



CANDIDATE
NAME

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CANDIDATE
NUMBER

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9702/41

October/November 2022

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) State the equation for the gravitational force F between two point masses m_1 and m_2 that are separated by a distance r . State the meaning of any other symbols you use.

[2]

- (b) A satellite is in a circular orbit of radius R around a planet of mass M .

Show that the period T of the orbit is given by

$$T^2 = kR^3$$

where k is a constant that depends on the value of M . Explain your reasoning.

[3]

- (c) A satellite is in a circular orbit around the Earth with a period of 24 hours. The mass of the Earth is 6.0×10^{24} kg.

- (i) Calculate the radius of the orbit.

radius = ... m [2]

(ii) State the **two** other conditions that must be met for the orbit to be geostationary.

1

.....

2

.....

[2]

[Total: 9]

- 2 Fig. 2.1 shows a laboratory thermometer that is calibrated to measure temperature in degrees Celsius.

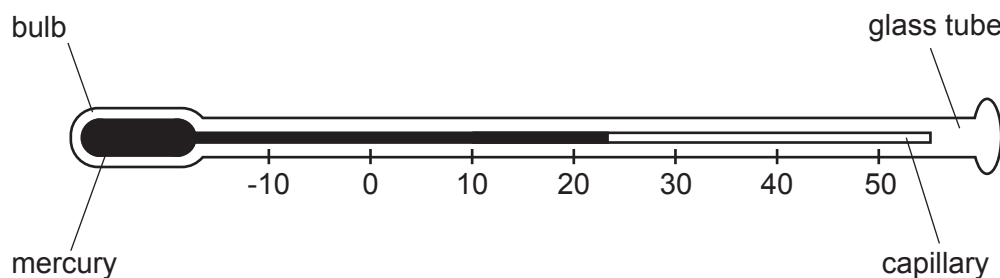


Fig. 2.1

The thermometer makes use of the fact that the density of mercury varies with temperature.

- (a) State **two** other physical properties of materials, apart from the density of a liquid, that can be used for measuring temperature.

1

2 [2]

- (b) The thermometer is initially at 23.0°C , as shown in Fig. 2.1. It is used to measure the temperature of an insulated beaker of water that is at 37.4°C . The bulb of the thermometer is inserted into the water, and the water is stirred until the reading on the thermometer becomes steady.

The mass of water in the beaker is 18.7 g.

The mass of mercury in the thermometer is 6.94 g.

The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.

The specific heat capacity of mercury is $0.140 \text{ J g}^{-1} \text{ K}^{-1}$.

The glass of the thermometer and the beaker containing the water can be considered to have negligible heat capacity.

- (i) Calculate, to three significant figures, the final steady temperature indicated by the thermometer in the water.

temperature = ... $^{\circ}\text{C}$ [4]

- (ii) Suggest **one** change that could be made to the design of the thermometer that would enable it to give a more accurate measurement of temperature.

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

- (c) (i) Explain why the thermometer in Fig. 2.1 does **not** provide a direct measurement of thermodynamic temperature.

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

- (ii) Thermodynamic temperature T may be determined by the behaviour of a type of substance for which T is proportional to the product of pressure and volume.

State the name of this type of substance.

..... [1]

[Total: 10]

- 3 An object is suspended from a spring that is attached to a fixed point as shown in Fig. 3.1.

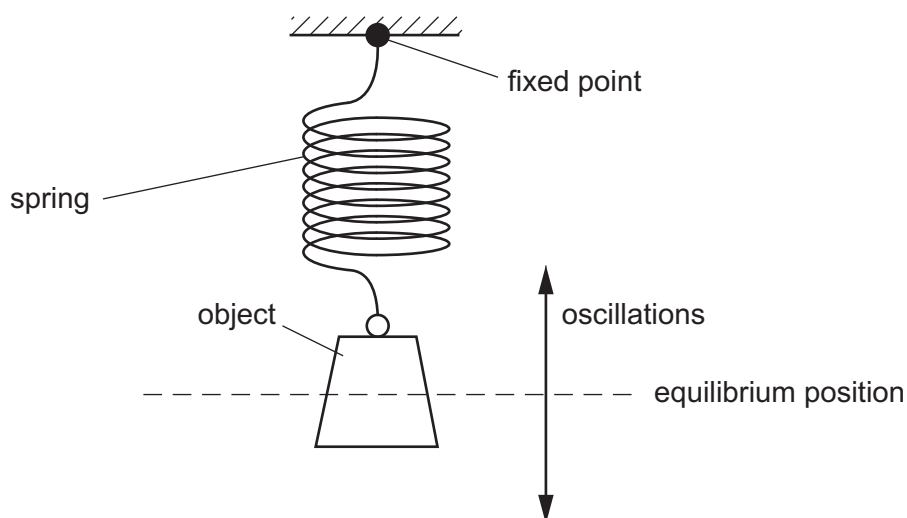


Fig. 3.1

The object oscillates vertically with simple harmonic motion about its equilibrium position.

- (a) State the defining equation for simple harmonic motion. Identify the meaning of each of the symbols used to represent physical quantities.

.....

.....

..... [2]

- (b) The variation with displacement x from the equilibrium position of the velocity v of the object is shown in Fig. 3.2.

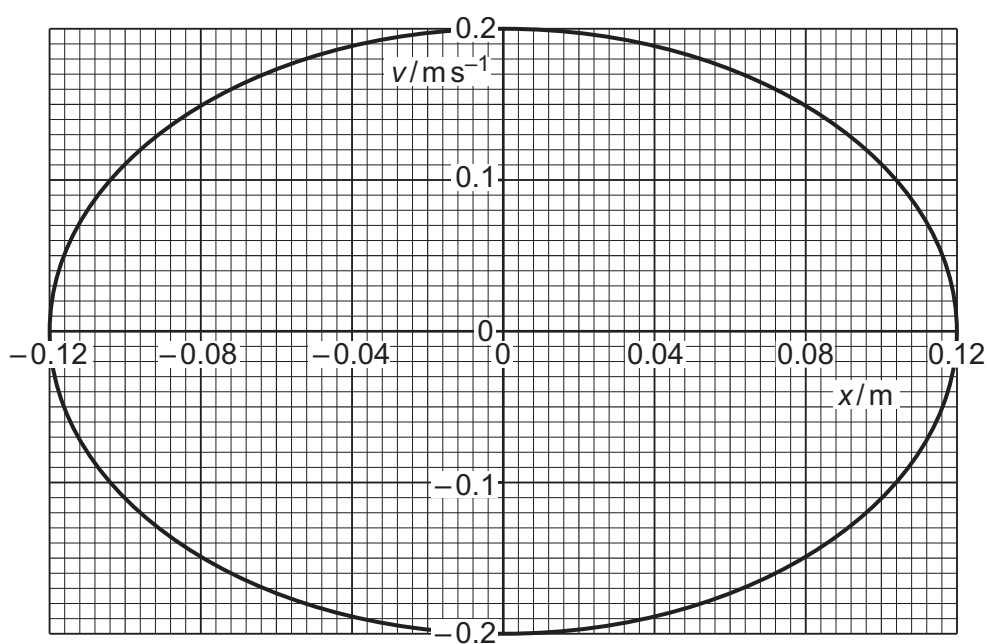


Fig. 3.2

The variation with x of the potential energy E_P of the oscillations of the object is shown in Fig. 3.3.

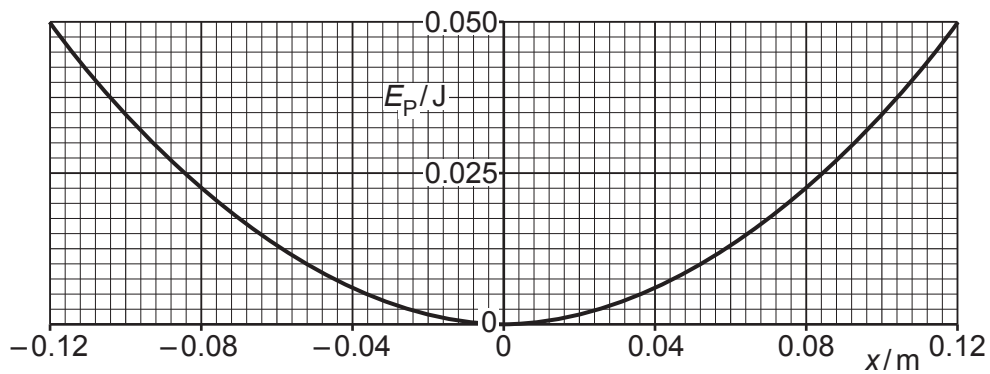


Fig. 3.3

Use Fig. 3.2 and Fig. 3.3 to:

- (i) determine the amplitude x_0 of the oscillations

$$x_0 = \dots\dots\dots \text{ m [1]}$$

- (ii) show that the angular frequency of the oscillations is 1.7 rad s^{-1}

[2]

- (iii) determine the mass M of the object.

$$M = \dots\dots\dots \text{ kg [2]}$$

(c) The oscillations of the object are now lightly damped.

(i) State what is meant by damping.

.....

.....

..... [2]

(ii) Assume that the damping does not change the angular frequency of the oscillations.

On Fig. 3.2, sketch the variation with x of v when the amplitude of the oscillations is 0.060 m. [2]

[Total: 11]

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- 4 (a) State what is indicated by the direction of an electric field line.

.....
 [2]

- (b) Fig. 4.1 shows a pair of parallel metal plates with a potential difference (p.d.) of 2400 V between them.

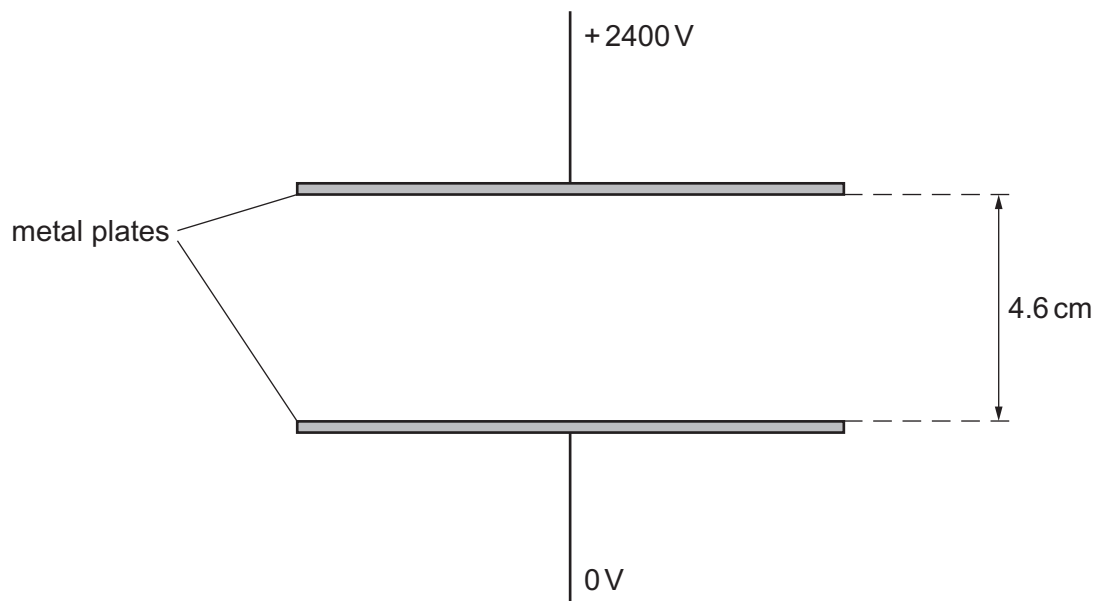


Fig. 4.1

The plates are separated by a distance of 4.6 cm. The plates are in a vacuum.

- (i) On Fig. 4.1, draw five lines to represent the electric field in the region between the plates. [3]
- (ii) Calculate the strength of the electric field between the plates.

electric field strength = ... NC^{-1} [2]

- (c) A moving proton enters the region between the plates from the left, as shown in Fig. 4.2.

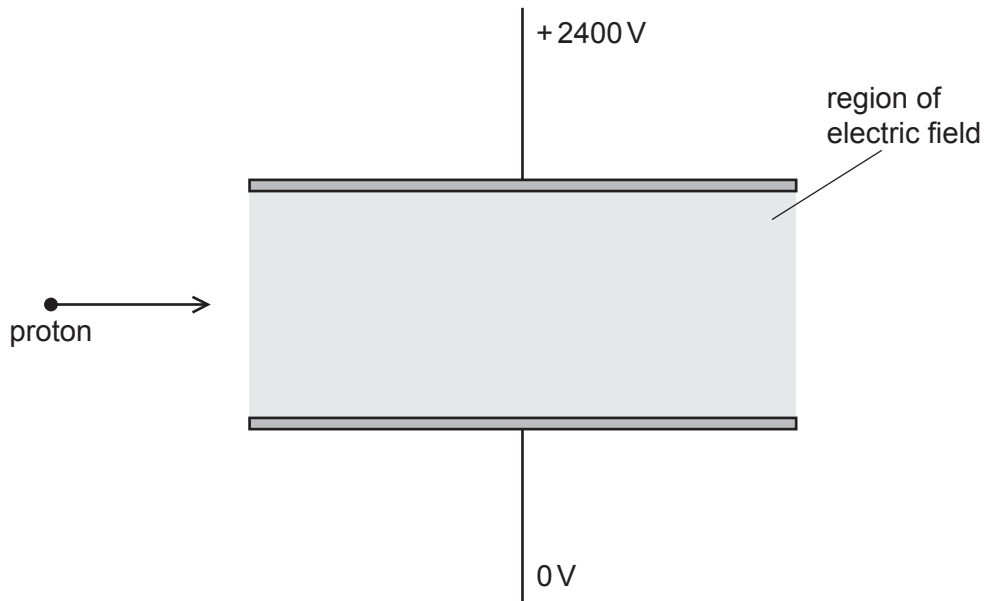


Fig. 4.2

- (i) The proton is deflected by the electric field.

On Fig. 4.2, draw a line to show the path of the proton as it moves through and out of the region of the electric field. [2]

- (ii) A helium nucleus (${}^4_2\text{He}$) now enters the region of the electric field along the same initial path as the proton and travelling at the same initial speed.

State and explain how the final speed of the helium nucleus compares with the final speed of the proton after leaving the region of the electric field.

.....

.....

.....

.....

..... [3]

[Total: 12]

- 5 A capacitor of capacitance $470\ \mu\text{F}$ is connected to a battery of electromotive force (e.m.f.) $24\ \text{V}$ in the circuit of Fig. 5.1.

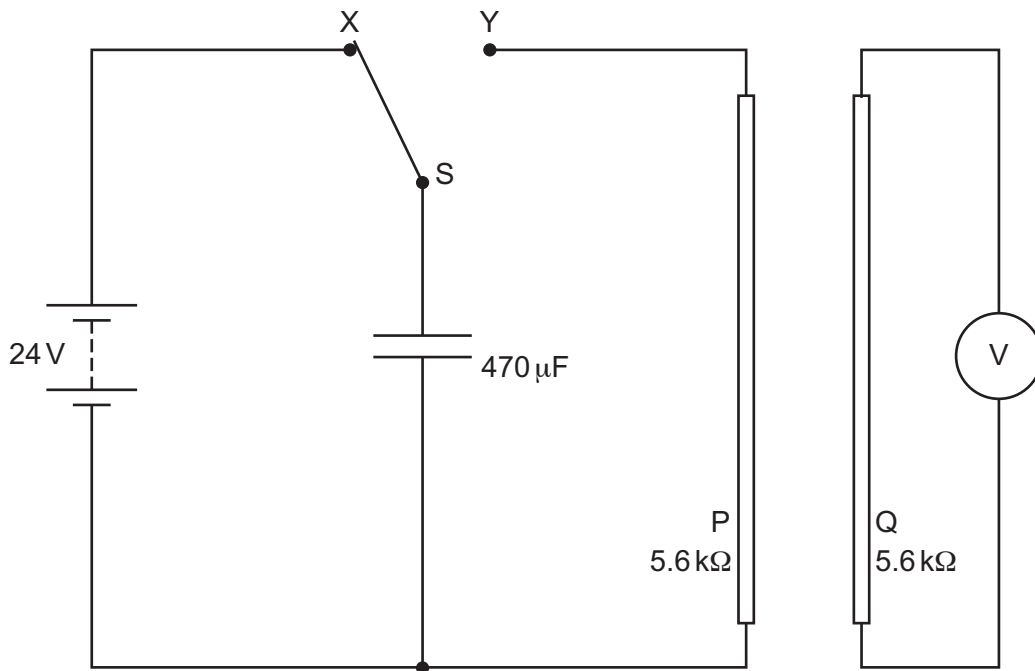


Fig. 5.1

The two-way switch S is initially at position X.

P and Q are identical long straight wires, each with a resistance of $5.6\ \text{k}\Omega$. These wires are placed near to, and parallel to, each other. Wire Q is connected to a voltmeter.

At time $t = 0$, switch S is moved to position Y so that the capacitor discharges through wire P.

- (a) (i) Calculate the charge Q_0 on the capacitor at time $t = 0$.

$$Q_0 = \dots\dots\dots \text{ C [2]}$$

- (ii) Calculate the current I_0 in wire P at time $t = 0$.

$$I_0 = \dots\dots\dots \text{ A [1]}$$

- (iii) Calculate the time constant τ of the discharge circuit.

$\tau = \dots\dots\dots$ s [2]

- (iv) On Fig. 5.2, sketch a line to show the variation with t of the current I in wire P as the capacitor discharges.



Fig. 5.2

[2]

- (b) (i) Explain why there is an induced e.m.f. across wire Q during the discharge of the capacitor.

.....

 [3]

- (ii) On Fig. 5.3, sketch a line to suggest the variation with t of the voltmeter reading V .



Fig. 5.3

[1]

[Total: 11]

- 6 Fig. 6.1 shows a thin slice of semiconducting material used in a Hall probe.

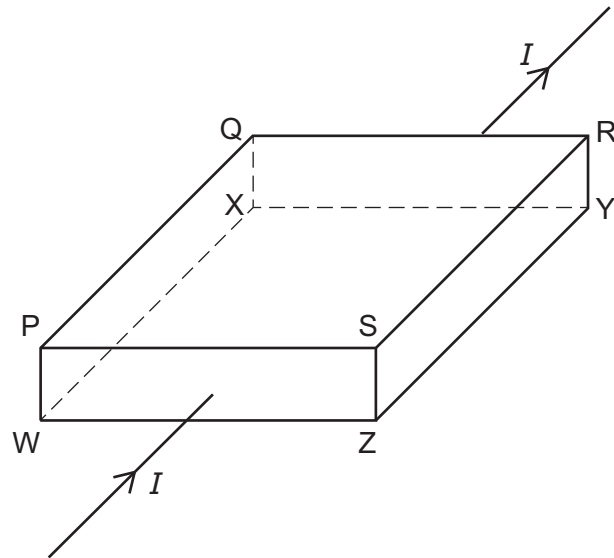


Fig. 6.1 (not to scale)

Current I passes through the slice in the direction shown.

The slice is placed in a uniform magnetic field of flux density B , so that two of its faces are perpendicular to the magnetic field.

A steady Hall voltage V_H is developed between face PQXW and face SRYZ.

- (a) (i) Use the letters in Fig. 6.1 to identify the faces that are perpendicular to the magnetic field.

..... and [1]

- (ii) Explain how the steady Hall voltage V_H is developed between faces PQXW and SRYZ.

.....

 [3]

(b) The magnitude of V_H is given by the equation

$$V_H = \frac{BI}{ntq}.$$

(i) State the meaning of the symbols n , t and q . You may refer to the letters in Fig. 6.1.

n :

t :

q : [3]

(ii) Suggest, with reference to the equation, why the slice of the material used in a Hall probe is thin.

.....

.....

..... [2]

[Total: 9]

- 7 (a) A sinusoidal alternating voltage has a root-mean-square (r.m.s.) potential difference (p.d.) of 4.2 V and a frequency of 50 kHz.

- (i) The alternating voltage is applied across a resistor of resistance $760\ \Omega$.

By considering the peak voltage, show that the maximum power dissipated by the resistor is 46 mW.

[2]

- (ii) On Fig. 7.1, draw a smooth curve to show how the power P dissipated in the resistor varies with time t between $t = 0$ and $t = 40\ \mu\text{s}$. Assume that $P = 0$ when $t = 0$.

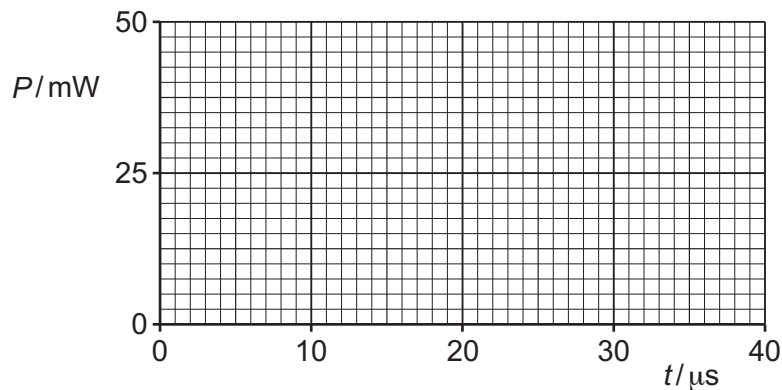


Fig. 7.1

[3]

- (iii) Use your line in (a)(ii) to explain why the mean power dissipated in the resistor is 23 mW.

.....

 [1]

(b) The alternating voltage in **(a)** is now applied to a piezoelectric crystal in air.

(i) Explain what happens to the air surrounding the crystal.

.....

.....

.....

..... [3]

(ii) A second piezoelectric crystal is placed in the air near to the first crystal.

Explain the effect of the surrounding air in **(b)(i)** on the second crystal.

..... [1]

[Total: 10]

- 8 (a) State what is meant by the work function energy of a metal.

.....

.....

..... [2]

- (b) Ultraviolet radiation of frequency $1.36 \times 10^{15} \text{ Hz}$ is incident, in a vacuum, on a metal surface. The power of the radiation incident on the surface is 8.36 mW . Photoelectrons are emitted with a maximum kinetic energy of $3.09 \times 10^{-19} \text{ J}$.

- (i) Determine the number of photons incident on the surface per unit time.

number per unit time = ... s^{-1} [2]

- (ii) Calculate the work function energy Φ of the metal.

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

- (c) The frequency of the radiation incident on the surface in (b) is increased while the power remains constant.

State and explain the effect of this change on:

- (i) the maximum kinetic energy of the photoelectrons

.....

.....

..... [2]

- (ii) the rate of emission of photoelectrons.

.....

.....

..... [2]

[Total: 10]

- 9 (a) State what is meant by the luminosity of a star.

..... [1]

- (b) A star in the constellation Canis Major is a distance of 8.14×10^{16} m from the Earth and has a luminosity of 9.86×10^{27} W. The surface temperature of the star is 9830 K.

- (i) Calculate the radiant flux intensity of the radiation from the star observed from the Earth. Give a unit with your answer.

radiant flux intensity = ... unit [2]

- (ii) Determine the radius of the star.

radius = ... m [2]

- (c) Explain how the surface temperature of a distant star may be determined from the wavelength spectrum of the light from the star.

.....

 [3]

[Total: 8]

- 10 Carbon-15 ($^{15}_6\text{C}$) is an isotope of carbon that undergoes radioactive decay to nitrogen-15 ($^{15}_7\text{N}$), which is a stable isotope of nitrogen.

Radioactive decay is both a random and a spontaneous process.

(a) State what is meant by:

(i) random

.....
 [1]

(ii) spontaneous.

.....
 [1]

- (b) A small sample of carbon-15 decays. The mass M of carbon-15 in the sample decreases with time t .

Fig. 10.1 shows the variation with t of the value of $\ln (M/10^{-16}\text{g})$.

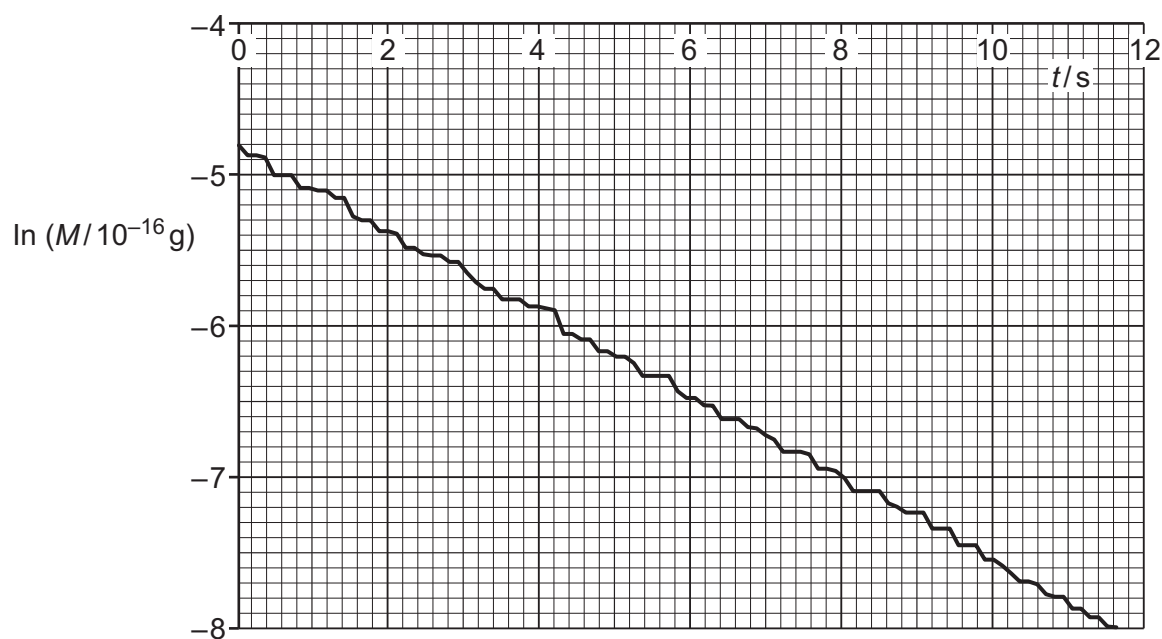


Fig. 10.1

- (i) State how Fig. 10.1 demonstrates that radioactive decay is random.

.....
 [1]

- (ii) On Fig. 10.1, draw the straight line of best fit.

[1]

- (iii) Show that the decay constant λ of carbon-15 is given by the magnitude of the gradient of your line in (b)(ii).

[1]

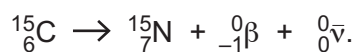
- (iv) Use your line in (b)(ii) to determine λ . Give a unit with your answer.

$\lambda = \dots\dots\dots$ unit $\dots\dots\dots$ [2]

- (v) Use your answer in (b)(iv) to calculate the half-life of carbon-15.

half-life = $\dots\dots\dots$ s [1]

- (c) The equation for the decay of carbon-15 can be written as



State and explain how the mass of the products of the decay must compare with the mass of the carbon-15 nucleus.

.....

 [2]

[Total: 10]

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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 gravitational field.

.....
 [1]

- (b) A spherical planet can be considered as a point mass at its centre.

- (i) On Fig. 1.1, draw gravitational field lines outside the planet to represent the gravitational field due to the planet.

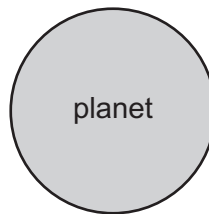


Fig. 1.1

[2]

- (ii) A satellite is in a circular orbit around the planet.

Explain, with reference to your answer in (b)(i), why the path of the satellite is circular.

.....

 [2]

- (c) An object rests on the surface of the Earth at the Equator.
The radius of the Earth is $6.4 \times 10^6 \text{ m}$.
- (i) Determine the centripetal acceleration of the object.

centripetal acceleration = ... ms^{-2} [3]

- (ii) Describe how the two forces acting on the object give rise to this centripetal acceleration.
You may draw a diagram if you wish.

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

[Total: 10]

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- 2 (a) Define specific heat capacity.

.....

.....

..... [2]

- (b) A fixed mass of water in a beaker is at atmospheric pressure.

- (i) The initial temperature of the water is 0°C .

The water is supplied with thermal energy E , so that its temperature increases to 8°C . There is no net change in the volume of the water.

Use the first law of thermodynamics to complete Table 2.1 for this process.

Table 2.1

work done on water	thermal energy supplied to water	increase in internal energy of water
	$+ E$	

[2]

- (ii) The water is now heated so that its temperature increases by a further 8°C to a final temperature of 16°C . This process causes the volume of the water to increase so that work W is done.

Assume that the change in internal energy is the same as in (b)(i).

Use the first law of thermodynamics to complete Table 2.2 for this process.

Table 2.2

work done on water	thermal energy supplied to water	increase in internal energy of water

[2]

- (c) Use the information in (b) to suggest, with a reason, how the average specific heat capacity of water between 8°C and 16°C compares with its average value between 0°C and 8°C .

.....

..... [1]

[Total: 7]

- 3 (a) The equation of state for an ideal gas can be written as

$$pV = NkT.$$

State the meaning of each of the symbols in this equation.

p :

V :

N :

k :

T :

[3]

- (b) Use the equation in (a) to show that the average translational kinetic energy E_K of a molecule of an ideal gas is given by

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

[2]

- (c) The mass of an oxygen molecule is 5.31×10^{-26} kg. Assume that oxygen behaves as an ideal gas.

- (i) Use the equation in (b) to determine the root-mean-square (r.m.s.) speed u of an oxygen molecule at 23°C .

$$u = \dots \text{ms}^{-1} \quad [3]$$

- (ii) A fixed mass of oxygen gas at initial pressure P is sealed in a cylindrical container by a movable piston at one end, as shown in Fig. 3.1.

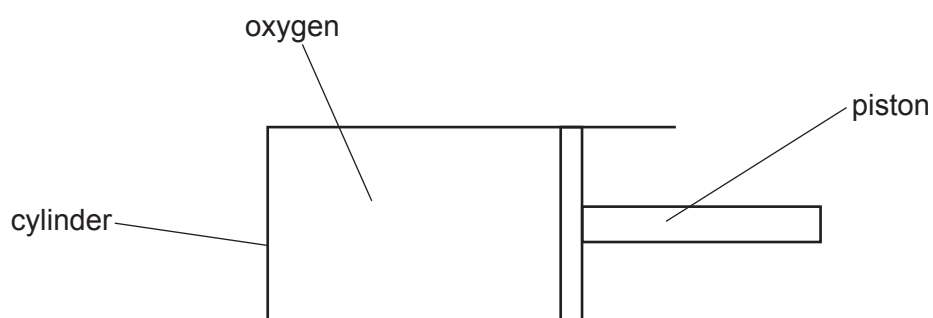


Fig. 3.1

The temperature of the gas is 23°C .

The piston is slowly moved into the cylinder so that the oxygen gas is compressed. At all times, the gas and the container remain in thermal equilibrium with the surroundings.

On Fig. 3.2, sketch the variation with pressure of the r.m.s. speed of the oxygen molecules as the pressure increases.



Fig. 3.2

[2]

[Total: 10]

- 4 Fig. 4.1 shows the variation with time t of the height h above the ground of an object of mass 36 kg that is undergoing vertical simple harmonic motion.

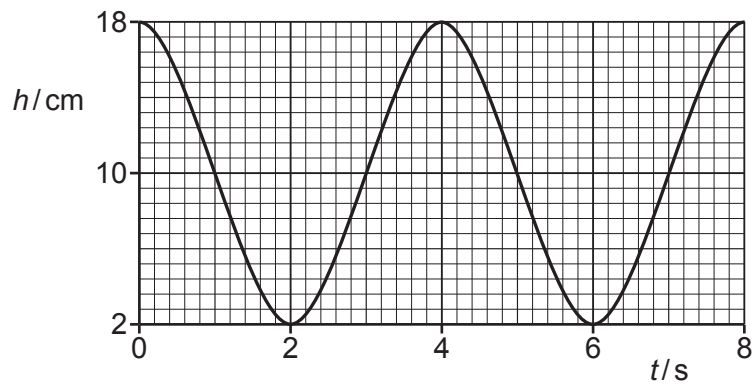


Fig. 4.1

- (a) For the oscillations of the object:

- (i) determine the amplitude x_0 , in cm

$$x_0 = \dots\dots\dots \text{ cm [1]}$$

- (ii) show that the angular frequency ω is 1.6 rad s^{-1}

[2]

- (iii) determine the total energy E .

$$E = \dots\dots\dots \text{ J [3]}$$

(b) On Fig. 4.2, sketch the variation with h of the kinetic energy E_K of the object.

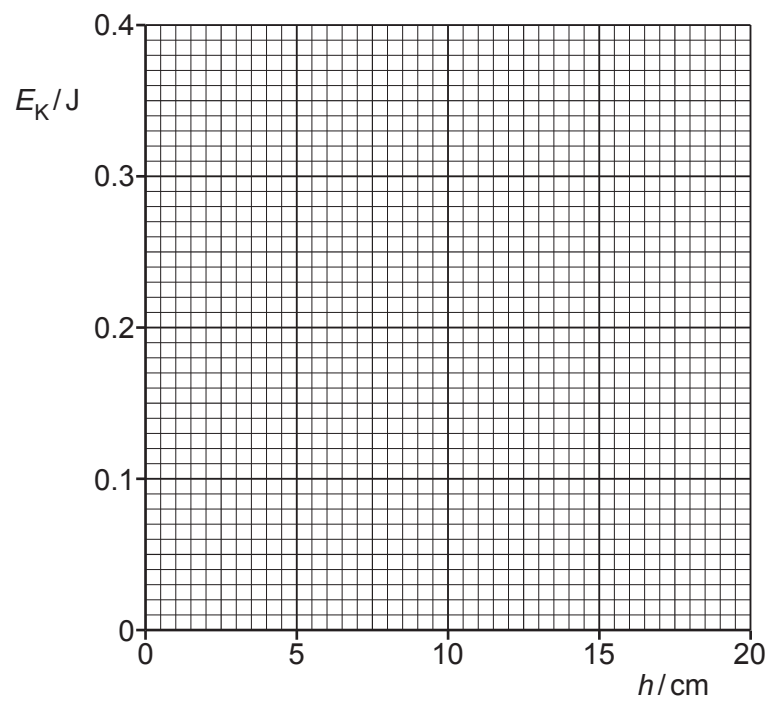


Fig. 4.2

[4]

[Total: 10]

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

.....

 [2]

- (b) An isolated conducting sphere is charged. Fig. 5.1 shows the variation of the potential V due to the sphere with displacement x from its centre.

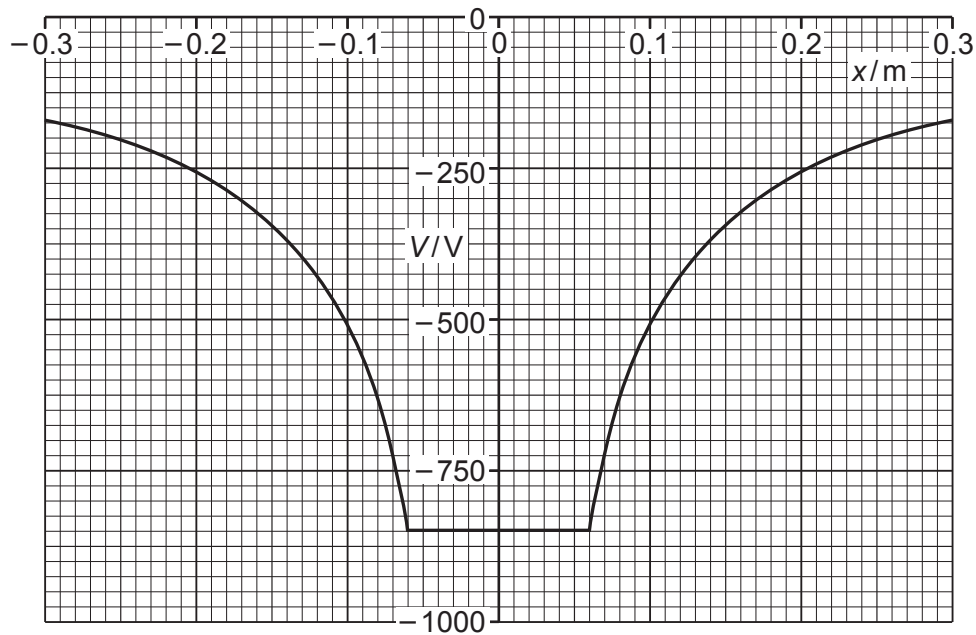


Fig. 5.1

Use Fig. 5.1 to determine:

- (i) the radius of the sphere

radius = ... m [1]

- (ii) the charge on the sphere.

charge = ... C [2]

- (c) Two spheres are identical to the sphere in (b). Each sphere has the same charge as the sphere in (b).

The spheres are held in a vacuum so that their centres are separated by a distance of 0.46 m. Assume that the charge on each sphere is a point charge at the centre of the sphere.

- (i) Calculate the electric potential energy E_p of the two spheres.

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

- (ii) The two spheres are now released simultaneously so that they are free to move.

Describe and explain the subsequent motion of the spheres.

.....

.....

.....

..... [3]

[Total: 10]

- 6 A capacitor of capacitance C and a resistor of resistance R are connected as shown in Fig. 6.1.

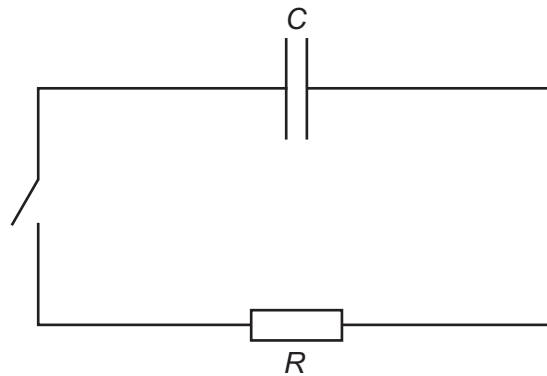


Fig. 6.1

Initially, the capacitor is charged and the switch is open.

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

Fig. 6.2 and Fig. 6.3 show, respectively, the variations with t of the charge Q on the capacitor and the potential difference (p.d.) V across the resistor.

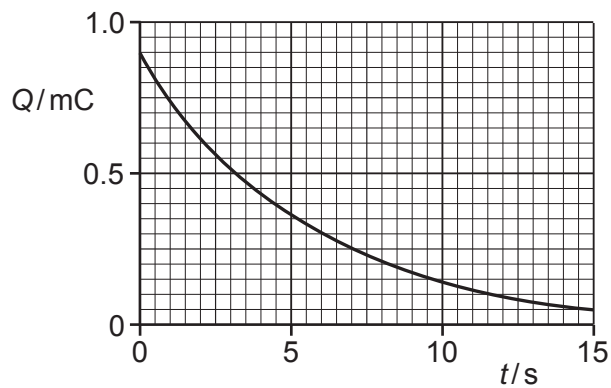


Fig. 6.2

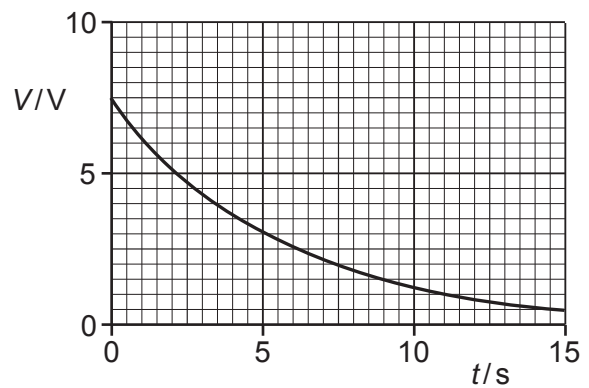


Fig. 6.3

- (a) Explain the shape of the line in Fig. 6.3 representing the variation of V with t .

.....

.....

.....

.....

..... [3]

(b) Use Fig. 6.2 to show that the time constant of the circuit in Fig. 6.1 is 5.5 s.

[3]

(c) Use Fig. 6.2, Fig. 6.3 and the information in (b) to determine:

(i) capacitance C , in μF

$C = \dots\dots\dots \mu\text{F}$ [2]

(ii) resistance R , in $\text{k}\Omega$.

$R = \dots\dots\dots \text{k}\Omega$ [2]

[Total: 10]

- 7 (a) Define magnetic flux density.

.....

.....

.....

..... [3]

- (b) An insulated rectangular coil of wire, consisting of 40 turns, is suspended in a cradle from a newton meter, as shown in Fig. 7.1.

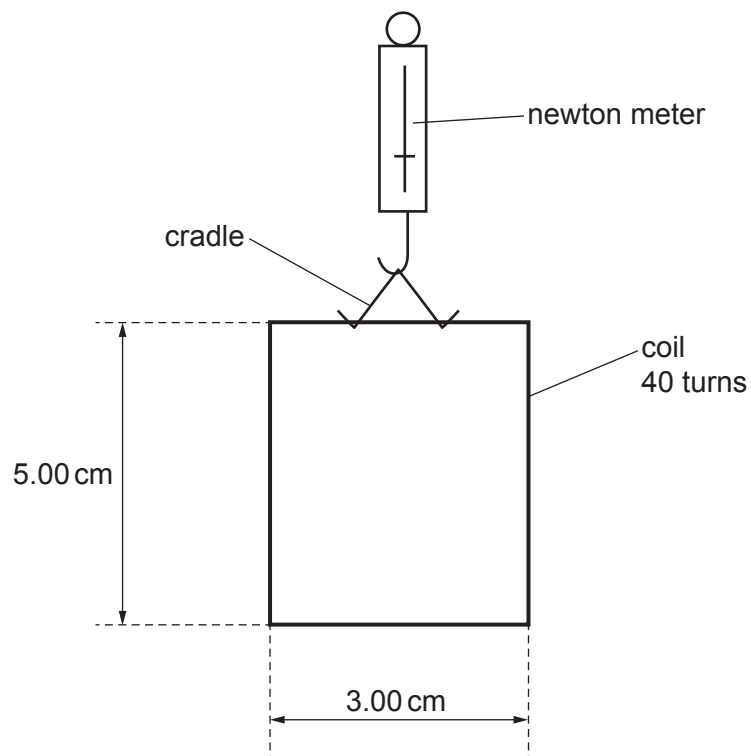


Fig. 7.1

The vertical sides of the coil have a length of 5.00 cm and the horizontal sides have a length of 3.00 cm. The initial reading on the newton meter is 0.563 N.

A U-shaped magnet rests on a top-pan balance that is set to a reading of 0.00 g. The lower edge of the coil is lowered into the region between the poles of the U-shaped magnet, as shown in the side view in Fig. 7.2.

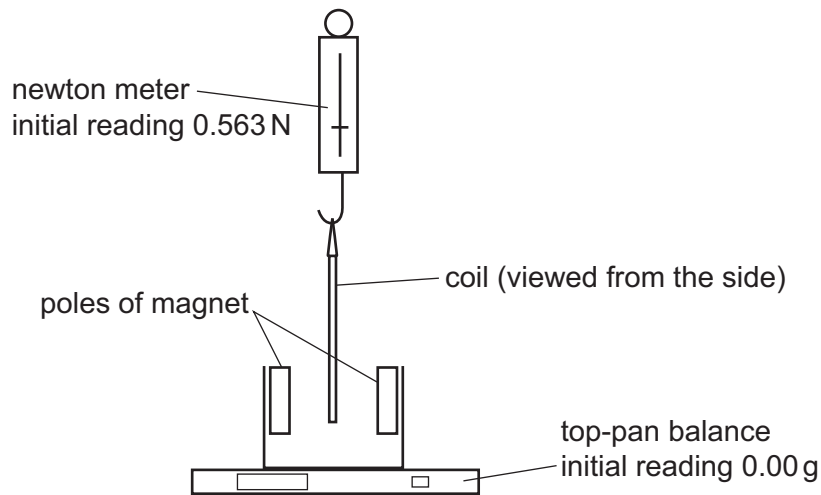


Fig. 7.2

The magnetic field in the region between the poles is uniform.
The lower edge of the coil is entirely within the uniform magnetic field.

A current of 3.94 A is now passed through the coil. This causes the reading on the top-pan balance to change to 2.16 g.

- (i) Explain why the current causes a vertical force to act on the coil.

.....

 [2]

- (ii) Determine, to three significant figures, the flux density B of the uniform magnetic field.

$B =$ T [3]

- (iii) Determine what is now the reading on the newton meter. Explain your reasoning.

reading = ... N [2]

[Total: 10]

[Turn over]

- 8 (a) State Lenz's law of electromagnetic induction.

.....

.....

..... [2]

- (b) Two coils of insulated wire are wound on an iron bar, as shown in Fig. 8.1.

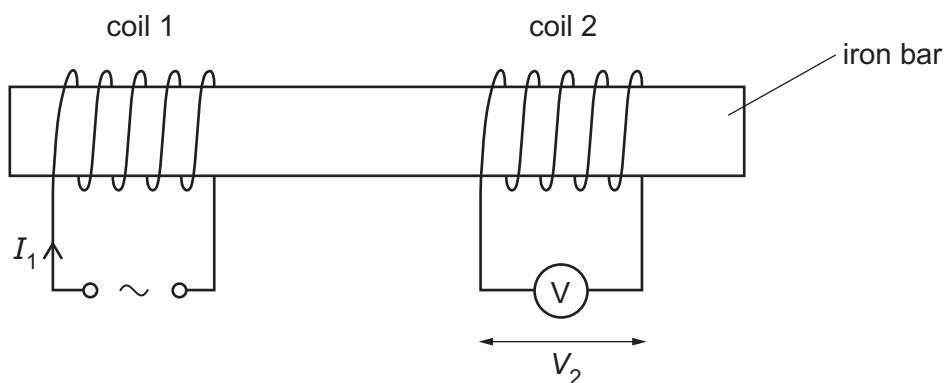


Fig. 8.1

There is a current I_1 in coil 1 that varies with time t as shown in Fig. 8.2.

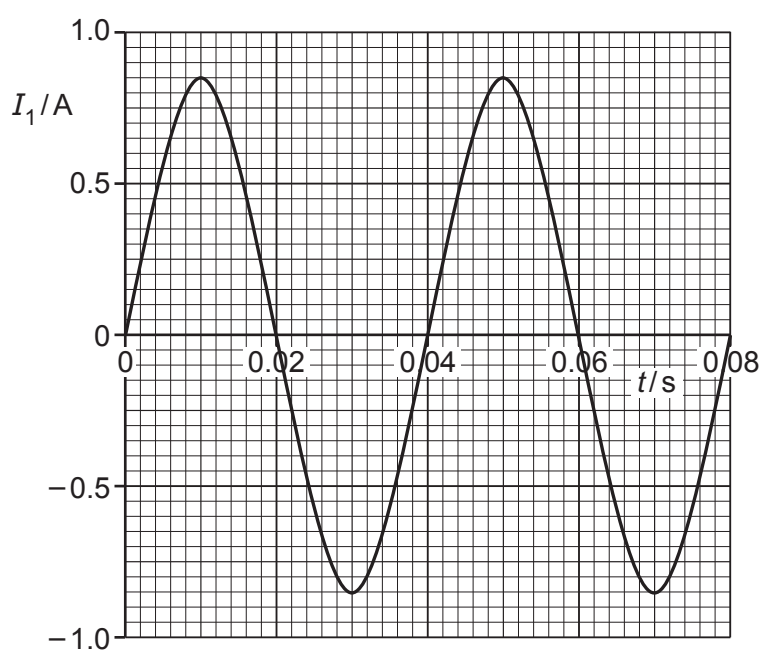


Fig. 8.2

- (i) The variation with t of I_1 can be represented by the equation

$$I_1 = X \sin Yt$$

where X and Y are constants.

Use Fig. 8.2 to determine the values of X and Y . Give units with your answers.

$X =$ unit

$Y =$ unit [3]

- (ii) The current in coil 1 gives rise to a magnetic field in the iron bar.
Assume that the flux density of this magnetic field is proportional to I_1 .

An alternating electromotive force (e.m.f.) is induced across coil 2. The p.d. across coil 2 is measured using the voltmeter and has a root-mean-square (r.m.s.) value of 4.6 V.

On Fig. 8.3, sketch a line to show the variation with t of V_2 between $t = 0$ and $t = 0.08$ s.

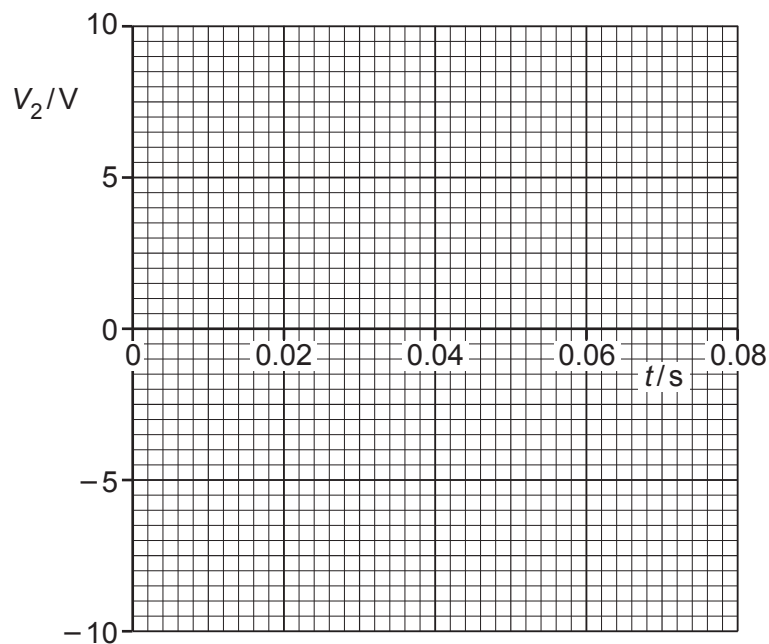


Fig. 8.3

[3]

- (iii) Use the laws of electromagnetic induction to explain the shape of your line in (b)(ii).

.....

 [3]

[Total: 11]

- 9 (a) Fig. 9.1 shows the visible part of the emission spectrum from hydrogen gas in a laboratory on the Earth. The numbers indicate the wavelength, in nm, represented by each line.

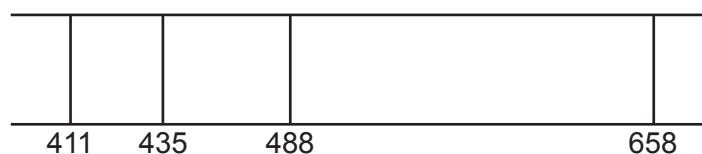


Fig. 9.1

- (i) Explain how the emission spectrum provides evidence for the existence of discrete energy levels for the electron in a hydrogen atom.

.....

 [3]

- (ii) Fig. 9.2 shows five of the energy levels in the hydrogen atom. The wavelengths of radiation shown in Fig. 9.1 relate to transitions to the -3.400 eV level in Fig. 9.2.

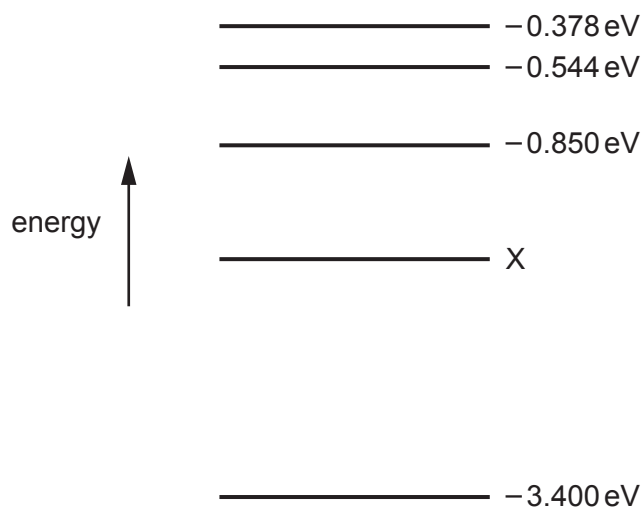


Fig. 9.2 (not to scale)

Show that the energy level X is -1.51 eV .

[3]

- (b) The same part of the emission spectrum from hydrogen as in (a), observed in light from stars in a distant galaxy, is shown in Fig. 9.3. The numbers indicate the wavelengths in nm.

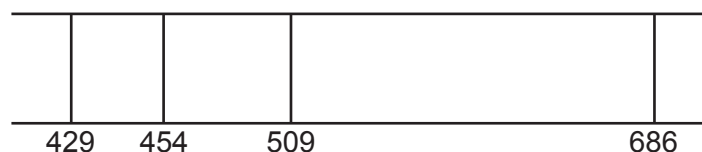


Fig. 9.3

The spectrum shows the same pattern as Fig. 9.1 but with different wavelengths.

- (i) State the name of the phenomenon that gives rise to the change in the wavelengths.
 [1]
- (ii) State what this phenomenon shows about the motion of the galaxy.
 [1]
- (iii) Use one of the lines in Fig. 9.1, and the corresponding line in Fig. 9.3, to determine the speed of the distant galaxy relative to the observer.

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

- (c) The galaxy in (b) is known to be a distance of $5.7 \times 10^{24} \text{ m}$ from the Earth.

Use your answer in (b)(iii) to determine a value for the Hubble constant H_0 .

$H_0 = \dots\dots\dots \text{s}^{-1}$ [2]

[Total: 13]

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- 10** Positron emission tomography (PET scanning) involves the detection of gamma-radiation in order to identify the position of origin of positrons in the body.

(a) (i) Positrons are not naturally present in the body.

Explain how positrons come to be present in the body during PET scanning.

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

(ii) Explain how positrons cause the emission of gamma-radiation from the body during PET scanning.

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

(b) Show that the wavelength of the gamma-radiation that is detected during PET scanning is approximately 2.4 pm. Explain your reasoning.

[4]

[Total: 9]

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PHYSICS

9702/43

Paper 4 A Level Structured Questions

October/November 2022

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- 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.

INFORMATION

- 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) State the equation for the gravitational force F between two point masses m_1 and m_2 that are separated by a distance r . State the meaning of any other symbols you use.

[2]

- (b) A satellite is in a circular orbit of radius R around a planet of mass M .

Show that the period T of the orbit is given by

$$T^2 = kR^3$$

where k is a constant that depends on the value of M . Explain your reasoning.

[3]

- (c) A satellite is in a circular orbit around the Earth with a period of 24 hours. The mass of the Earth is 6.0×10^{24} kg.

- (i) Calculate the radius of the orbit.

radius = ... m [2]

(ii) State the **two** other conditions that must be met for the orbit to be geostationary.

1

.....

2

.....

[2]

[Total: 9]

- 2 Fig. 2.1 shows a laboratory thermometer that is calibrated to measure temperature in degrees Celsius.

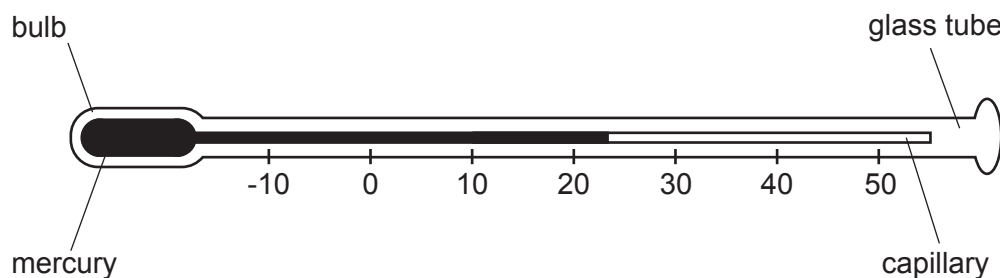


Fig. 2.1

The thermometer makes use of the fact that the density of mercury varies with temperature.

- (a) State **two** other physical properties of materials, apart from the density of a liquid, that can be used for measuring temperature.

1

2

[2]

- (b) The thermometer is initially at 23.0°C , as shown in Fig. 2.1. It is used to measure the temperature of an insulated beaker of water that is at 37.4°C . The bulb of the thermometer is inserted into the water, and the water is stirred until the reading on the thermometer becomes steady.

The mass of water in the beaker is 18.7 g.

The mass of mercury in the thermometer is 6.94 g.

The specific heat capacity of water is $4.18 \text{ J g}^{-1} \text{ K}^{-1}$.

The specific heat capacity of mercury is $0.140 \text{ J g}^{-1} \text{ K}^{-1}$.

The glass of the thermometer and the beaker containing the water can be considered to have negligible heat capacity.

- (i) Calculate, to three significant figures, the final steady temperature indicated by the thermometer in the water.

temperature = ... $^{\circ}\text{C}$ [4]

- (ii) Suggest **one** change that could be made to the design of the thermometer that would enable it to give a more accurate measurement of temperature.

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

- (c) (i) Explain why the thermometer in Fig. 2.1 does **not** provide a direct measurement of thermodynamic temperature.

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

- (ii) Thermodynamic temperature T may be determined by the behaviour of a type of substance for which T is proportional to the product of pressure and volume.

State the name of this type of substance.

..... [1]

[Total: 10]

- 3 An object is suspended from a spring that is attached to a fixed point as shown in Fig. 3.1.

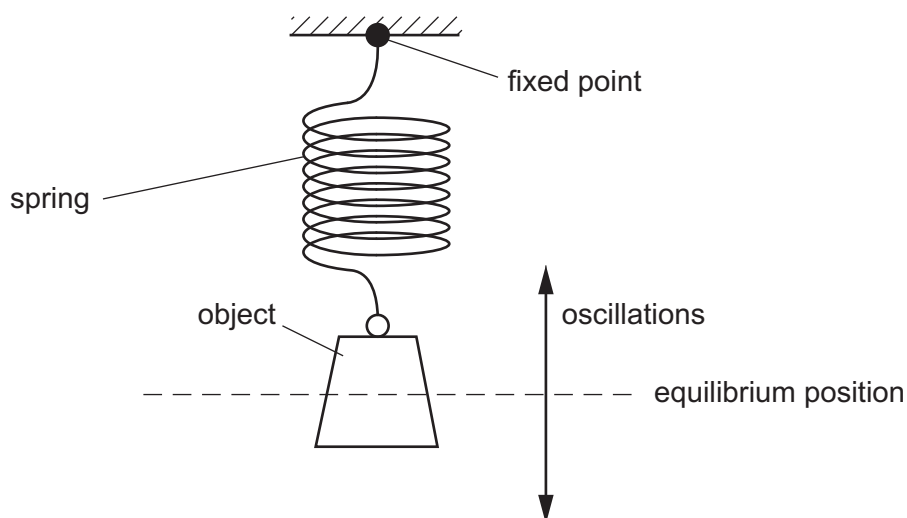


Fig. 3.1

The object oscillates vertically with simple harmonic motion about its equilibrium position.

- (a) State the defining equation for simple harmonic motion. Identify the meaning of each of the symbols used to represent physical quantities.

.....

.....

..... [2]

- (b) The variation with displacement x from the equilibrium position of the velocity v of the object is shown in Fig. 3.2.

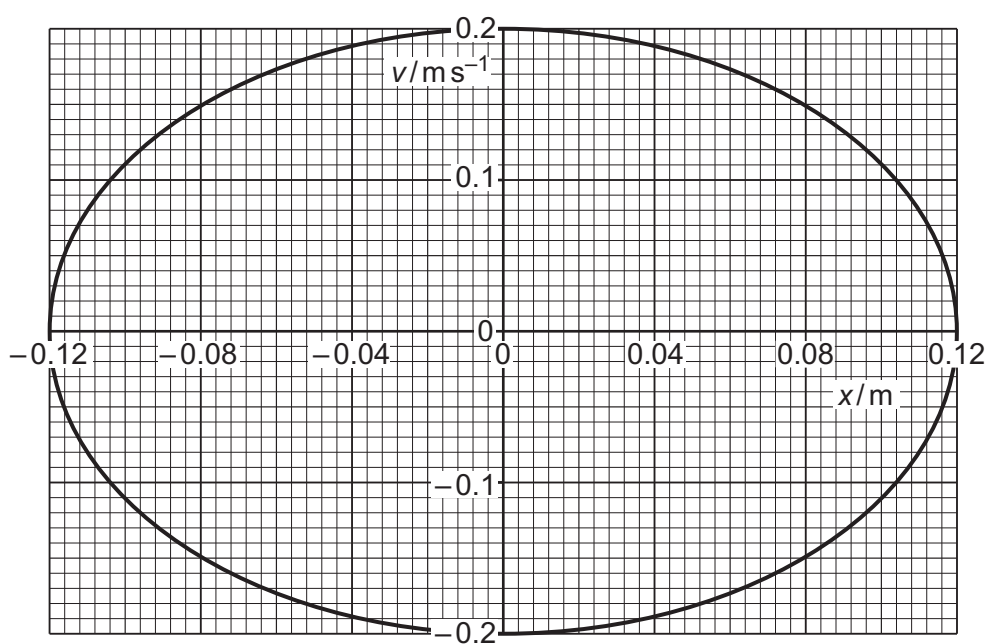


Fig. 3.2

The variation with x of the potential energy E_P of the oscillations of the object is shown in Fig. 3.3.

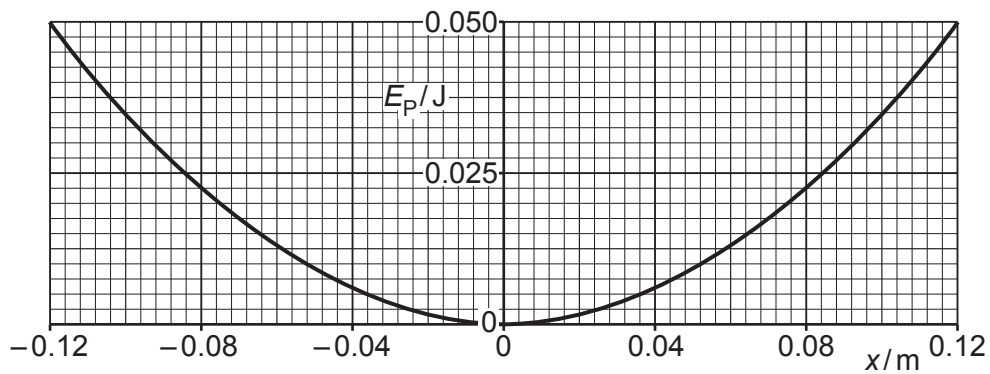


Fig. 3.3

Use Fig. 3.2 and Fig. 3.3 to:

- (i) determine the amplitude x_0 of the oscillations

$$x_0 = \dots\dots\dots \text{ m [1]}$$

- (ii) show that the angular frequency of the oscillations is 1.7 rad s^{-1}

[2]

- (iii) determine the mass M of the object.

$$M = \dots\dots\dots \text{ kg [2]}$$

(c) The oscillations of the object are now lightly damped.

(i) State what is meant by damping.

.....

.....

..... [2]

(ii) Assume that the damping does not change the angular frequency of the oscillations.

On Fig. 3.2, sketch the variation with x of v when the amplitude of the oscillations is 0.060 m. [2]

[Total: 11]

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- 4 (a) State what is indicated by the direction of an electric field line.

.....
 [2]

- (b) Fig. 4.1 shows a pair of parallel metal plates with a potential difference (p.d.) of 2400 V between them.

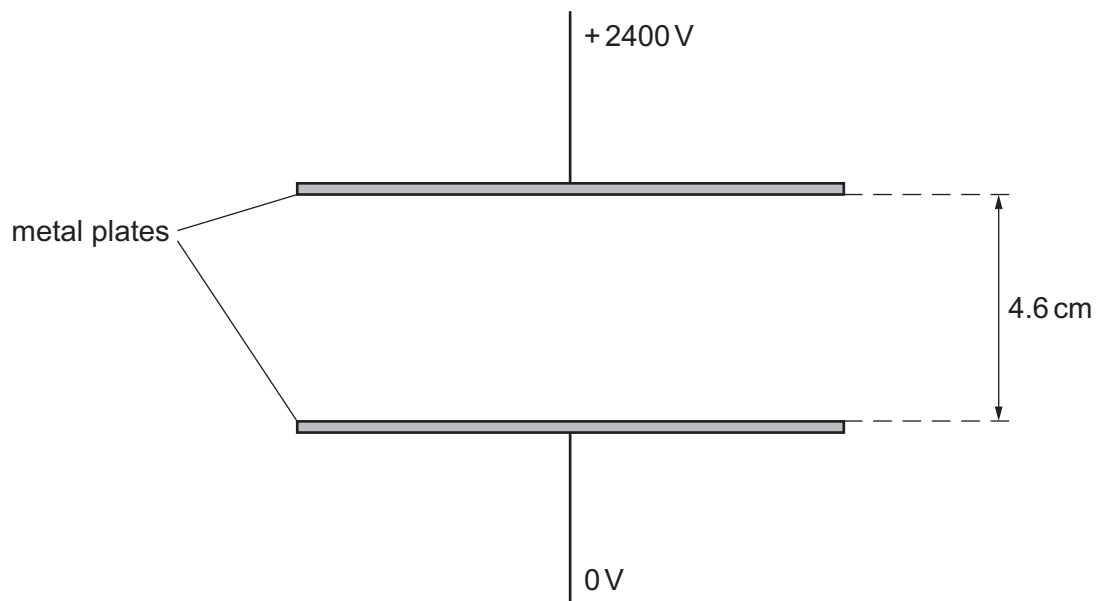


Fig. 4.1

The plates are separated by a distance of 4.6 cm. The plates are in a vacuum.

- (i) On Fig. 4.1, draw five lines to represent the electric field in the region between the plates. [3]
- (ii) Calculate the strength of the electric field between the plates.

electric field strength = ... NC^{-1} [2]

- (c) A moving proton enters the region between the plates from the left, as shown in Fig. 4.2.

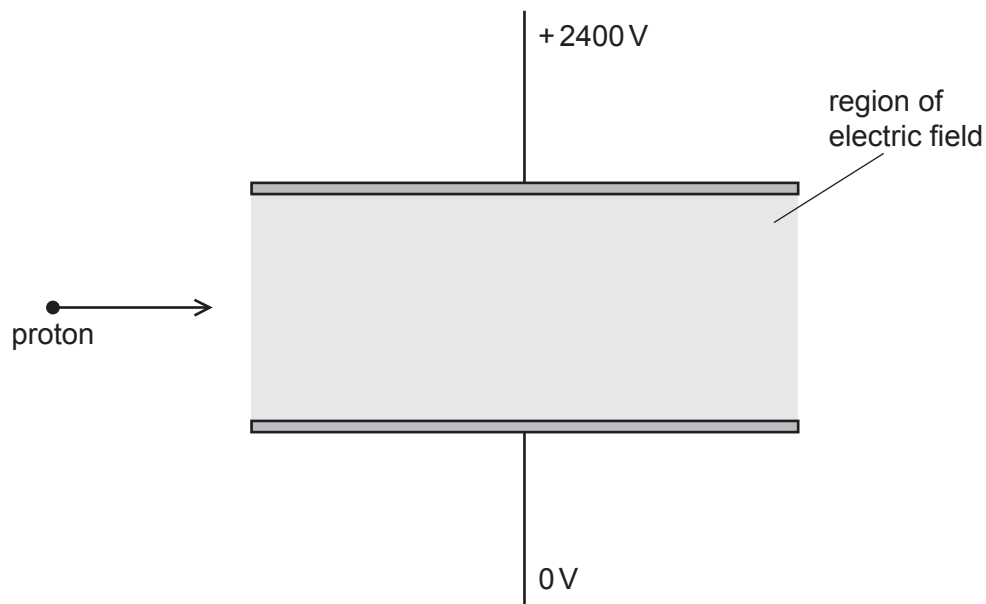


Fig. 4.2

- (i) The proton is deflected by the electric field.

On Fig. 4.2, draw a line to show the path of the proton as it moves through and out of the region of the electric field. [2]

- (ii) A helium nucleus (${}^4_2\text{He}$) now enters the region of the electric field along the same initial path as the proton and travelling at the same initial speed.

State and explain how the final speed of the helium nucleus compares with the final speed of the proton after leaving the region of the electric field.

.....

.....

.....

.....

..... [3]

[Total: 12]

- 5 A capacitor of capacitance $470\ \mu\text{F}$ is connected to a battery of electromotive force (e.m.f.) $24\ \text{V}$ in the circuit of Fig. 5.1.

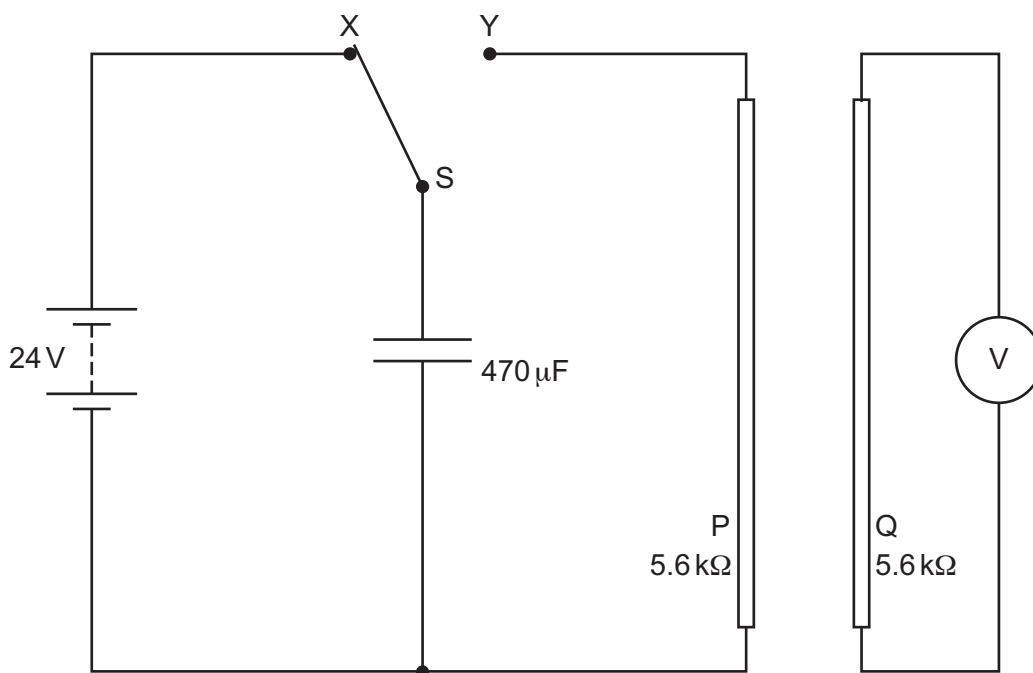


Fig. 5.1

The two-way switch S is initially at position X.

P and Q are identical long straight wires, each with a resistance of $5.6\ \text{k}\Omega$. These wires are placed near to, and parallel to, each other. Wire Q is connected to a voltmeter.

At time $t = 0$, switch S is moved to position Y so that the capacitor discharges through wire P.

- (a) (i) Calculate the charge Q_0 on the capacitor at time $t = 0$.

$$Q_0 = \dots\dots\dots \text{ C [2]}$$

- (ii) Calculate the current I_0 in wire P at time $t = 0$.

$$I_0 = \dots\dots\dots \text{ A [1]}$$

- (iii) Calculate the time constant τ of the discharge circuit.

$\tau = \dots\dots\dots$ s [2]

- (iv) On Fig. 5.2, sketch a line to show the variation with t of the current I in wire P as the capacitor discharges.



Fig. 5.2

[2]

- (b) (i) Explain why there is an induced e.m.f. across wire Q during the discharge of the capacitor.

.....

 [3]

- (ii) On Fig. 5.3, sketch a line to suggest the variation with t of the voltmeter reading V .



Fig. 5.3

[1]

[Total: 11]

- 6 Fig. 6.1 shows a thin slice of semiconducting material used in a Hall probe.

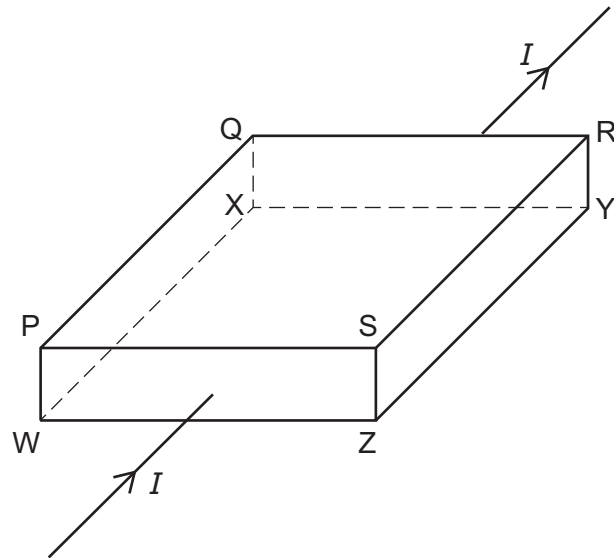


Fig. 6.1 (not to scale)

Current I passes through the slice in the direction shown.

The slice is placed in a uniform magnetic field of flux density B , so that two of its faces are perpendicular to the magnetic field.

A steady Hall voltage V_H is developed between face PQXW and face SRYZ.

- (a) (i) Use the letters in Fig. 6.1 to identify the faces that are perpendicular to the magnetic field.

..... and [1]

- (ii) Explain how the steady Hall voltage V_H is developed between faces PQXW and SRYZ.

.....

 [3]

(b) The magnitude of V_H is given by the equation

$$V_H = \frac{BI}{ntq}.$$

(i) State the meaning of the symbols n , t and q . You may refer to the letters in Fig. 6.1.

n :

t :

q : [3]

(ii) Suggest, with reference to the equation, why the slice of the material used in a Hall probe is thin.

.....

.....

..... [2]

[Total: 9]

- 7 (a) A sinusoidal alternating voltage has a root-mean-square (r.m.s.) potential difference (p.d.) of 4.2 V and a frequency of 50 kHz.

- (i) The alternating voltage is applied across a resistor of resistance $760\ \Omega$.

By considering the peak voltage, show that the maximum power dissipated by the resistor is 46 mW.

[2]

- (ii) On Fig. 7.1, draw a smooth curve to show how the power P dissipated in the resistor varies with time t between $t = 0$ and $t = 40\ \mu\text{s}$. Assume that $P = 0$ when $t = 0$.

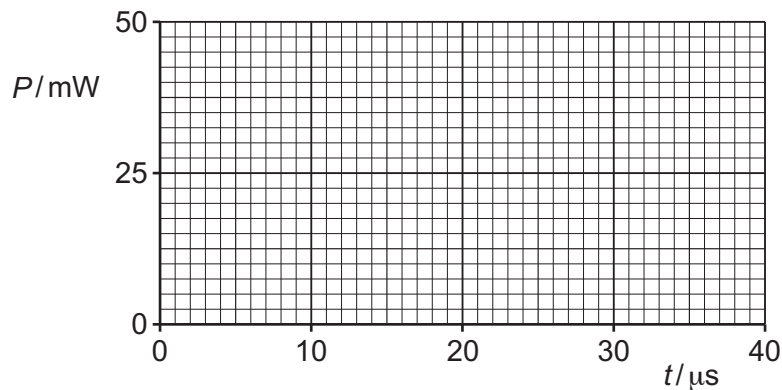


Fig. 7.1

[3]

- (iii) Use your line in (a)(ii) to explain why the mean power dissipated in the resistor is 23 mW.

.....

 [1]

(b) The alternating voltage in **(a)** is now applied to a piezoelectric crystal in air.

(i) Explain what happens to the air surrounding the crystal.

.....

.....

.....

..... [3]

(ii) A second piezoelectric crystal is placed in the air near to the first crystal.

Explain the effect of the surrounding air in **(b)(i)** on the second crystal.

..... [1]

[Total: 10]

- 8 (a) State what is meant by the work function energy of a metal.

.....

 [2]

- (b) Ultraviolet radiation of frequency $1.36 \times 10^{15} \text{ Hz}$ is incident, in a vacuum, on a metal surface. The power of the radiation incident on the surface is 8.36 mW . Photoelectrons are emitted with a maximum kinetic energy of $3.09 \times 10^{-19} \text{ J}$.

- (i) Determine the number of photons incident on the surface per unit time.

number per unit time = ... s^{-1} [2]

- (ii) Calculate the work function energy Φ of the metal.

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

- (c) The frequency of the radiation incident on the surface in (b) is increased while the power remains constant.

State and explain the effect of this change on:

- (i) the maximum kinetic energy of the photoelectrons

.....

 [2]

- (ii) the rate of emission of photoelectrons.

.....

 [2]

[Total: 10]

- 9 (a) State what is meant by the luminosity of a star.

..... [1]

- (b) A star in the constellation Canis Major is a distance of 8.14×10^{16} m from the Earth and has a luminosity of 9.86×10^{27} W. The surface temperature of the star is 9830 K.

- (i) Calculate the radiant flux intensity of the radiation from the star observed from the Earth. Give a unit with your answer.

radiant flux intensity = ... unit [2]

- (ii) Determine the radius of the star.

radius = ... m [2]

- (c) Explain how the surface temperature of a distant star may be determined from the wavelength spectrum of the light from the star.

.....

 [3]

[Total: 8]

- 10 Carbon-15 ($^{15}_6\text{C}$) is an isotope of carbon that undergoes radioactive decay to nitrogen-15 ($^{15}_7\text{N}$), which is a stable isotope of nitrogen.

Radioactive decay is both a random and a spontaneous process.

(a) State what is meant by:

(i) random

.....
 [1]

(ii) spontaneous.

.....
 [1]

- (b) A small sample of carbon-15 decays. The mass M of carbon-15 in the sample decreases with time t .

Fig. 10.1 shows the variation with t of the value of $\ln (M/10^{-16}\text{g})$.

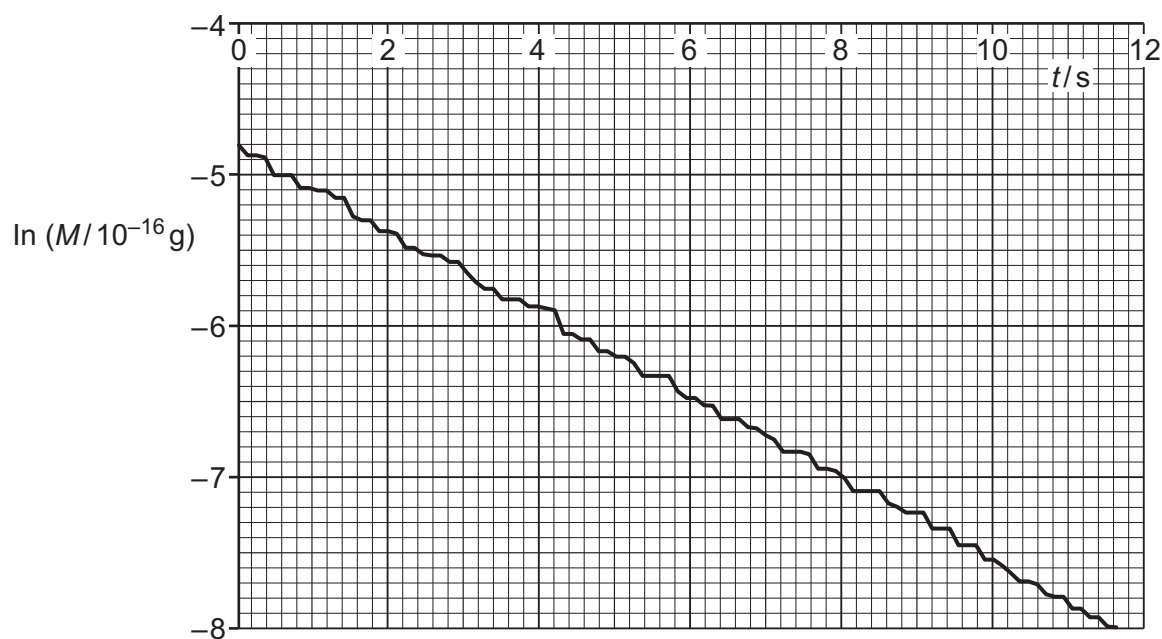


Fig. 10.1

- (i) State how Fig. 10.1 demonstrates that radioactive decay is random.

.....
 [1]

- (ii) On Fig. 10.1, draw the straight line of best fit.

[1]

- (iii) Show that the decay constant λ of carbon-15 is given by the magnitude of the gradient of your line in (b)(ii).

[1]

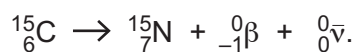
- (iv) Use your line in (b)(ii) to determine λ . Give a unit with your answer.

$\lambda = \dots\dots\dots$ unit $\dots\dots\dots$ [2]

- (v) Use your answer in (b)(iv) to calculate the half-life of carbon-15.

half-life = $\dots\dots\dots$ s [1]

- (c) The equation for the decay of carbon-15 can be written as



State and explain how the mass of the products of the decay must compare with the mass of the carbon-15 nucleus.

.....

 [2]

[Total: 10]

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