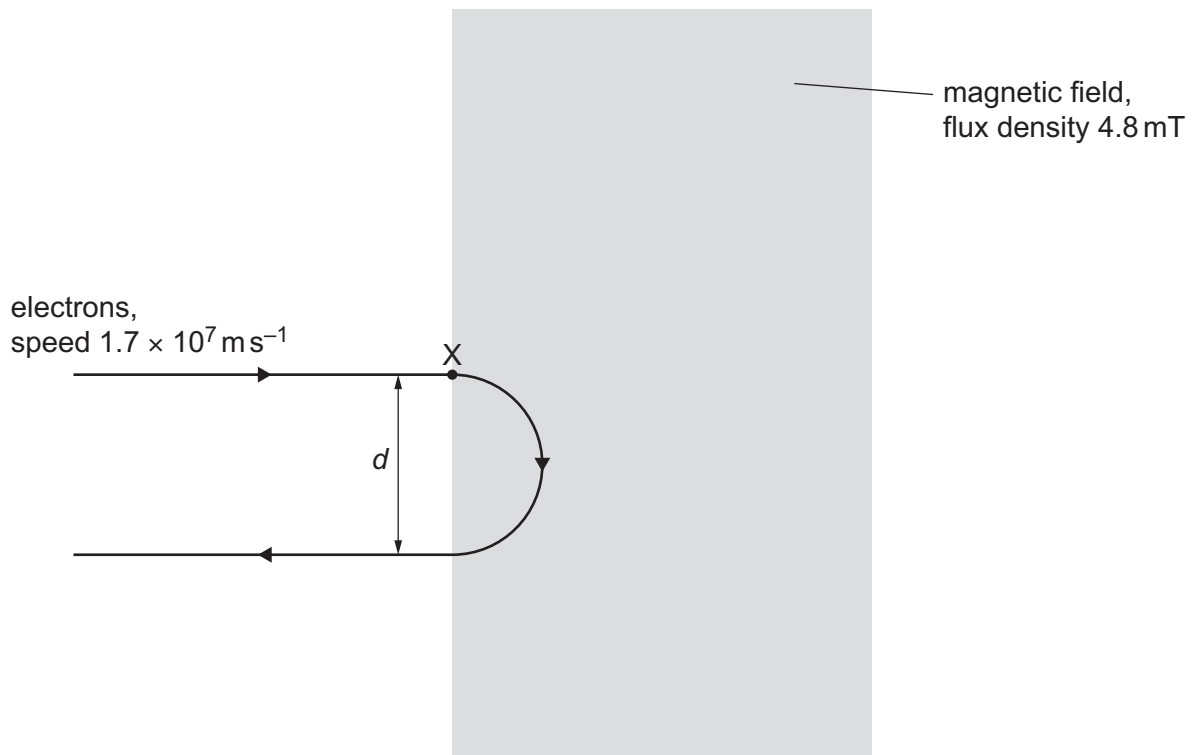


Fig. 6.1

The path of the electrons remains in the plane of the page.

- (i) State the direction of the magnetic field.

.....

..... [1]

- (ii) Show that the magnitude of the force exerted on each electron by the magnetic field is $1.3 \times 10^{-14} \text{ N}$.

[2]

- (iii) On Fig. 6.1, draw an arrow to indicate the direction of the centripetal acceleration of the electron where it enters the magnetic field at point X. [1]

- (iv) Use the information in **(b)(ii)** to calculate the distance d between the path of the electrons entering the magnetic field and the path of the electrons leaving it.

$d = \dots\dots\dots \text{ m}$ [3]

- (c) The electrons in **(b)** are replaced with positrons that are moving with speed $3.4 \times 10^7 \text{ ms}^{-1}$ along the same initial path as the electrons.

The positrons enter the magnetic field at point X on Fig. 6.1.

On Fig. 6.1, draw a line to show the path of the positrons through the magnetic field. [3]

[Total: 12]

- 7 A varying current I passes through a resistor of resistance R in the circuit shown in Fig. 7.1.

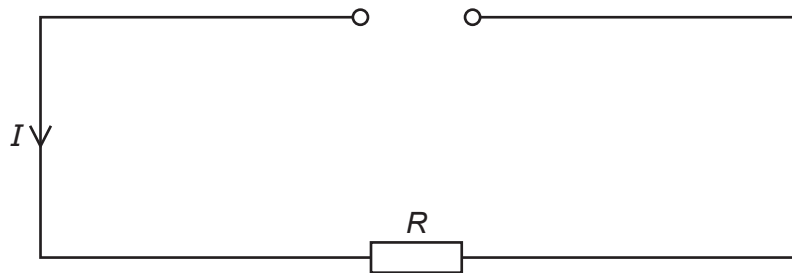


Fig. 7.1

Fig. 7.2 shows the variation with time t of I .

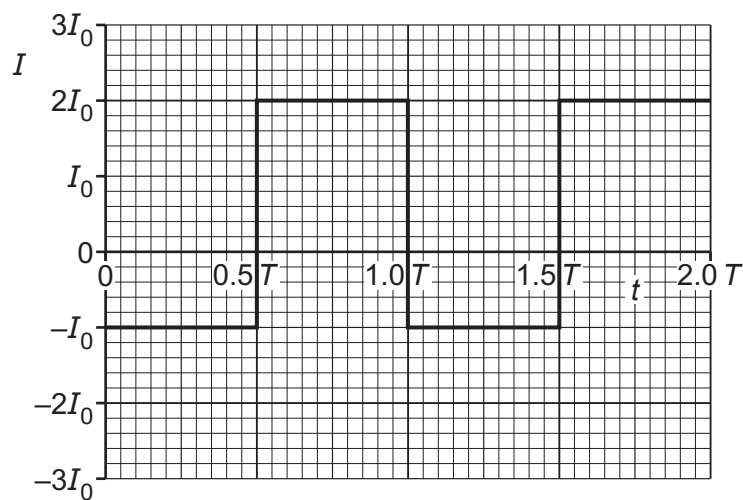


Fig. 7.2

The current has magnitude $2I_0$ when it is in the positive direction and I_0 when it is in the negative direction. The period of the variation of the current is T .

- (a) Determine expressions, in terms of I_0 and R , for the power P dissipated in the resistor for the times when:

- (i) the current is in the negative direction

$$P = \dots\dots\dots [1]$$

- (ii) the current is in the positive direction.

$$P = \dots\dots\dots [1]$$

- (b) On Fig. 7.3, sketch the variation of P with t between $t = 0$ and $t = 2.0T$. Label the power axis with an appropriate scale.

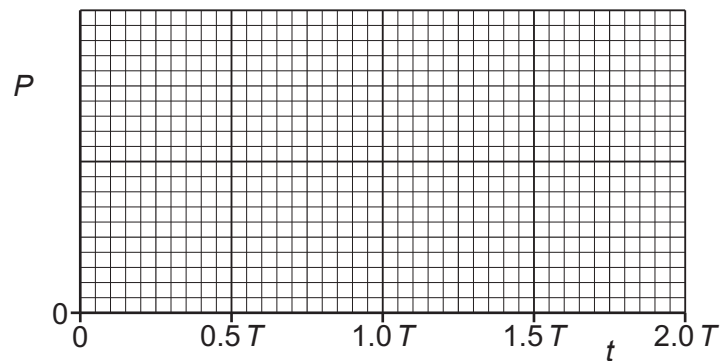


Fig. 7.3

[3]

- (c) Use your answer in (b) to determine an expression, in terms of I_0 and R , for:

- (i) the mean power $\langle P \rangle$ in the resistor

$$\langle P \rangle = \dots\dots\dots [1]$$

- (ii) the root-mean-square (r.m.s.) current $I_{\text{r.m.s.}}$ in the resistor.

$$I_{\text{r.m.s.}} = \dots\dots\dots [2]$$

[Total: 8]

- 8 (a) (i) Show that the momentum p of a photon of electromagnetic radiation with wavelength λ is given by

$$p = \frac{h}{\lambda}$$

where h is the Planck constant.

[2]

- (ii) Use the expression in (a)(i) to show that a photon in free space that has a momentum of $9.5 \times 10^{-28} \text{ N s}$ is a photon of red light.

[1]

- (b) A beam of red light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 8.1. The momentum of each photon in the beam is $9.5 \times 10^{-28} \text{ N s}$.

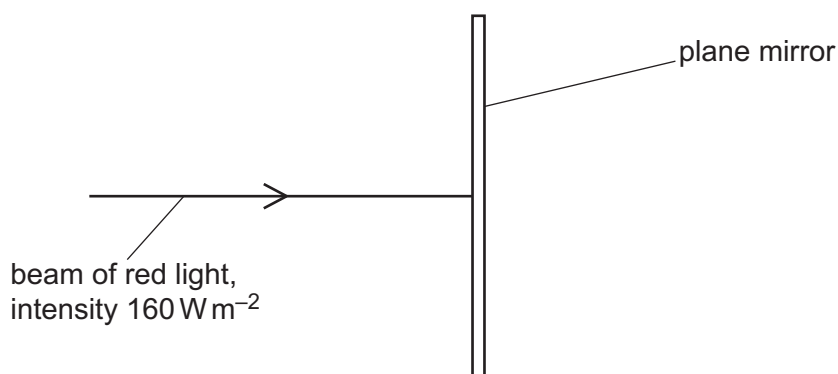


Fig. 8.1

All of the light is reflected by the mirror in the opposite direction to its original path. The cross-sectional area of the beam is $2.5 \times 10^{-6} \text{ m}^2$.

- (i) Show that the number of photons incident on the mirror per unit time is $1.4 \times 10^{15} \text{ s}^{-1}$.

[2]

- (ii) Use the information in **(b)(i)** to determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [3]

- (c) The beam of red light in **(b)** is now replaced with a beam of blue light of the same intensity.

Suggest and explain whether the pressure exerted on the mirror by the beam of blue light is less than, the same as, or greater than the pressure exerted by the beam of red light.

.....

 [2]

[Total: 10]

- 9 (a) State what is meant by nuclear fusion.

.....

.....

..... [2]

- (b) On Fig. 9.1, sketch the variation of binding energy per nucleon with nucleon number A for values of A between 1 and 250.

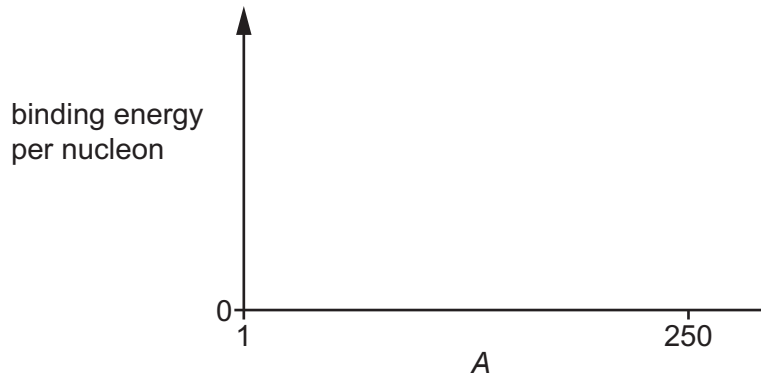


Fig. 9.1

[2]

- (c) On your line in Fig. 9.1, label:

- (i) a point X that could represent a nucleus that undergoes alpha-decay [1]
- (ii) a point Y that could represent a nucleus that undergoes nuclear fusion. [1]

- (d) A nucleus Z undergoes nuclear fission to form strontium-93 ($^{93}_{38}\text{Sr}$) and xenon-139 ($^{139}_{54}\text{Xe}$) according to

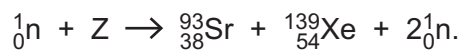


Table 9.1 shows the binding energies of the strontium-93 and xenon-139 nuclei.

Table 9.1

nucleus	binding energy/J
$^{93}_{38}\text{Sr}$	1.25×10^{-10}
$^{139}_{54}\text{Xe}$	1.81×10^{-10}

The fission of 1.00 mol of Z releases 1.77×10^{13} J of energy.

Determine the binding energy per nucleon, in MeV, of Z.

binding energy per nucleon = ... MeV [4]

[Total: 10]

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- 10** Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(a) Complete Table 10.1 to state, for each type of wave:

- the method of production of the wave
- whether the wave that is detected and used to form the image is the wave that has been absorbed, reflected or transmitted by the internal body structure.

Table 10.1

	ultrasound	X-rays
method of production		
detected wave (absorbed, reflected or transmitted)		

[4]

- (b) (i)** For one type of wave passing through tissue, the wave has 72% of its initial intensity after it has passed through 6.2 cm of the tissue.

Calculate the linear attenuation coefficient μ of the tissue for this wave.

$$\mu = \dots\dots\dots \text{ cm}^{-1} \quad [2]$$

- (ii)** Another wave of the same type as in **(b)(i)** passes through 9.3 cm of the same tissue.

Calculate the percentage of the initial intensity of the wave that is attenuated by the tissue.

$$\text{percentage attenuated} = \dots\dots\dots \% \quad [2]$$

[Total: 8]

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simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) Define the radian.

..... [1]

- (b) The minute hand of a clock revolves at constant angular speed around the face of the clock, completing one revolution every hour. A small piece of modelling clay is attached to the hand with its centre of gravity at a distance L from the fixed end of the hand, as shown in Fig. 1.1.

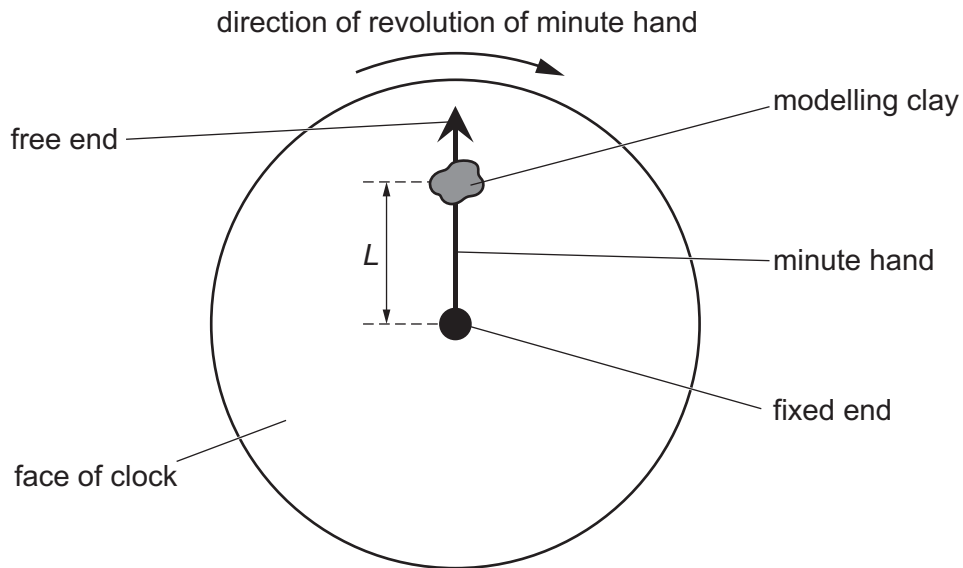


Fig. 1.1

Calculate the angular speed ω of the minute hand.

$$\omega = \dots \text{ rad s}^{-1} \quad [2]$$

- (c) During a time interval of 1400 s, the centre of gravity of the piece of modelling clay in Fig. 1.1 moves through a total distance of 0.44 m.

- (i) Calculate the angle through which the minute hand moves in this time interval.

$$\text{angle} = \dots \text{ rad} \quad [1]$$

(ii) Determine distance L .

$L = \dots\dots\dots$ m [2]

(iii) Calculate the magnitude of the centripetal acceleration of the piece of modelling clay.

centripetal acceleration = $\dots\dots\dots$ ms^{-2} [2]

(d) Use your answer in (c)(iii) to explain why the variation with time of the magnitude of the force exerted by the minute hand on the piece of modelling clay is negligible as the minute hand undergoes one full revolution.

$\dots\dots\dots$
 $\dots\dots\dots$
 $\dots\dots\dots$ [2]

[Total: 10]

- 2 (a) (i) Define gravitational potential at a point.

.....

 [2]

- (ii) The Moon may be considered to be an isolated uniform sphere of mass $7.3 \times 10^{22} \text{ kg}$ and radius $1.7 \times 10^6 \text{ m}$.

Calculate the gravitational potential at the surface of the Moon. Give a unit with your answer.

gravitational potential = ... unit [2]

- (b) An isolated uniform spherical planet has gravitational potential ϕ at its surface.

A particle of mass m is projected vertically upwards from the surface. The particle is given just enough kinetic energy to travel to an infinite distance away from the planet, escaping from the gravitational pull of the planet, without any additional work being done on it.

- (i) Determine an expression, in terms of m and ϕ , for the gravitational potential energy E_p of the particle at the surface of the planet.

$E_p = \dots\dots\dots$ [1]

- (ii) Show that the speed v at which the particle is projected upwards from the surface of the planet is given by

$$v = \sqrt{-2\phi}.$$

[2]

- (c) A particle is moving upwards at the surface of the Moon.

Use your answer in (a)(ii) and the expression in (b)(ii) to determine the minimum speed of this particle that will result in it escaping from the gravitational pull of the Moon.

speed = ... ms^{-1} [1]

- (d) Hydrogen may be assumed to be an ideal gas.
The mass of a hydrogen molecule is $3.34 \times 10^{-27} \text{ kg}$.

Calculate the root-mean-square (r.m.s.) speed of a hydrogen molecule in hydrogen gas that is at a temperature of 400 K.

r.m.s. speed = ... ms^{-1} [3]

- (e) The surface of the Moon reaches temperatures of approximately 400 K when in direct sunlight.

Use your answers in (c) and (d) to suggest a reason why the Moon does not have an atmosphere consisting of hydrogen.

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

[Total: 12]

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- 3 (a) State what is meant by the internal energy of a system.

.....

.....

..... [2]

- (b) Use the first law of thermodynamics to explain what happens to the internal energy:

- (i) of a spring when it is stretched at constant temperature within its elastic limit

.....

.....

.....

.....

..... [3]

- (ii) of a sample of water when it evaporates from a rain puddle on a hot day.

.....

.....

.....

.....

..... [3]

[Total: 8]

- 4 An electron in a metal rod moves randomly about a mean position. When an alternating voltage is applied to the ends of the rod, the mean position can be considered to oscillate with simple harmonic motion along the axis of the rod. Fig. 4.1 shows the variation with time t of the displacement x of the mean position from a fixed point on the axis of the rod.

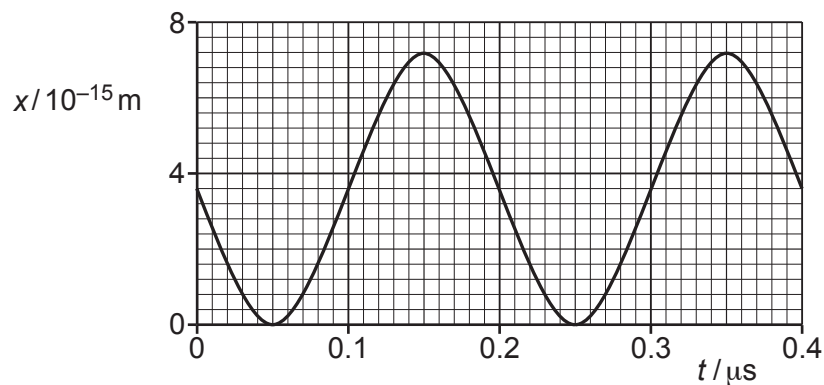


Fig. 4.1

- (a) (i) Determine the amplitude of the oscillations.

amplitude = ... m [1]

- (ii) Determine the angular frequency of the oscillations.

angular frequency = ... rad s^{-1} [1]

- (iii) Use your answers in (a)(i) and (a)(ii) to show that the maximum drift speed v_0 of the electron is $1.1 \times 10^{-7} \text{ m s}^{-1}$.

[2]

- (b) The rod has a cross-sectional area of 4.3 cm^2 and contains a number density of conduction electrons (charge carriers) of $8.5 \times 10^{28} \text{ m}^{-3}$.

All of the conduction electrons in the rod may be assumed to be oscillating in phase with, and with the same amplitude as, the oscillation shown in Fig. 4.1.

- (i) Use the information in (a)(iii) to calculate the magnitude I_0 of the maximum current in the rod.

$$I_0 = \dots\dots\dots \text{A} \quad [2]$$

- (ii) On Fig. 4.2, sketch the variation of the current I in the rod with time t between $t = 0$ and $t = 0.40 \mu\text{s}$.

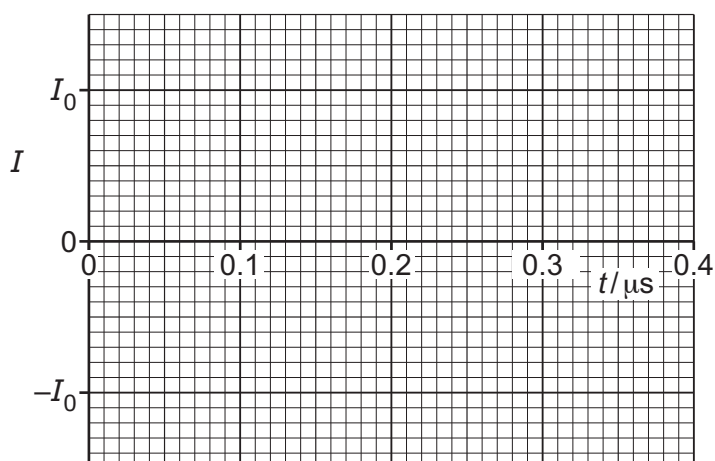


Fig. 4.2

[2]

- (iii) Use your answers in (a)(ii) and (b)(i) to determine an expression for I in terms of t , where I is in A and t is in s.

$$I = \dots\dots\dots [2]$$

- (iv) Determine the root-mean-square (r.m.s.) current in the rod.

$$\text{r.m.s. current} = \dots\dots\dots \text{A} \quad [1]$$

[Total: 11]

- 5 (a) State Coulomb's law.

.....

 [2]

- (b) Two identical oil droplets are in a vacuum. The centres of the droplets are a distance of $3.8 \times 10^{-6} \text{ m}$ apart. The droplets have equal charge and exert an electric force on each other of magnitude $6.3 \times 10^{-17} \text{ N}$.

Determine the magnitude of the charge on each droplet.

charge = ... C [2]

- (c) One of the oil droplets in (b) is now placed between two horizontal metal plates, as shown in Fig. 5.1.

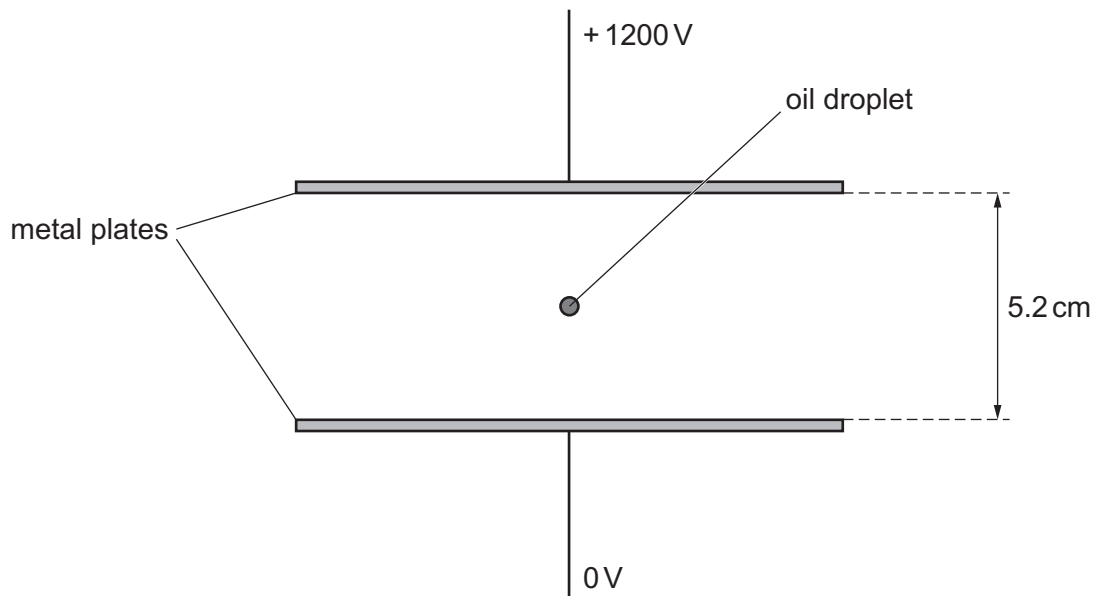


Fig. 5.1 (not to scale)

A potential difference (p.d.) of 1200 V is applied between the plates, with the top plate at the higher potential. The oil droplet is stationary and in equilibrium.

- (i) State the sign of the charge on the oil droplet.

..... [1]

- (ii) On Fig. 5.1, draw four lines to represent the electric field between the plates. [3]

- (iii) The distance between the plates is 5.2 cm.

Determine the mass of the oil droplet.

mass = ... kg [3]

[Total: 11]

- 6 A capacitor C is charged so that the potential difference (p.d.) V across its terminals is 8.0 V . The capacitor is connected into the circuit of Fig. 6.1.

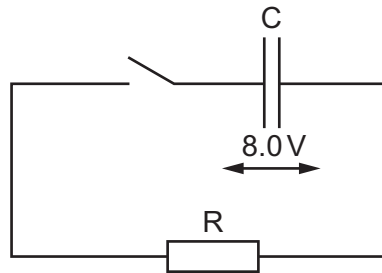


Fig. 6.1

The switch is initially open. The switch is closed at time $t = 0$.

- (a) Fig. 6.2 shows the variation of V with the charge Q on the plates of capacitor C as the capacitor discharges.

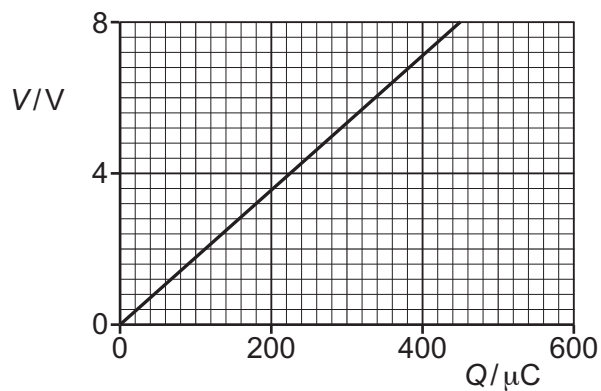


Fig. 6.2

- (i) Show that the energy stored in capacitor C at time $t = 0$ is 1.8 mJ .

[2]

- (ii) Determine the capacitance of capacitor C . Give a unit with your answer.

capacitance = ... unit [2]

(b) Fig. 6.3 shows the variation with t of $-\ln\left(\frac{V}{8.0\text{V}}\right)$.

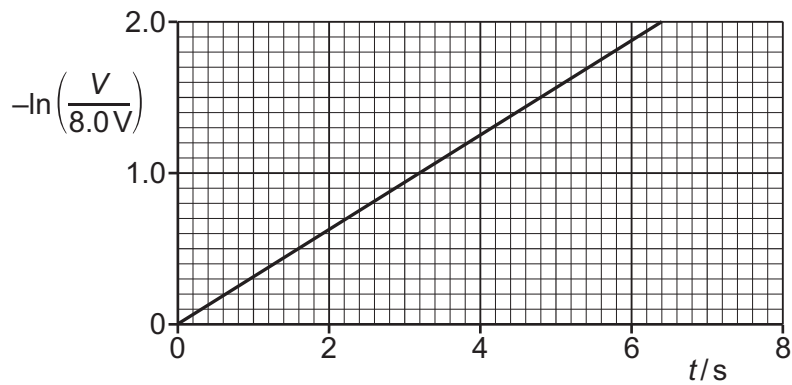


Fig. 6.3

(i) Show that, when t is equal to one time constant, the value of $-\ln\left(\frac{V}{8.0\text{V}}\right)$ is equal to 1.0.

[2]

(ii) Determine the time constant τ of the circuit in Fig. 6.1.

$\tau = \dots\dots\dots \text{s}$ [1]

(iii) Calculate the resistance of resistor R.

resistance = $\dots\dots\dots \Omega$ [2]

[Total: 9]

- 7 (a) A Hall probe containing a thin slice of semiconducting material is placed in a uniform magnetic field of flux density B . The largest faces of the slice are perpendicular to the magnetic field, as shown in Fig. 7.1.

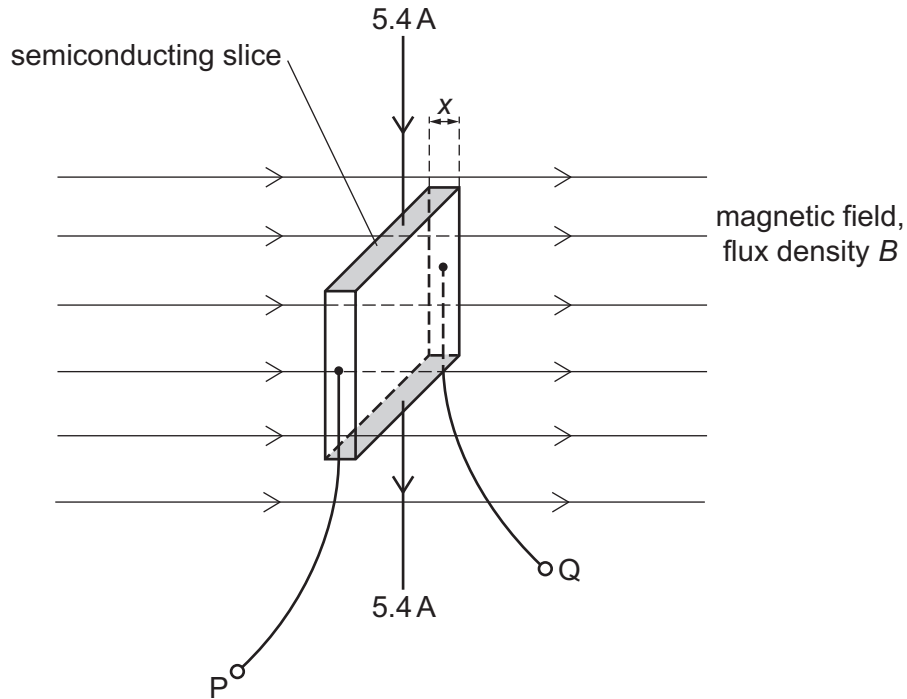


Fig. 7.1

The thickness x of the slice is 1.8 mm. The number density of charge carriers in the semiconducting material is $1.5 \times 10^{16} \text{ m}^{-3}$. A constant current of 5.4 A is passed through the slice between the shaded faces. The Hall voltage V_H that is developed between the terminals PQ is recorded.

Fig. 7.2 shows the variation with time t of B .

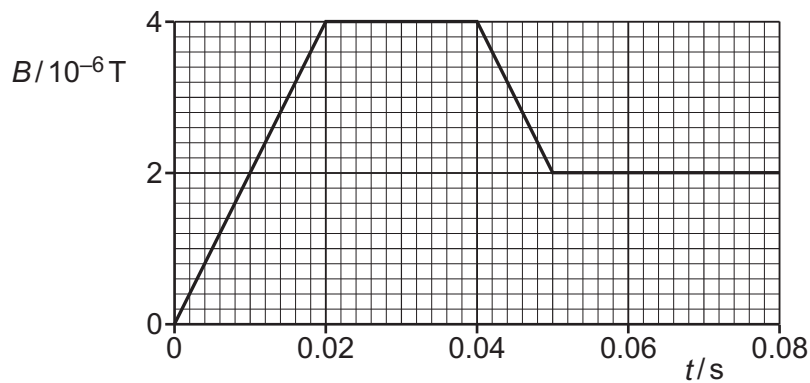


Fig. 7.2

- (i) Show that, when B is equal to $4.0 \times 10^{-6} \text{ T}$, the magnitude of V_H is 5.0 V.

- (ii) On Fig. 7.3, sketch the variation of V_H with t between $t = 0$ and $t = 0.080$ s.

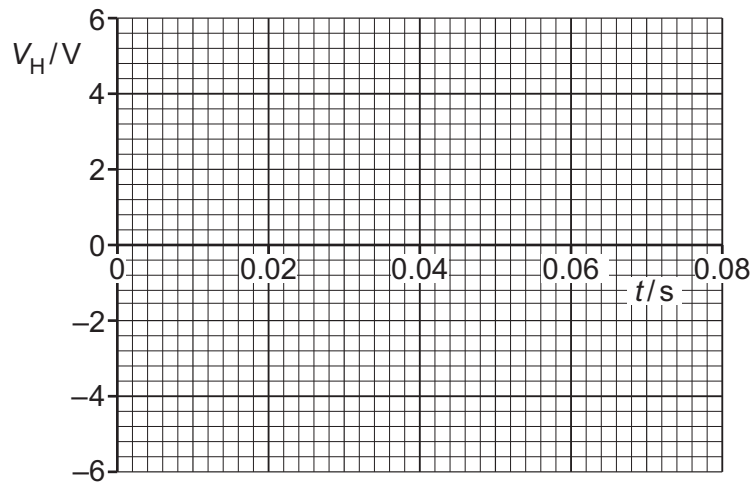


Fig. 7.3

[3]

- (b) The Hall probe in (a) is replaced with a small flat coil that has 3000 turns. The cross-sectional area of the coil is $3.4 \times 10^{-4} \text{ m}^2$. The plane of the coil is perpendicular to the magnetic field. The electromotive force (e.m.f.) E induced between the terminals of the coil is recorded as B varies as shown in Fig. 7.2.

- (i) Show that the magnitude of E at time $t = 0.010$ s is $2.0 \times 10^{-4} \text{ V}$.

[3]

- (ii) On Fig. 7.4, sketch the variation of E with t between $t = 0$ and $t = 0.080$ s.

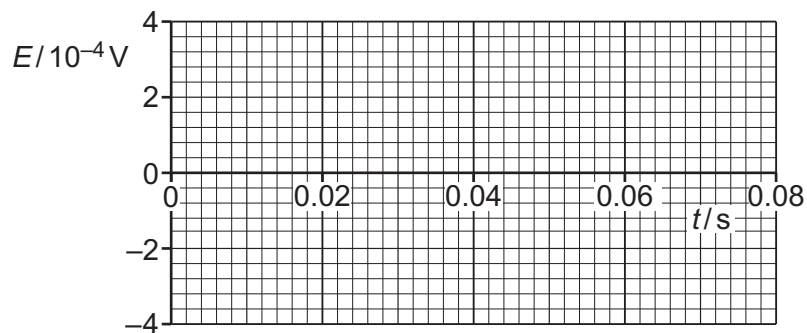


Fig. 7.4

[4]

[Total: 11]

- 8 (a) State what is meant by a photon.

.....

.....

..... [2]

- (b) When the surface of a metal plate is illuminated with electromagnetic radiation, electrons are sometimes emitted from the metal.

- (i) State the name of this phenomenon.

..... [1]

- (ii) It is observed that this phenomenon occurs only when the frequency of the electromagnetic radiation is greater than a certain minimum value, regardless of the intensity of the radiation.

Explain how this observation provides evidence for the existence of photons.

.....

.....

.....

.....

..... [3]

- (c) Fig. 8.1 shows the variation of the maximum kinetic energy of the emitted electrons in (b) with the frequency of the incident radiation.

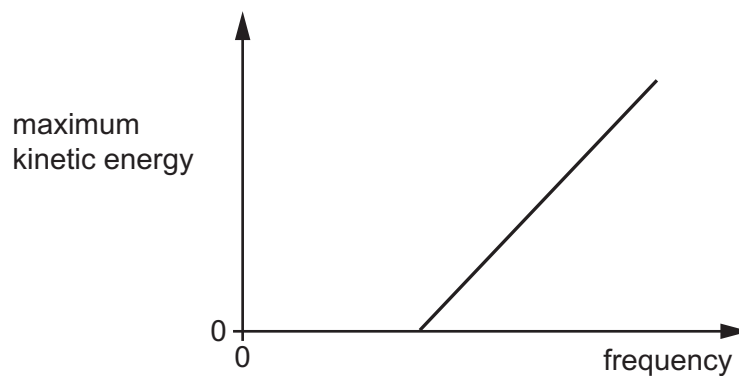


Fig. 8.1

State the name of the quantity represented by:

- (i) the gradient of the line in Fig. 8.1

..... [1]

- (ii) the y -intercept of the extrapolated line in Fig. 8.1.

..... [1]

[Total: 8]

- 9 Fluorine-18 ($^{18}_9\text{F}$) is a radioactive nuclide that is used as a tracer in positron emission tomography (PET scanning). Fluorine-18 decays to a nuclide of oxygen (O) according to



- (a) (i) State what is meant by a tracer.

.....
 [1]

- (ii) State the symbol of the particle that is represented by X and the values of P , Q and R .

X: P :

Q: R :

[2]

- (b) (i) Explain how the radioactive decay of fluorine-18 results in the emission from the body of the gamma-ray photons that are detected during a PET scan.

.....

 [2]

- (ii) Explain how the detection of the gamma-ray photons is used to produce an image of the tissue being examined.

.....

 [2]

- (c) The half-life of fluorine-18 is T .

A patient is injected with amount of substance n of fluorine-18.

- (i) Determine an expression for the initial value R_0 of the rate R of production of gamma-ray photons by the tracer, in terms of n , T and the Avogadro constant N_A .

$R_0 =$ [3]

- (ii) On Fig. 9.1, sketch the variation with time t of R .

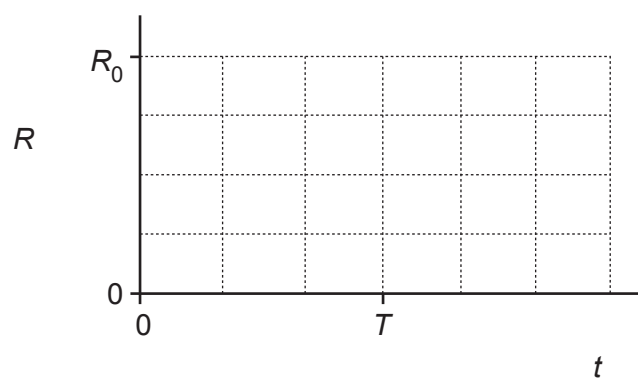


Fig. 9.1

[2]

[Total: 12]

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- 10 (a) State Wien's displacement law. Identify any symbols that you use.

.....

.....

..... [2]

- (b) A cosmology student observes the electromagnetic radiation received from a star in a galaxy. The student uses Wien's law to estimate the surface temperature of the star, a standard candle to estimate the distance to the galaxy, and the Stefan–Boltzmann law to estimate the radius of the star.

The student observes that the radiation from the star is redshifted.

- (i) State what is meant by a standard candle.

..... [1]

- (ii) State the reason why the radiation from the star is redshifted.

..... [1]

- (iii) The true values of the quantities observed or estimated are those that are corrected to allow for redshift. However, the student does not correct for redshift.

By placing one tick (✓) in each row, complete Table 10.1 to indicate how the observations and estimates made by the student compare with the true values.

Table 10.1

	student's uncorrected value		
	too low	the same	too high
wavelength of radiation			
surface temperature of star			
distance to star			
radius of star			

[4]

[Total: 8]

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9702/43

October/November 2023

2 hours

You must answer on the question paper.

No additional materials are needed.

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [].

This document has **24** pages. Any blank pages are indicated.

Data

acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$
speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
Stefan–Boltzmann constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
hydrostatic pressure	$\Delta p = \rho g \Delta h$
upthrust	$F = \rho g V$
Doppler effect for sound waves	$f_o = \frac{f_s v}{v \pm v_s}$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

gravitational potential	$\phi = -\frac{GM}{r}$
gravitational potential energy	$E_P = -\frac{GMm}{r}$
pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
simple harmonic motion	$a = -\omega^2 x$
velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
electrical potential energy	$E_P = \frac{Qq}{4\pi\epsilon_0 r}$
capacitors in series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
discharge of a capacitor	$x = x_0 e^{-\frac{t}{RC}}$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 e^{-\lambda t}$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$
intensity reflection coefficient	$\frac{I_R}{I_0} = \frac{(Z_1 - Z_2)^2}{(Z_1 + Z_2)^2}$
Stefan–Boltzmann law	$L = 4\pi\sigma r^2 T^4$
Doppler redshift	$\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta f}{f} \approx \frac{v}{c}$

- 1 (a) (i) State what is indicated by the direction of the gravitational field line at a point in a gravitational field.

.....
 [1]

- (ii) Explain, with reference to gravitational field lines, why the gravitational field near the surface of the Earth is approximately constant for small changes in height.

.....

 [2]

- (b) A large isolated uniform sphere has mass M and radius R .

Point P lies on a straight line passing through the centre of the sphere, at a variable displacement x from the centre, as shown in Fig. 1.1.

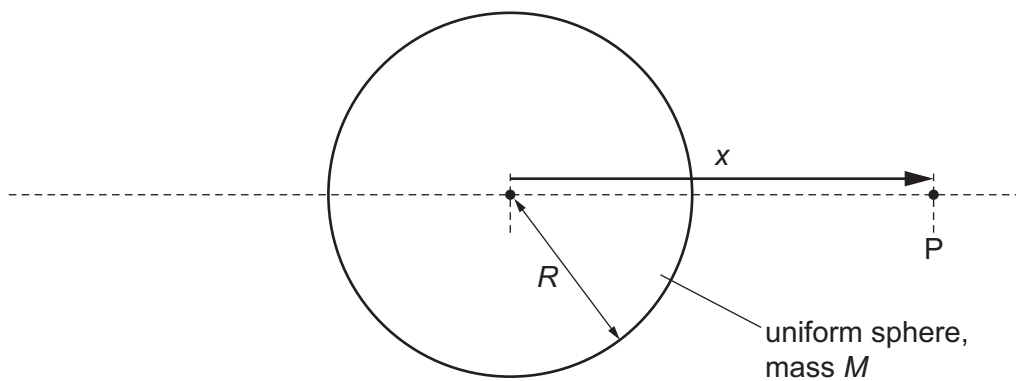


Fig. 1.1

Fig. 1.2 shows the variation with x of the gravitational field g at point P due to the sphere for the values of x for which P is inside the sphere.

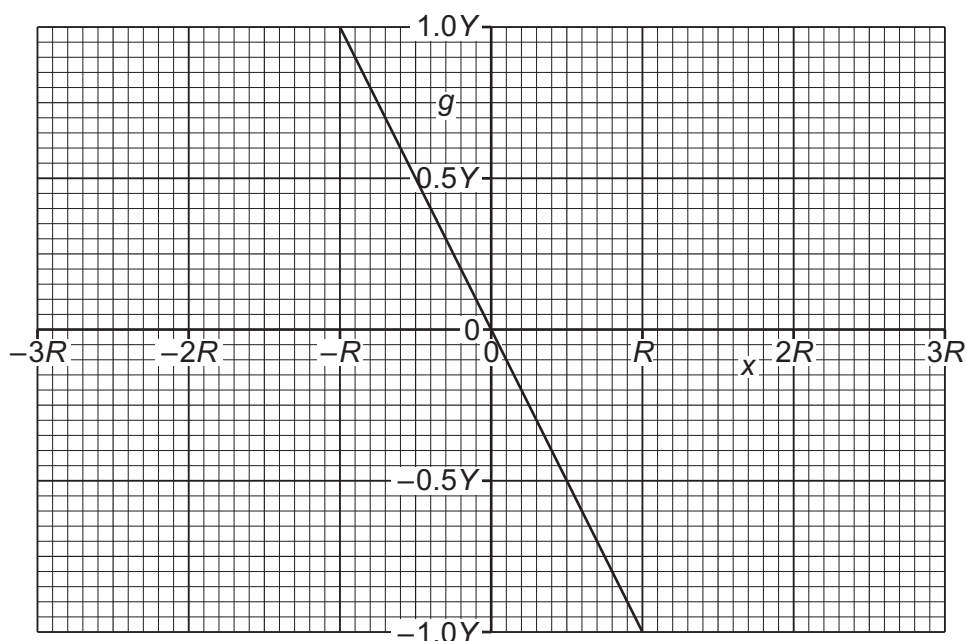


Fig. 1.2

The magnitude of the gravitational field at the surface of the sphere is Y .

- (i) Determine an expression for Y in terms of M and R . Identify any other symbols that you use.

[2]

- (ii) Explain why, at the surface of the sphere, g always has the opposite sign to x .

.....

 [2]

- (iii) Complete Fig. 1.2 to show the variation of g with x for values of x , up to $\pm 3R$, for which point P is outside the sphere. [3]

[Total: 10]

- 2 (a) Define specific heat capacity.

.....

.....

..... [2]

- (b) An ideal gas of mass 0.35 kg is heated at a constant pressure of $2.0 \times 10^5 \text{ Pa}$ so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 m^3 to 0.063 m^3 and the temperature increases by 56°C .

- (i) Show that the magnitude of the work done on the gas is 5000 J.

[1]

- (ii) Explain whether the work done on the gas is positive or negative.

.....

.....

..... [2]

- (iii) Determine the magnitude of the thermal energy q transferred to the gas.

$$q = \dots\dots\dots \text{ J [2]}$$

- (iv) Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

$$\text{specific heat capacity} = \dots\dots\dots \text{ unit } \dots\dots\dots [2]$$

- (c) The gas in (b) is now heated at constant volume rather than at constant pressure. The increase in internal energy of the gas is the same as in (b).

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in (b)(iv).

.....

.....

.....

.....

..... [3]

[Total: 12]

- 3 (a) The product pV for an ideal gas is given by

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

where p is the pressure of the gas and V is the volume of the gas.

- (i) State the meaning of the symbols N , m and $\langle c^2 \rangle$ in this equation.

N :

m :

$\langle c^2 \rangle$:

[3]

- (ii) Use the equation of state for an ideal gas to show that the average translational kinetic energy E_K of a molecule of the gas at thermodynamic temperature T is given by

$$E_K = \frac{3}{2} kT.$$

[2]

- (b) The surface of a star consists mainly of a gas that may be assumed to be ideal. The molecules of the gas have a root-mean-square (r.m.s.) speed of 9300 m s^{-1} .

The mass of a molecule of the gas is $3.34 \times 10^{-27} \text{ kg}$.

Determine, to three significant figures, the temperature of the surface of the star.

temperature = ... K [2]

- (c) The radiant flux intensity of the radiation from the star in (b) is $2.52 \times 10^{-8} \text{ W m}^{-2}$ when observed at a distance of $4.16 \times 10^{16} \text{ m}$ from the star.

(i) Calculate the luminosity of the star. Give a unit with your answer.

luminosity = ... unit [2]

(ii) Determine the radius of the star.

radius = ... m [2]

- (d) The gas at the surface of a star has a very high pressure.

Use the basic assumptions of the kinetic theory to suggest why, in practice, a gas at the surface of a star is unlikely to behave as an ideal gas.

.....

 [2]

[Total: 13]

- 4 A heavy metal sphere of mass 0.81 kg is suspended from a string. The sphere is undergoing small oscillations from side to side, as shown in Fig. 4.1.

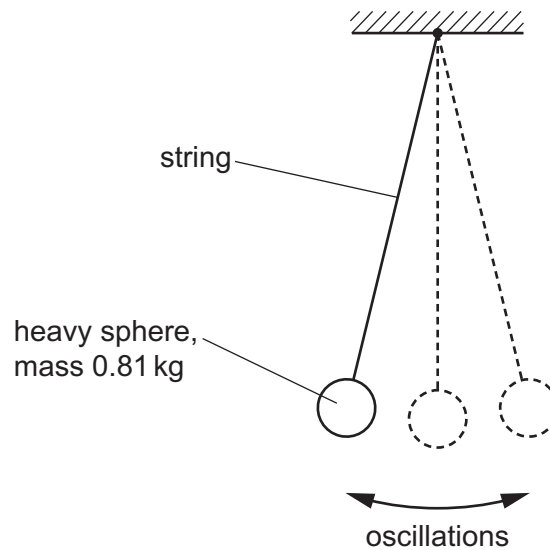


Fig. 4.1

The oscillations of the sphere may be considered to be simple harmonic with amplitude 0.036 m and period 3.0 s.

- (a) State what is meant by simple harmonic motion.

.....

.....

..... [2]

- (b) Calculate:

- (i) the angular frequency of the oscillations

angular frequency = ... rad s^{-1} [2]

(ii) the total energy of the oscillations.

total energy = ... J [2]

- (c) The suspended sphere is now lowered into water. The sphere is given a sideways displacement of $+0.036\text{ m}$ from its equilibrium position and is then released at time $t = 0$. The water causes the motion of the sphere to be critically damped.

On Fig. 4.2, sketch the variation of the displacement x of the sphere from its equilibrium position with t from $t = 0$ to $t = 6.0\text{ s}$.

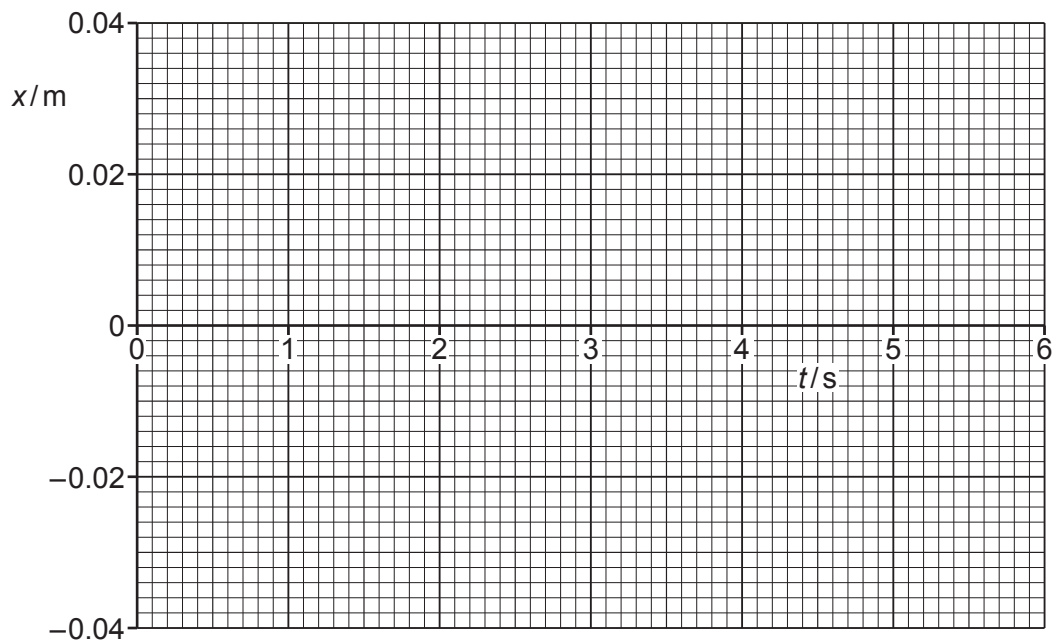


Fig. 4.2

[3]

[Total: 9]

- 5 (a) Define electric potential at a point.

.....

.....

..... [2]

- (b) Two isolated charged metal spheres X and Y are situated near to each other in a vacuum with their centres a distance of 24 m apart. Point P is at a variable distance x from the centre of sphere X on the line joining the centres of the spheres.

Fig. 5.1 shows the variation with x of the electric potential V due to the spheres at point P.

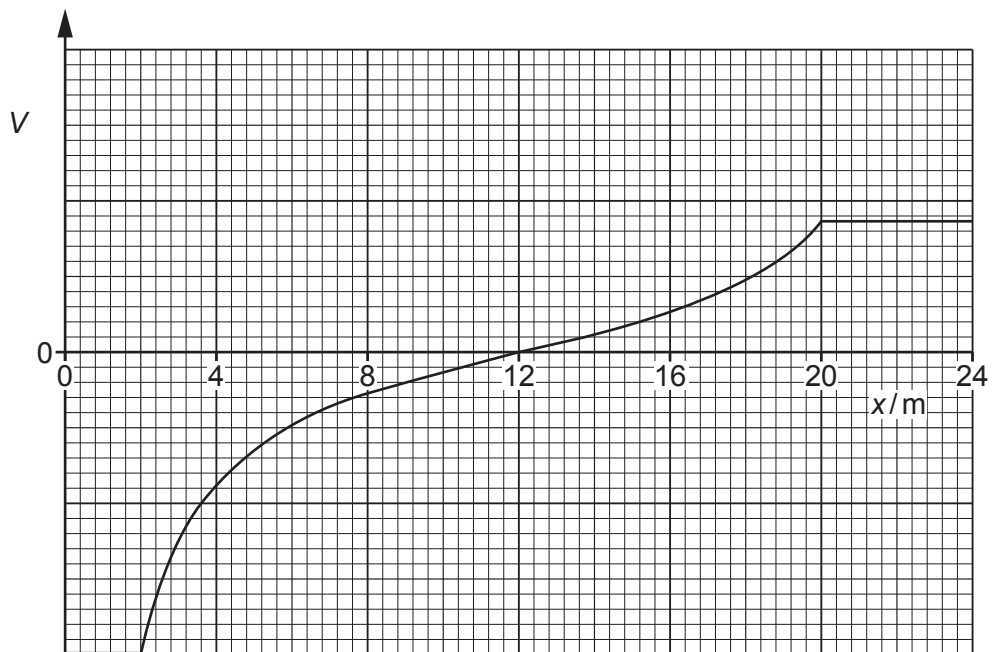


Fig. 5.1

State **three** conclusions that can be drawn about the spheres from Fig. 5.1. The conclusions may be qualitative or quantitative.

1

.....

2

.....

3

.....

[3]

- (c) A positively charged particle is placed at point P in (b), such that $x = 12\text{ m}$. The particle is released.

Describe and explain the subsequent motion of the particle.

.....

.....

.....

.....

..... [3]

[Total: 8]

- 6 (a) Define magnetic flux density.

.....

.....

.....

..... [2]

- (b) Electrons are moving in a vacuum with speed $1.7 \times 10^7 \text{ ms}^{-1}$. The electrons enter a uniform magnetic field of flux density 4.8 mT . Fig. 6.1 shows the path of the electrons.

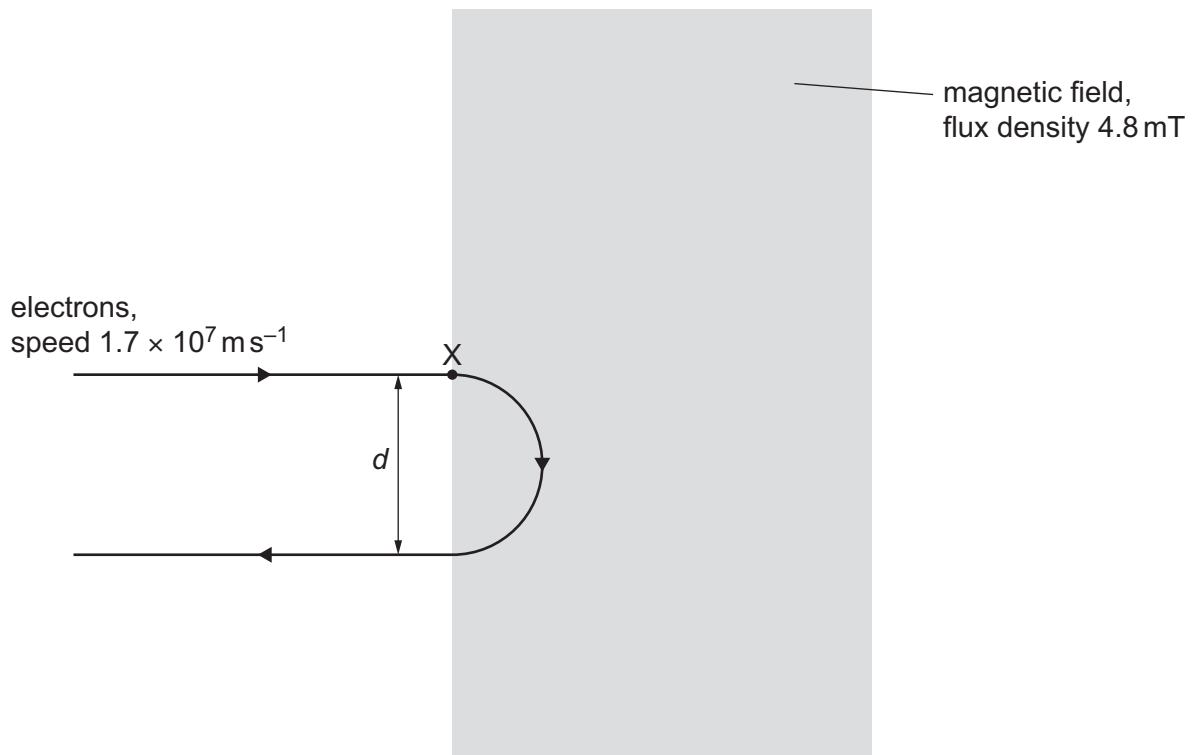


Fig. 6.1

The path of the electrons remains in the plane of the page.

- (i) State the direction of the magnetic field.

.....

..... [1]

- (ii) Show that the magnitude of the force exerted on each electron by the magnetic field is $1.3 \times 10^{-14} \text{ N}$.

[2]

- (iii) On Fig. 6.1, draw an arrow to indicate the direction of the centripetal acceleration of the electron where it enters the magnetic field at point X. [1]

- (iv) Use the information in **(b)(ii)** to calculate the distance d between the path of the electrons entering the magnetic field and the path of the electrons leaving it.

$d = \dots\dots\dots \text{ m}$ [3]

- (c) The electrons in **(b)** are replaced with positrons that are moving with speed $3.4 \times 10^7 \text{ ms}^{-1}$ along the same initial path as the electrons.

The positrons enter the magnetic field at point X on Fig. 6.1.

On Fig. 6.1, draw a line to show the path of the positrons through the magnetic field. [3]

[Total: 12]

- 7 A varying current I passes through a resistor of resistance R in the circuit shown in Fig. 7.1.

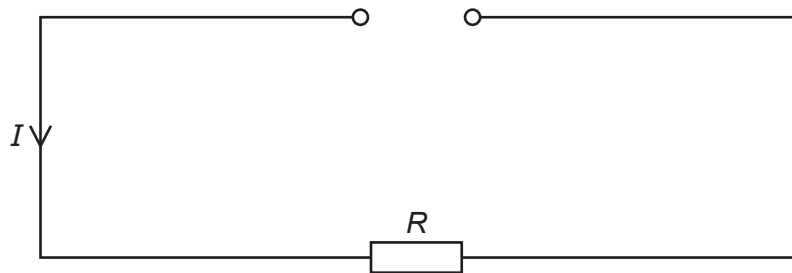


Fig. 7.1

Fig. 7.2 shows the variation with time t of I .

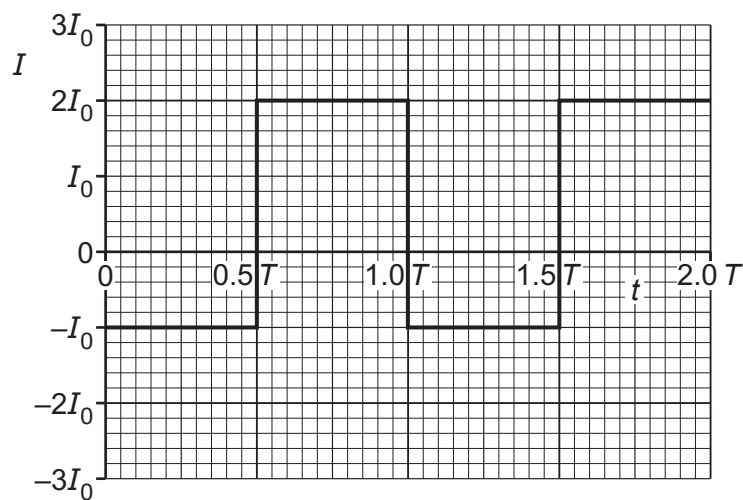


Fig. 7.2

The current has magnitude $2I_0$ when it is in the positive direction and I_0 when it is in the negative direction. The period of the variation of the current is T .

- (a) Determine expressions, in terms of I_0 and R , for the power P dissipated in the resistor for the times when:

- (i) the current is in the negative direction

$$P = \dots\dots\dots [1]$$

- (ii) the current is in the positive direction.

$$P = \dots\dots\dots [1]$$

- (b) On Fig. 7.3, sketch the variation of P with t between $t = 0$ and $t = 2.0T$. Label the power axis with an appropriate scale.

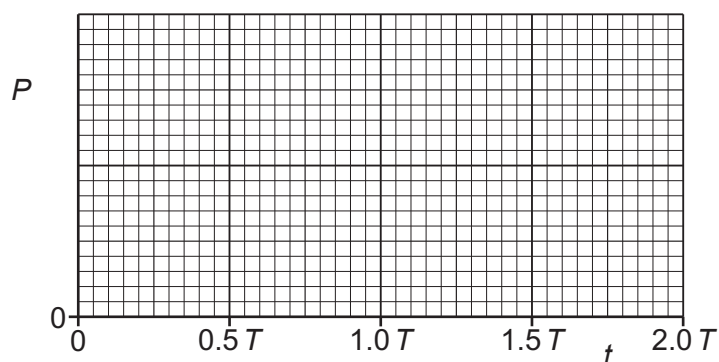


Fig. 7.3

[3]

- (c) Use your answer in (b) to determine an expression, in terms of I_0 and R , for:

- (i) the mean power $\langle P \rangle$ in the resistor

$$\langle P \rangle = \dots\dots\dots [1]$$

- (ii) the root-mean-square (r.m.s.) current $I_{\text{r.m.s.}}$ in the resistor.

$$I_{\text{r.m.s.}} = \dots\dots\dots [2]$$

[Total: 8]

- 8 (a) (i) Show that the momentum p of a photon of electromagnetic radiation with wavelength λ is given by

$$p = \frac{h}{\lambda}$$

where h is the Planck constant.

[2]

- (ii) Use the expression in (a)(i) to show that a photon in free space that has a momentum of $9.5 \times 10^{-28} \text{ N s}$ is a photon of red light.

[1]

- (b) A beam of red light of intensity 160 W m^{-2} is incident normally on a plane mirror, as shown in Fig. 8.1. The momentum of each photon in the beam is $9.5 \times 10^{-28} \text{ N s}$.

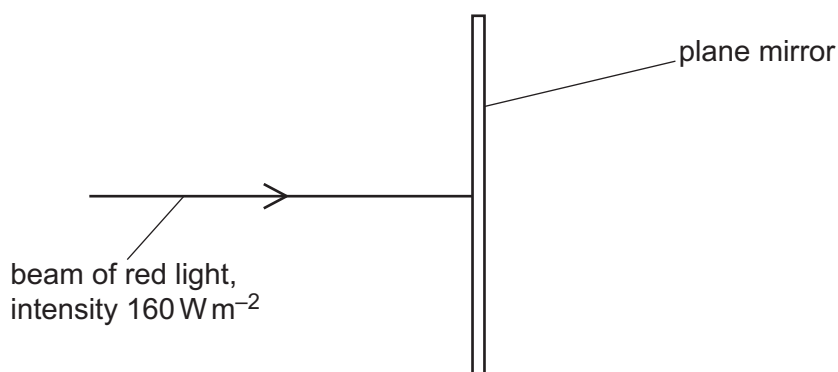


Fig. 8.1

All of the light is reflected by the mirror in the opposite direction to its original path. The cross-sectional area of the beam is $2.5 \times 10^{-6} \text{ m}^2$.

- (i) Show that the number of photons incident on the mirror per unit time is $1.4 \times 10^{15} \text{ s}^{-1}$.

[2]

- (ii) Use the information in **(b)(i)** to determine the pressure exerted by the light beam on the mirror.

pressure = ... Pa [3]

- (c) The beam of red light in **(b)** is now replaced with a beam of blue light of the same intensity.

Suggest and explain whether the pressure exerted on the mirror by the beam of blue light is less than, the same as, or greater than the pressure exerted by the beam of red light.

.....

 [2]

[Total: 10]

- 9 (a) State what is meant by nuclear fusion.

.....

.....

..... [2]

- (b) On Fig. 9.1, sketch the variation of binding energy per nucleon with nucleon number A for values of A between 1 and 250.

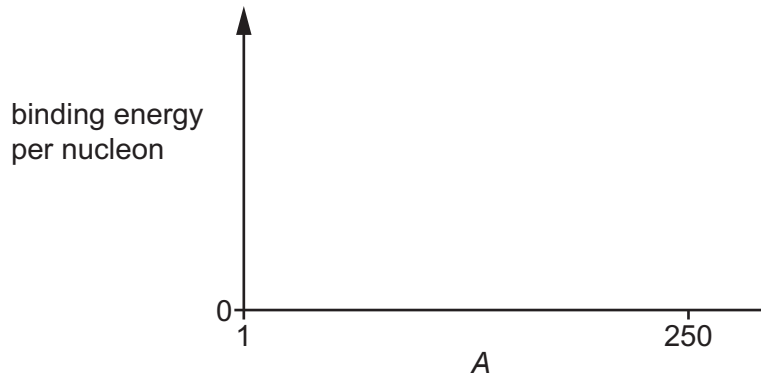


Fig. 9.1

[2]

- (c) On your line in Fig. 9.1, label:

- (i) a point X that could represent a nucleus that undergoes alpha-decay [1]
- (ii) a point Y that could represent a nucleus that undergoes nuclear fusion. [1]

- (d) A nucleus Z undergoes nuclear fission to form strontium-93 ($^{93}_{38}\text{Sr}$) and xenon-139 ($^{139}_{54}\text{Xe}$) according to

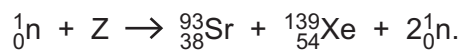


Table 9.1 shows the binding energies of the strontium-93 and xenon-139 nuclei.

Table 9.1

nucleus	binding energy/J
$^{93}_{38}\text{Sr}$	1.25×10^{-10}
$^{139}_{54}\text{Xe}$	1.81×10^{-10}

The fission of 1.00 mol of Z releases 1.77×10^{13} J of energy.

Determine the binding energy per nucleon, in MeV, of Z.

binding energy per nucleon = ... MeV [4]

[Total: 10]

- 10** Ultrasound and X-rays are both types of wave that are used in medical diagnosis to form images of internal body structures.

(a) Complete Table 10.1 to state, for each type of wave:

- the method of production of the wave
- whether the wave that is detected and used to form the image is the wave that has been absorbed, reflected or transmitted by the internal body structure.

Table 10.1

	ultrasound	X-rays
method of production		
detected wave (absorbed, reflected or transmitted)		

[4]

- (b) (i)** For one type of wave passing through tissue, the wave has 72% of its initial intensity after it has passed through 6.2 cm of the tissue.

Calculate the linear attenuation coefficient μ of the tissue for this wave.

$$\mu = \dots\dots\dots \text{ cm}^{-1} \quad [2]$$

- (ii)** Another wave of the same type as in **(b)(i)** passes through 9.3 cm of the same tissue.

Calculate the percentage of the initial intensity of the wave that is attenuated by the tissue.

$$\text{percentage attenuated} = \dots\dots\dots \% \quad [2]$$

[Total: 8]

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