



CANDIDATE
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9702/41

May/June 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) (i) State Newton's law of gravitation.

.....

.....

..... [2]

- (ii) Use Newton's law of gravitation to show that the gravitational field strength g at a distance r away from a point mass M is given by

$$g = \frac{GM}{r^2}.$$

[2]

- (b) The Earth has a mass of 5.98×10^{24} kg and a radius of 6.37×10^6 m.
 The Moon has a mass of 7.35×10^{22} kg and a radius of 1.74×10^6 m.
 The Earth and the Moon can both be considered as point masses at their centres. Their centres are a distance of 3.84×10^8 m apart.

- (i) Show that the gravitational field strength at the surface of the Moon due to the mass of the Moon is 1.62 N kg^{-1} .

[1]

- (ii) Explain why there is a point X on the line between the centres of the Earth and the Moon where the resultant gravitational field strength due to the Earth and the Moon is zero.

.....

.....

..... [2]

- (iii) Calculate the distance x of point X from the centre of the Moon.

$x = \dots\dots\dots$ m [3]

[Total: 10]

- 2 A sphere of mass $1.6 \times 10^{-10} \text{ kg}$ has a charge of $+0.27 \text{ nC}$. The sphere is in a uniform electric field that acts vertically upwards, as shown in the side view in Fig. 2.1.

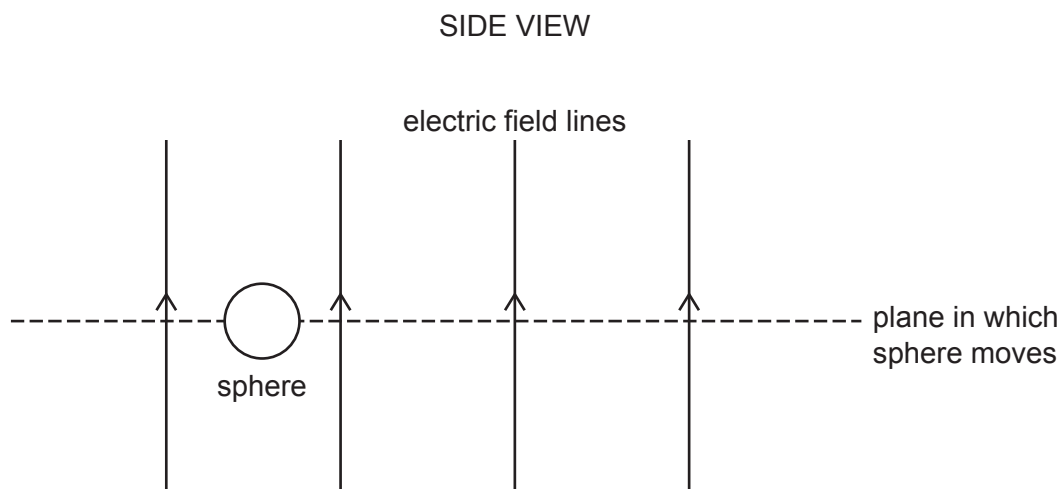


Fig. 2.1

The force exerted on the sphere by the electric field causes the sphere to remain at a fixed vertical height in a horizontal plane.

There is a uniform magnetic field in the region of the electric field. The sphere moves at a speed of 0.78 m s^{-1} in the horizontal plane. The magnetic field causes the sphere to move in a circular path of radius 3.4 m , as shown in the view from above in Fig. 2.2.

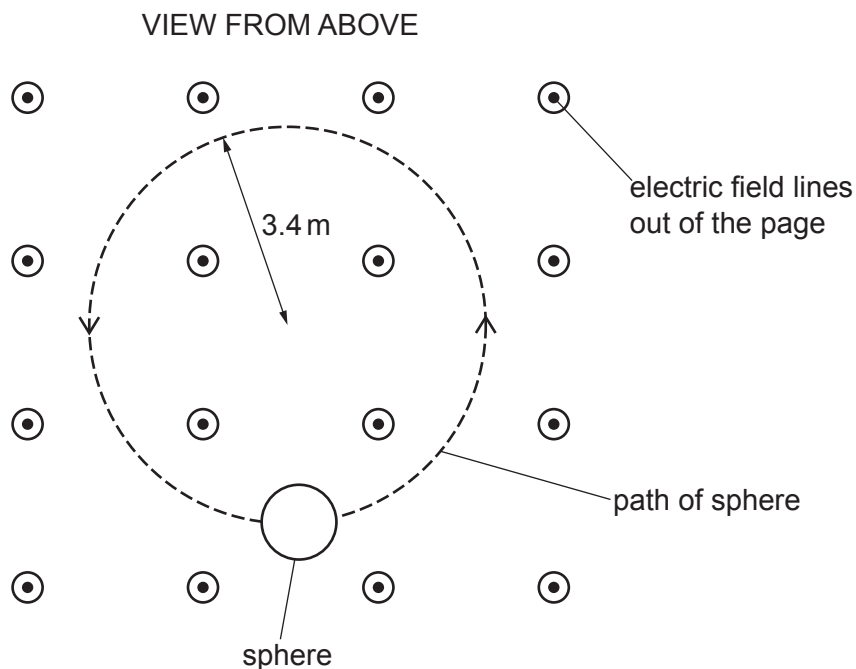


Fig. 2.2

- (a) (i) Determine the direction of the uniform magnetic field.

..... [1]

- (ii) Explain why the motion of the sphere in the horizontal plane is circular.

.....

.....

..... [2]

- (b) Calculate the strength of the uniform electric field.

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

- (c) By considering the magnetic force on the sphere, show that the flux density of the uniform magnetic field is 0.14 T.

[3]

[Total: 8]

- 3 A fixed mass of an ideal gas is initially at a temperature of 17°C . The gas has a volume of 0.24 m^3 and a pressure of $1.2 \times 10^5\text{ Pa}$.

(a) (i) State what is meant by an ideal gas.

.....

 [2]

(ii) Calculate the amount n of gas.

$n = \dots\dots\dots$ mol [2]

(b) The gas undergoes three successive changes, as shown in Fig. 3.1.

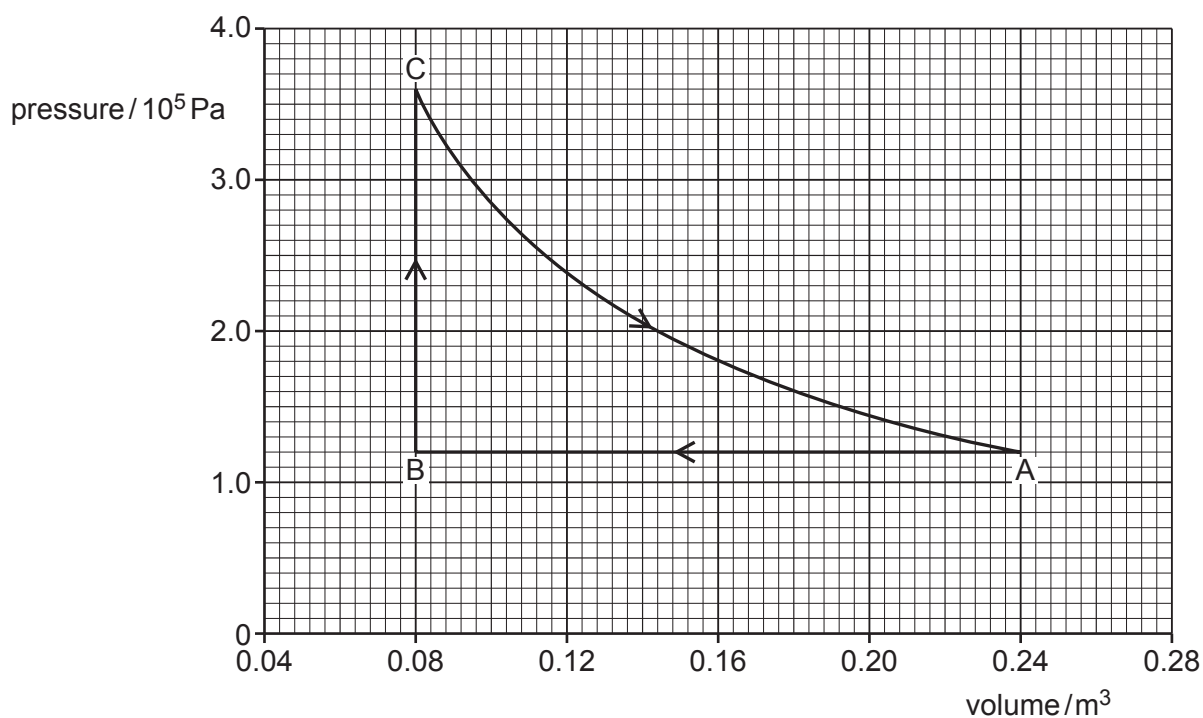


Fig. 3.1

The initial state is represented by point A. The gas is cooled at constant pressure to point B by the removal of 48.0 kJ of thermal energy.

The gas is then heated at constant volume to point C.

Finally, the gas expands at constant temperature back to its original pressure and volume at point A. During this expansion, the gas does 31.6 kJ of work.

- (i) Show that the magnitude of the work done during the change AB is 19.2 kJ.

[2]

- (ii) Complete Table 3.1 to show the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas, for each of the changes AB, BC and CA.

Table 3.1

change	work done on gas / kJ	thermal energy supplied to gas / kJ	increase in internal energy of gas / kJ
AB		-48.0	
BC			
CA	-31.6		

[5]

[Total: 11]

- 4 A pendulum consists of a bob (small metal sphere) attached to the end of a piece of string. The other end of the string is attached to a fixed point. The bob oscillates with small oscillations about its equilibrium position, as shown in Fig. 4.1.

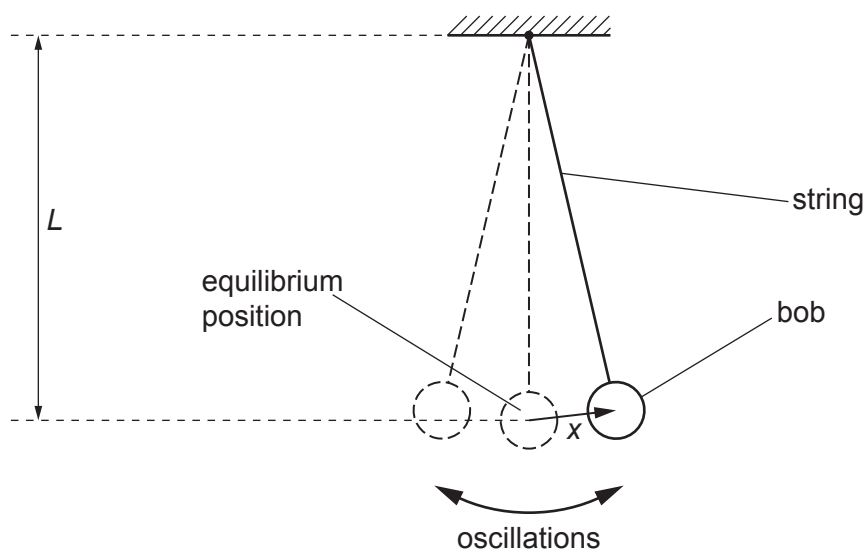


Fig. 4.1 (not to scale)

The length L of the pendulum, measured from the fixed point to the centre of the bob, is 1.24 m.

The acceleration a of the bob varies with its displacement x from the equilibrium position as shown in Fig. 4.2.

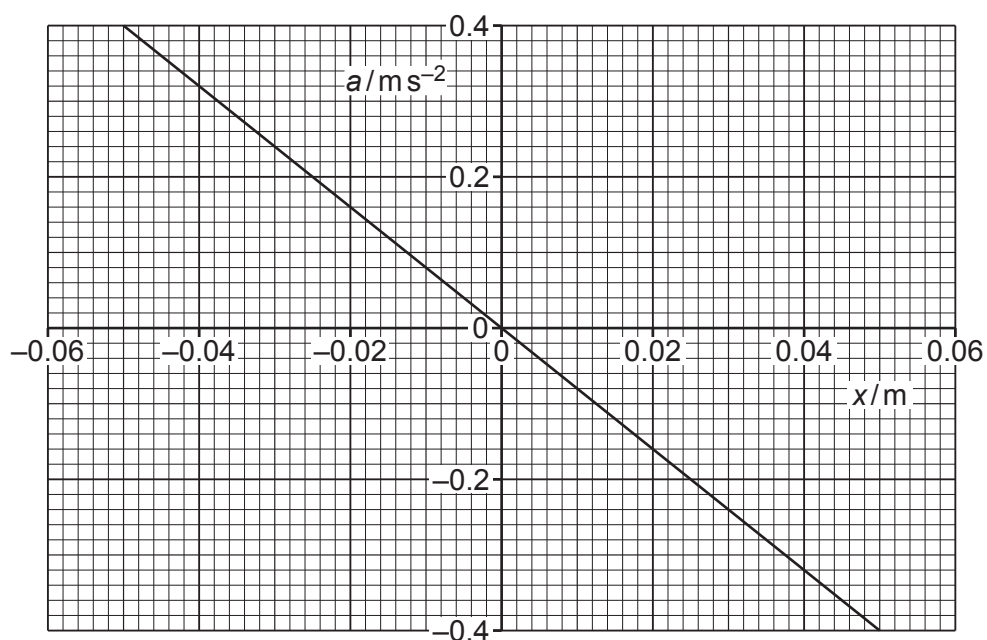


Fig. 4.2

- (a) State how Fig. 4.2 shows that the motion of the pendulum is simple harmonic.

.....

.....

..... [2]

- (b) (i) Use Fig. 4.2 to determine the angular frequency ω of the oscillations.

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

- (ii) The angular frequency ω is related to the length L of the pendulum by

$$\omega = \sqrt{\frac{k}{L}}$$

where k is a constant.

Use your answer in (b)(i) to determine k . Give a unit with your answer.

$$k = \dots\dots\dots \text{unit} \dots\dots\dots [2]$$

- (c) While the pendulum is oscillating, the length of the string is increased in such a way that the total energy of the oscillations remains constant.

Suggest and explain the qualitative effect of this change on the amplitude of the oscillations.

.....

.....

..... [2]

[Total: 8]

- 5 Fig. 5.1 shows four diodes and a load resistor of resistance $1.2\text{ k}\Omega$, connected in a circuit that is used to produce rectification of an alternating voltage.

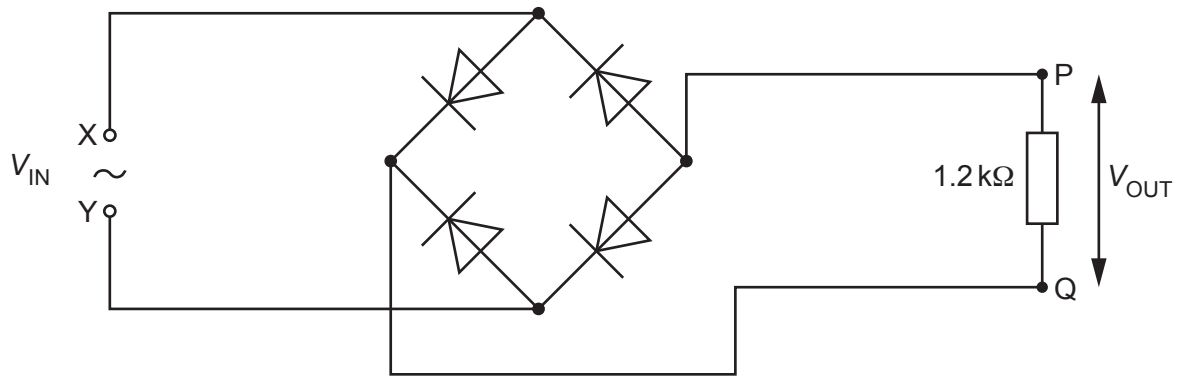


Fig. 5.1

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

.....
 [1]

- (ii) State the type of rectification produced by the circuit in Fig. 5.1.

..... [1]

- (b) A sinusoidal alternating voltage V_{IN} is applied across the input terminals X and Y. The variation with time t of V_{IN} is given by the equation

$$V_{IN} = 6.0 \sin 25\pi t$$

where V_{IN} is in volts and t is in seconds.

- (i) On Fig. 5.1, label the output terminals P and Q with the appropriate symbols to indicate the polarity of the output voltage V_{OUT} . [1]

- (ii) The magnitude of the output voltage V_{OUT} varies with t as shown in Fig. 5.2.

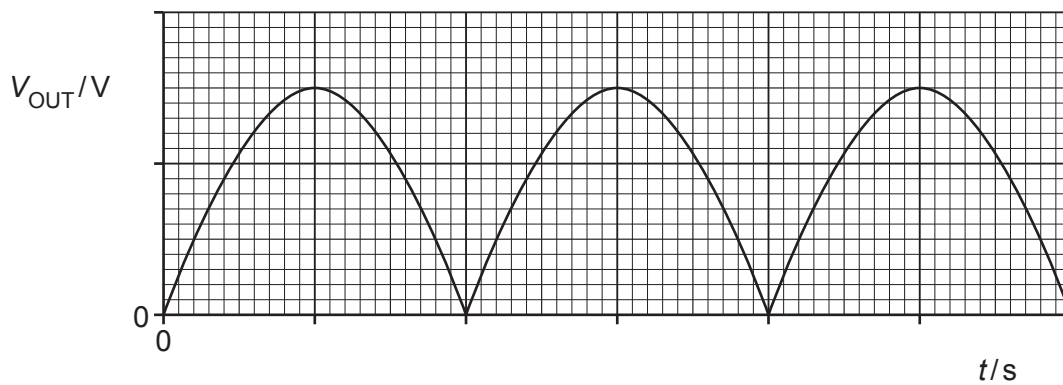


Fig. 5.2

On Fig. 5.2, label both of the axes with the correct scales. Use the space below for any working that you need.

[3]

- (c) The output voltage in (b) is smoothed by adding a capacitor to the circuit in Fig. 5.1. The difference between the maximum and minimum values of the smoothed output voltage is 10% of the peak voltage.

- (i) On Fig. 5.1, draw the circuit symbol for a capacitor showing the capacitor correctly connected into the circuit. [1]

- (ii) On Fig. 5.2, sketch the variation with t of the smoothed output voltage. [2]

- (iii) Calculate the capacitance C of the capacitor.

$C = \dots\dots\dots$ F [3]

[Total: 12]

- 6 (a) Define magnetic flux.

.....

.....

..... [2]

- (b) A square coil of wire of side length 12 cm consists of 8 insulated turns. The coil is stationary in a uniform magnetic field. The plane of the coil is perpendicular to the magnetic field, as shown in Fig. 6.1.

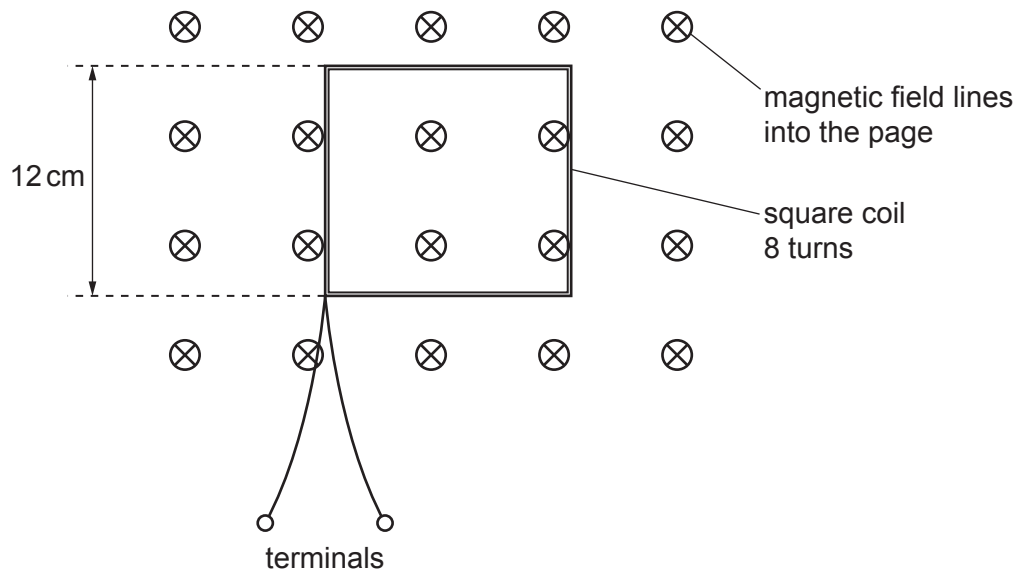


Fig. 6.1

The flux density B of the magnetic field varies with time t as shown in Fig. 6.2.

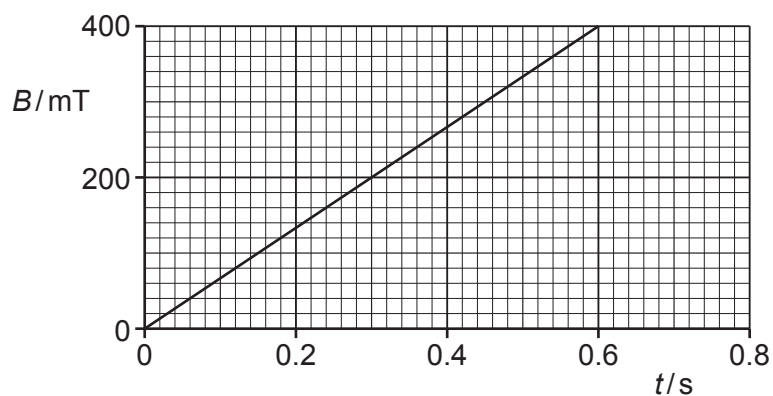


Fig. 6.2

- (i) Determine the magnetic flux linkage inside the coil at time $t = 0.60\text{ s}$. Give a unit with your answer.

magnetic flux linkage = ... unit [3]

- (ii) State how Fig. 6.2 shows that the electromotive force (e.m.f.) E induced across the terminals between $t = 0$ and $t = 0.60\text{ s}$ is constant.

..... [1]

- (iii) Calculate the magnitude of E .

$E = \dots\dots\dots \text{ V}$ [2]

- (c) The procedure in (b) is repeated, but this time the terminals of the coil are connected together.

State and explain the effect on the coil of connecting the terminals together during the change of magnetic flux density shown in Fig. 6.2.

.....

 [3]

[Total: 11]

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

.....

 [2]

- (b) Electromagnetic radiation of a varying frequency f and constant intensity I is used to illuminate a metal surface. At certain frequencies, electrons are emitted from the surface of the metal. The variation with f of the maximum kinetic energy E_{MAX} of the emitted electrons is shown in Fig. 7.1.

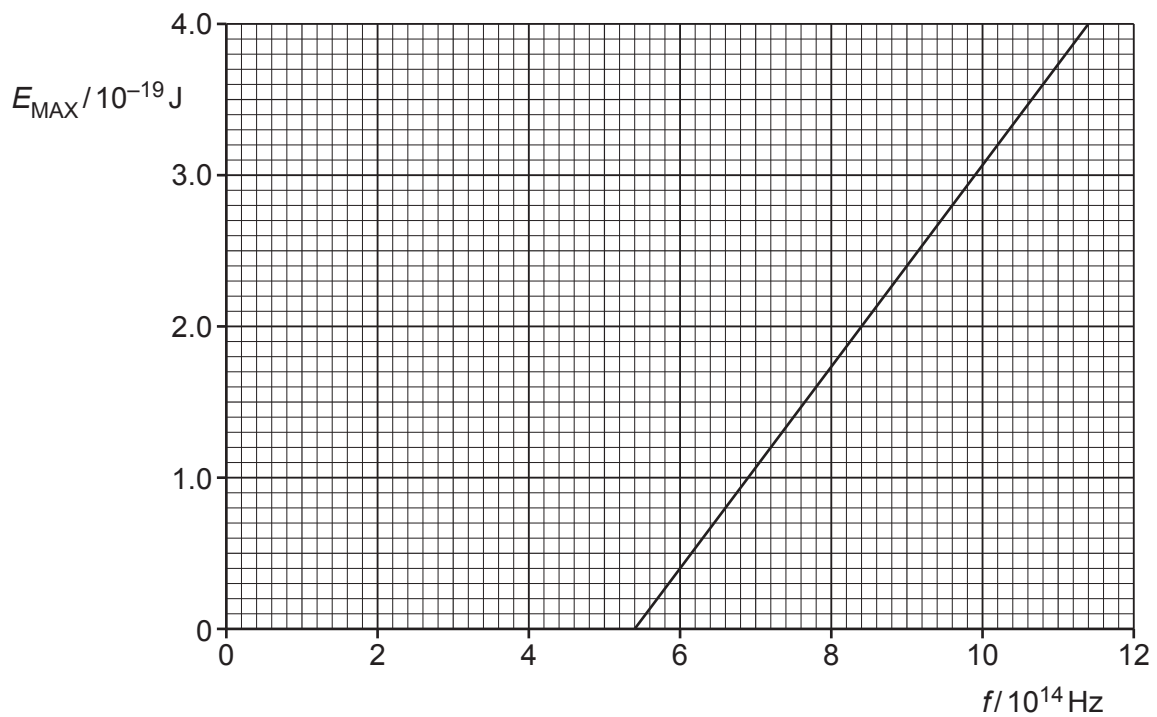


Fig. 7.1

- (i) State the name of this phenomenon.

..... [1]

- (ii) Describe **three** conclusions that can be drawn from the graph in Fig. 7.1. The conclusions may be qualitative or quantitative.

1

.....

2

.....

3

.....

[3]

- (c) The experiment in (b) is repeated twice, each time making one change.

State, with a reason, how the graph obtained would compare with Fig. 7.1 when:

- (i) a different metal is used, but keeping the intensity I of the radiation the same

.....

.....

..... [2]

- (ii) the same metal is used, but with electromagnetic radiation of intensity $2I$.

.....

.....

..... [2]

[Total: 10]

- 8 (a) (i) State what is meant by nuclear binding energy.

.....

 [2]

- (ii) On Fig. 8.1, sketch a line to show the variation with nucleon number A of the binding energy per nucleon E of a nucleus.

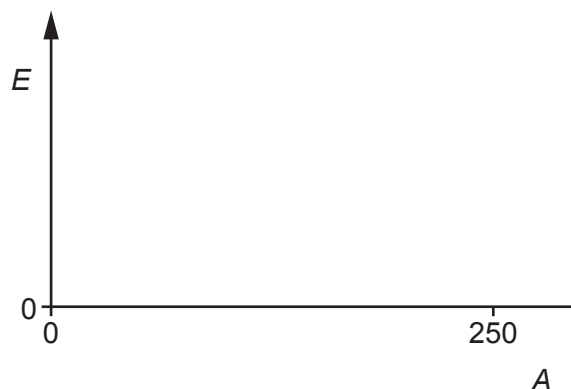


Fig. 8.1

[2]

- (b) In one type of nuclear process, deuterium (${}^2_1\text{H}$) undergoes the reaction



- (i) State the name of this type of nuclear process.

..... [1]

- (ii) Explain, with reference to your line in (a)(ii), why this reaction results in the release of energy.

.....

 [2]

(c) Table 8.1 shows the masses of the particles involved in the reaction in (b).

Table 8.1

particle	mass/u
${}_0^1\text{n}$	1.008 665
${}_1^2\text{H}$	2.014 102
${}_2^3\text{He}$	3.016 029

Calculate the energy released when 1.00 mol of deuterium undergoes the reaction.

energy = ... J [5]

[Total: 12]

- 9 (a) (i) Explain how X-rays are produced for use in medical diagnosis.

.....

 [3]

- (ii) State why X-ray images are taken of multiple sections of the body during computed tomography (CT) scanning.

.....
 [1]

- (b) An X-ray image is taken of the structure shown in Fig. 9.1.

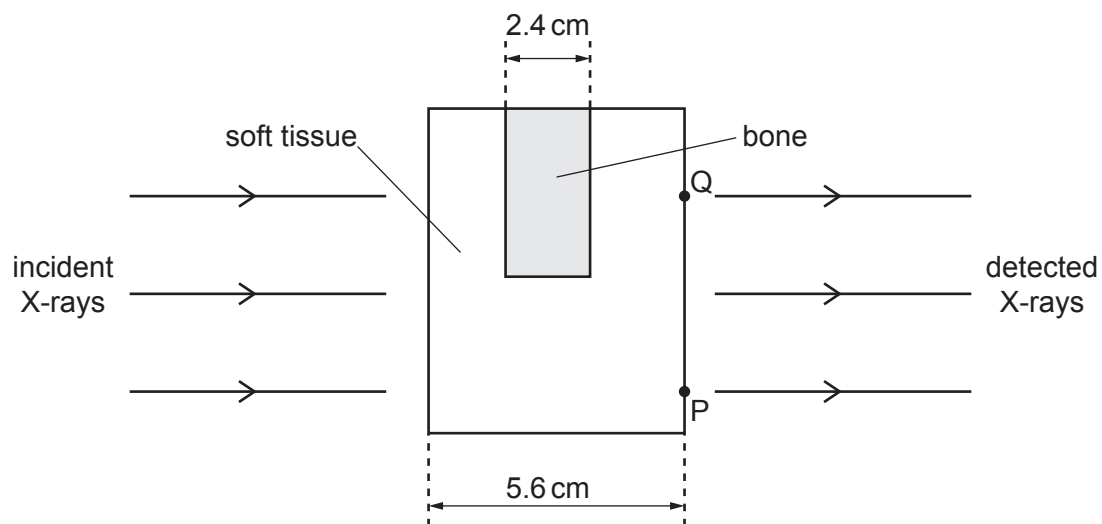


Fig. 9.1

The linear attenuation coefficient of bone is 3.4 cm^{-1} .

The linear attenuation coefficient of soft tissue is 0.89 cm^{-1} .

The incident X-rays are parallel and have a uniform intensity I_0 across the structure.

Determine, in terms of I_0 , the intensity of the detected X-rays from:

(i) point P

detected intensity = ... I_0 [2]

(ii) point Q.

detected intensity = ... I_0 [2]

(c) Explain, with reference to your answers in (b), whether the X-ray image of the structure in Fig. 9.1 has good contrast.

.....

 [1]

[Total: 9]

10 (a) State Wien's displacement law.

.....
 [1]

(b) Fig. 10.1 shows the wavelength distributions of electromagnetic radiation emitted by two stars A and B.

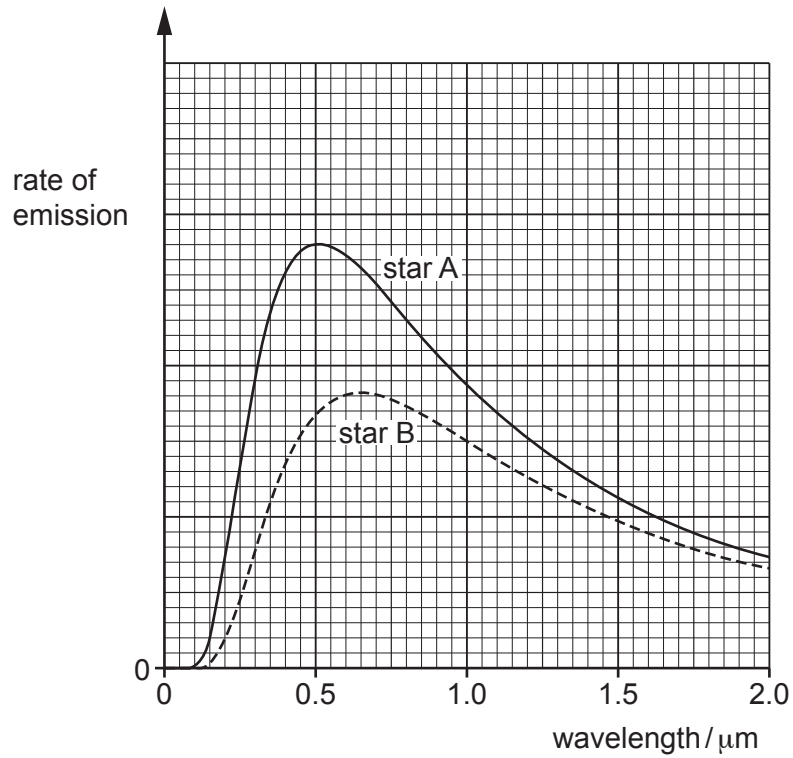


Fig. 10.1

The surface temperature of star A is known to be 5800 K.

(i) Determine the surface temperature of star B.

surface temperature = ... K [2]

- (ii) Star B appears less bright than star A when viewed from the Earth.

Use Fig. 10.1 to suggest, with a reason, how else the physical appearance of star B compares with that of star A.

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

- (c) The lines in Fig. 10.1 have been corrected for redshift.

- (i) State what is meant by redshift.

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

- (ii) Explain how cosmologists are able to determine that light from a distant star has undergone redshift.

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

[Total: 9]

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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) Define gravitational potential at a point.

.....

 [2]

- (ii) Starting from the equation for the gravitational potential due to a point mass, show that the gravitational potential energy E_P of a point mass m at a distance r from another point mass M is given by

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

where G is the gravitational constant.

[1]

- (b) Fig. 1.1 shows the path of a comet of mass $2.20 \times 10^{14} \text{ kg}$ as it passes around a star of mass $1.99 \times 10^{30} \text{ kg}$.

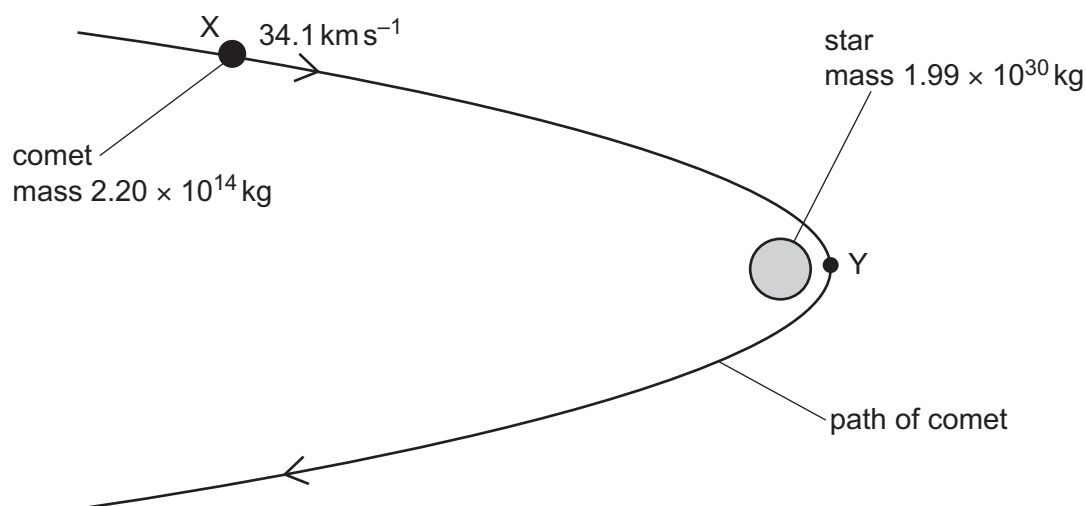


Fig. 1.1 (not to scale)

At point X, the comet is $8.44 \times 10^{11} \text{ m}$ from the centre of the star and is moving at a speed of 34.1 km s^{-1} .

At point Y, the comet passes its point of closest approach to the star. At this point, the comet is a distance of $6.38 \times 10^{10} \text{ m}$ from the centre of the star.

Both the comet and the star can be considered as point masses at their centres.

- (i) Calculate the magnitude of the change in the gravitational potential energy ΔE_p of the comet as it moves from position X to position Y.

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

- (ii) State, with a reason, whether the change in gravitational potential energy in (b)(i) is an increase or a decrease.

.....
 [1]

- (iii) Use your answer in (b)(i) to determine the speed, in km s^{-1} , of the comet at point Y.

$$\text{speed} = \dots\dots\dots \text{ km s}^{-1} [3]$$

- (c) A second comet passes point X with the same speed as the comet in (b) and travelling in the same direction. This comet is gradually losing mass. The mass of this comet when it passes point X is the same as the mass of the comet in (b).

Suggest, with a reason, how the path of the second comet compares with the path shown in Fig. 1.1.

.....
 [1]

[Total: 10]

- 2 (a) State Coulomb's law.

.....

.....

..... [2]

- (b) Positronium is a system in which an electron and a positron orbit, with the same period, around their common centre of mass, as shown in Fig. 2.1.

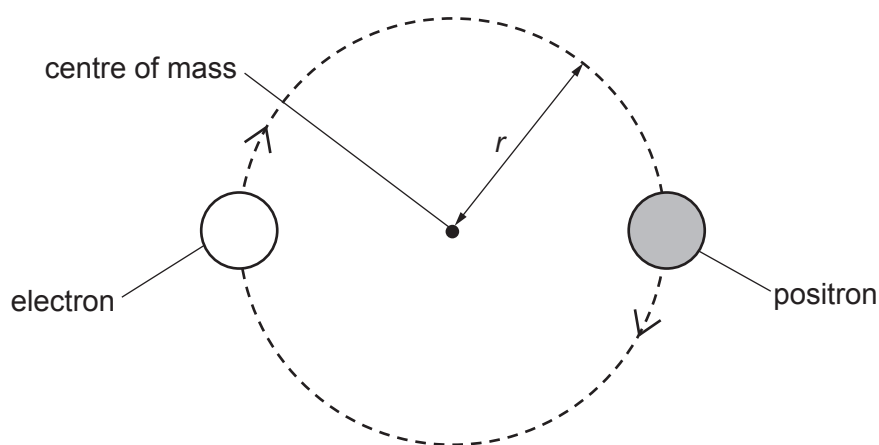


Fig. 2.1 (not to scale)

The radius r of the orbit of both particles is $1.59 \times 10^{-10} \text{ m}$.

- (i) Explain how the electric force between the electron and the positron causes the path of the moving particles to be circular.

.....

.....

..... [2]

- (ii) Show that the magnitude of the electric force between the electron and the positron is $2.28 \times 10^{-9} \text{ N}$.

[2]

- (iii) Use the information in (b)(ii) to determine the period of the circular orbit of the two particles.

period = ... s [3]

- (c) Positronium is highly unstable, and after a very short period of time it becomes gamma radiation.

- (i) Describe how gamma radiation is formed from the two particles in positronium.

.....

 [3]

- (ii) State **one** medical application of the process described in (c)(i).

..... [1]

[Total: 13]

- 3 (a) Define specific latent heat of vaporisation.

.....

.....

..... [2]

- (b) The specific latent heat of vaporisation of water at atmospheric pressure of $1.0 \times 10^5 \text{ Pa}$ is $2.3 \times 10^6 \text{ J kg}^{-1}$. A mass of 0.37 kg of liquid water at 100°C is provided with the thermal energy needed to vaporise all of the water at atmospheric pressure.

- (i) Calculate the thermal energy q supplied to the water.

$$q = \dots\dots\dots \text{ J [1]}$$

- (ii) The mass of 1.0 mol of water is 18 g . Assume that water vapour can be considered to behave as an ideal gas.

Show that the volume of water vapour produced is 0.64 m^3 .

[3]

- (iii) Assume that the initial volume of the liquid water is negligible compared with the volume of water vapour produced.

Determine the magnitude of the work done by the water in expanding against the atmosphere when it vaporises.

$$\text{work done} = \dots\dots\dots \text{ J [2]}$$

- (iv) Use your answers in (b)(i) and (b)(iii) to determine the increase in internal energy of the water when it vaporises at 100 °C. Explain your reasoning.

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

- (c) Use the first law of thermodynamics to suggest, with a reason, how the specific latent heat of vaporisation of water at a pressure greater than atmospheric pressure compares with its value at atmospheric pressure.

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

[Total: 12]

- 4 (a) State what is meant by resonance.

.....

.....

..... [2]

- (b) Fig. 4.1 shows a heavy pendulum and a light pendulum, both suspended from the same piece of string. This string is secured at each end to fixed points.

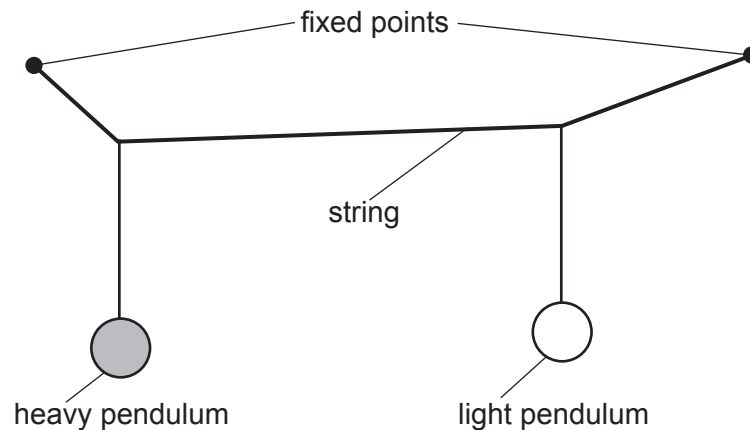


Fig. 4.1

Both pendulums have the same natural frequency.

The heavy pendulum is set oscillating perpendicular to the plane of the diagram. As it oscillates, it causes the light pendulum to oscillate.

Fig. 4.2 shows the variation with time t of the displacements of the two pendulums for three oscillations.

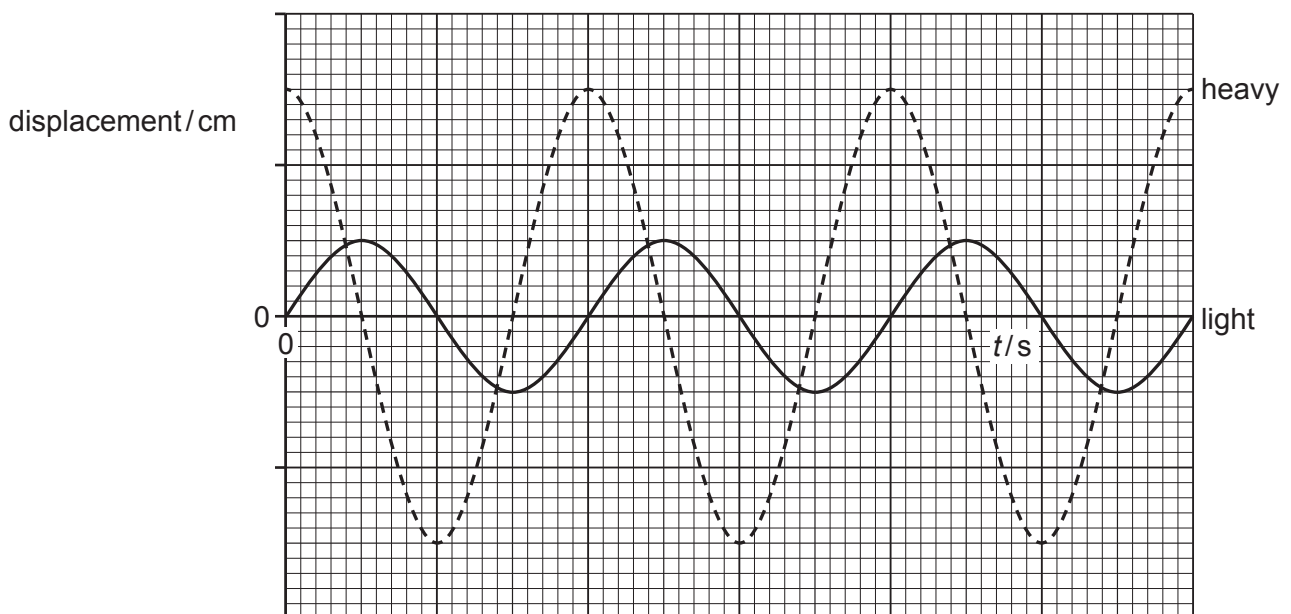


Fig. 4.2

The variation with t of the displacement x of the light pendulum is given by

$$x = 0.25 \sin 5.0\pi t$$

where x is in centimetres and t is in seconds.

- (i) Calculate the period T of the oscillations.

$$T = \dots\dots\dots \text{ s [2]}$$

- (ii) On Fig. 4.2, label both of the axes with the correct scales. Use the space below for any additional working that you need.

[2]

- (iii) Determine the magnitude of the phase difference ϕ between the oscillations of the light and heavy pendulums. Give a unit with your answer.

$$\phi = \dots\dots\dots \text{ unit } \dots\dots\dots [2]$$

[Total: 8]

- 5 (a) Define the capacitance of a parallel plate capacitor.

.....

.....

..... [2]

- (b) Two capacitors, of capacitances C_1 and C_2 , are connected in parallel to a power supply of electromotive force (e.m.f.) E , as shown in Fig. 5.1.

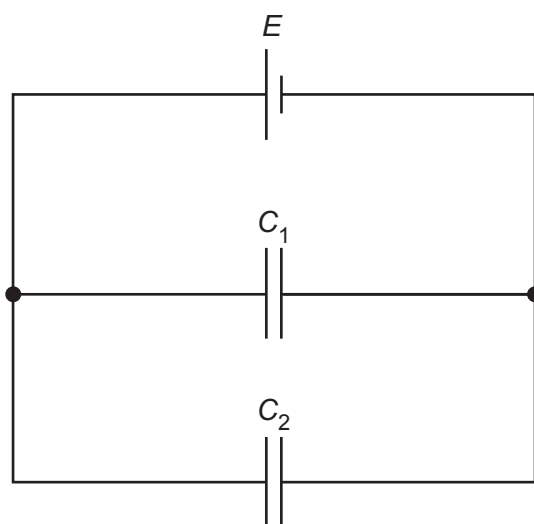


Fig. 5.1

Show that the combined capacitance C_T of the two capacitors is given by

$$C_T = C_1 + C_2.$$

Explain your reasoning. You may draw on Fig. 5.1 if you wish.

[3]

- (c) Two capacitors of capacitances $22\mu\text{F}$ and $47\mu\text{F}$, and a resistor of resistance $2.7\text{M}\Omega$, are connected into the circuit of Fig. 5.2.

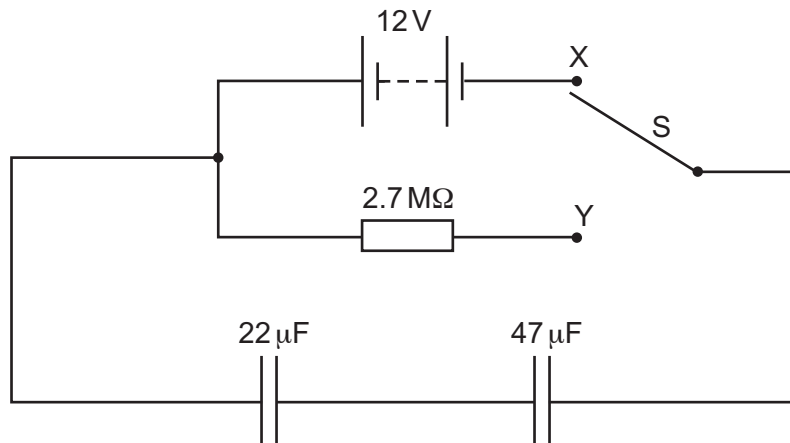


Fig. 5.2

The battery has an e.m.f. of 12 V.

- (i) Show that the combined capacitance of the two capacitors is $15\mu\text{F}$.

[1]

- (ii) The two-way switch S is initially at position X, so that the capacitors are fully charged.

Use the information in (c)(i) to calculate the total energy stored in the two capacitors.

total energy = ... J [2]

- (iii) The two-way switch is now moved to position Y.

Determine the time taken for the potential difference (p.d.) across the $22\mu\text{F}$ capacitor to become 6.0 V.

time = ... s [3]

[Total: 11]

[Turn over]

- 6 (a) State the **two** conditions that must be satisfied for a copper wire, placed in a magnetic field, to experience a magnetic force.

1

.....

2

.....

[2]

- (b) A long air-cored solenoid is connected to a power supply, so that the solenoid creates a magnetic field. Fig. 6.1 shows a cross-section through the middle of the solenoid.

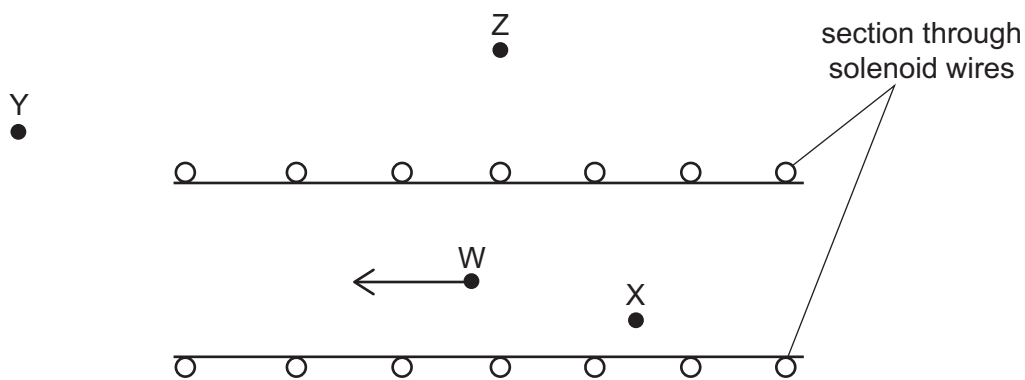


Fig. 6.1

The direction of the magnetic field at point W is indicated by the arrow. Three other points are labelled X, Y and Z.

- (i) On Fig. 6.1, draw arrows to indicate the direction of the magnetic field at each of the points X, Y and Z. [3]

- (ii) Compare the magnitude of the flux density of the magnetic field:

• at X and at W

.....

• at Y and at Z.

.....

[2]

- (c) Two long parallel current-carrying wires are placed near to each other in a vacuum.

Explain why these wires exert a magnetic force on each other. You may draw a labelled diagram if you wish.

.....

.....

.....

..... [3]

[Total: 10]

- 7 (a) State Faraday's law of electromagnetic induction.

.....

.....

..... [2]

- (b) Two coils are wound on an iron bar, as shown in Fig. 7.1.

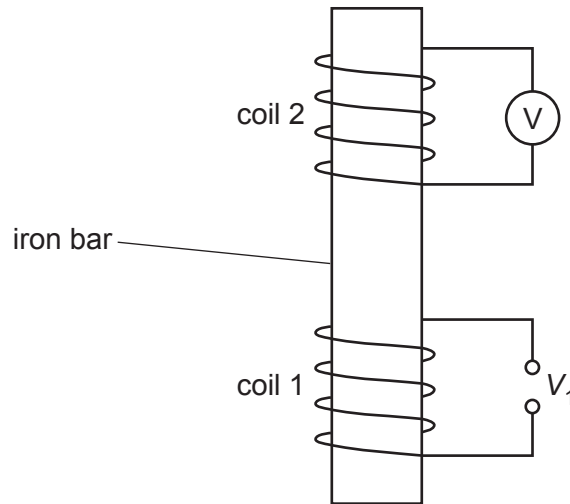


Fig. 7.1

Coil 1 is connected to a potential difference (p.d.) V_1 that gives rise to a magnetic field in the iron bar.

Fig. 7.2 shows the variation with time t of the magnetic flux density B in the iron bar.

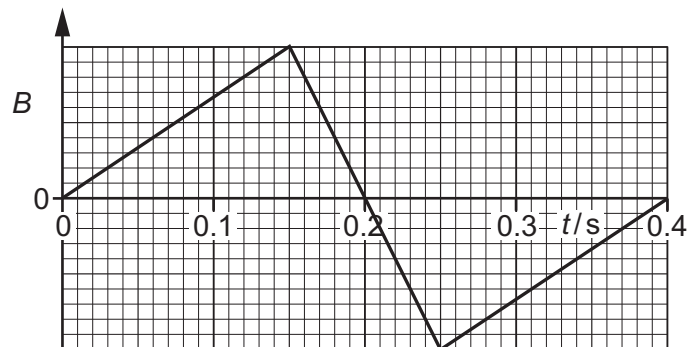


Fig. 7.2

A voltmeter measures the electromotive force (e.m.f.) V_2 that is induced across coil 2.

On Fig. 7.3, sketch the variation with t of V_2 between $t = 0$ and $t = 0.40$ s.

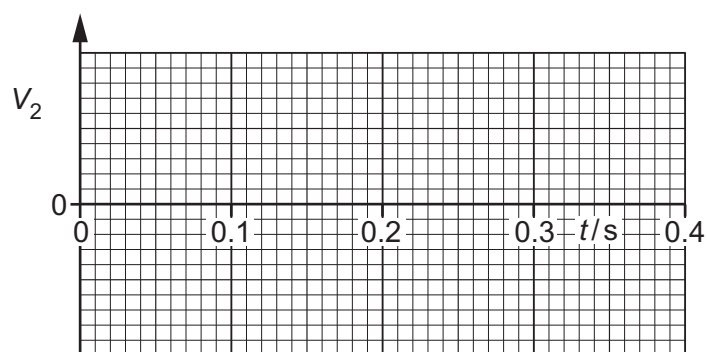


Fig. 7.3

[4]

- (c) Coil 2 in (b) is now replaced with a copper ring that rests loosely on top of coil 1. The supply to coil 1 is replaced with a cell and a switch that is initially open, as shown in Fig. 7.4.

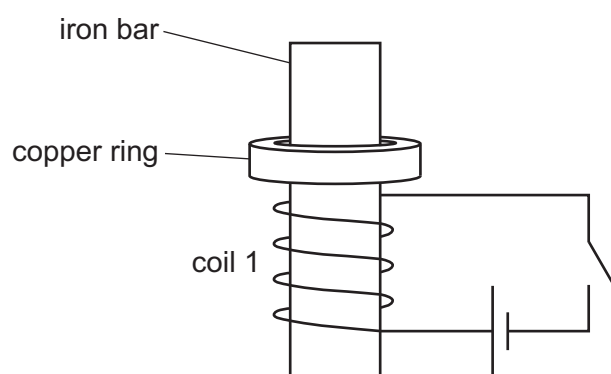


Fig. 7.4

- (i) The switch is now closed. As it is closed, the copper ring is observed to jump upwards.

Explain why this happens.

.....

 [3]

- (ii) Suggest, with a reason, what would be the effect of repeating the procedure in (c)(i) with the terminals of the cell reversed.

.....
 [1]

[Total: 10]

8 (a) State **one** piece of experimental evidence for:

(i) the particulate nature of electromagnetic radiation

..... [1]

(ii) the wave nature of matter.

..... [1]

(b) (i) Calculate the de Broglie wavelength λ of an alpha-particle moving at a speed of $6.2 \times 10^7 \text{ m s}^{-1}$.

$\lambda =$ m [3]

(ii) The speed v of the alpha-particle in (b)(i) is gradually reduced to zero.

On Fig. 8.1, sketch the variation with v of λ .

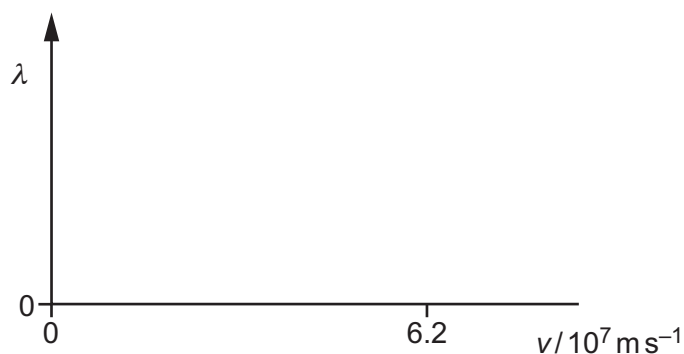


Fig. 8.1

[2]

(c) Suggest an explanation for why people are not observed to diffract when they walk through a doorway.

.....

 [1]

[Total: 8]

9 (a) (i) State Hubble's law.

.....

.....

..... [2]

(ii) Explain how cosmologists use observations of emission spectra from stars in distant galaxies to determine that the Universe is expanding.

.....

.....

.....

..... [2]

(b) Explain how Hubble's law and the idea of the expanding Universe lead to the Big Bang theory of the origin of the Universe.

.....

.....

.....

..... [3]

[Total: 7]

- 10 (a) State what is meant by radioactive decay.

.....

.....

..... [2]

- (b) A radioactive sample consists of an isotope X of half-life T that decays to form a stable product. Only X and the stable product are present in the sample.

At time $t = 0$, the sample has an activity of A_0 and contains N_0 nuclei of X.

- (i) On Fig. 10.1, sketch the variation with t of the number N of nuclei of X present in the sample. Your line should extend from time $t = 0$ to time $t = 3T$.

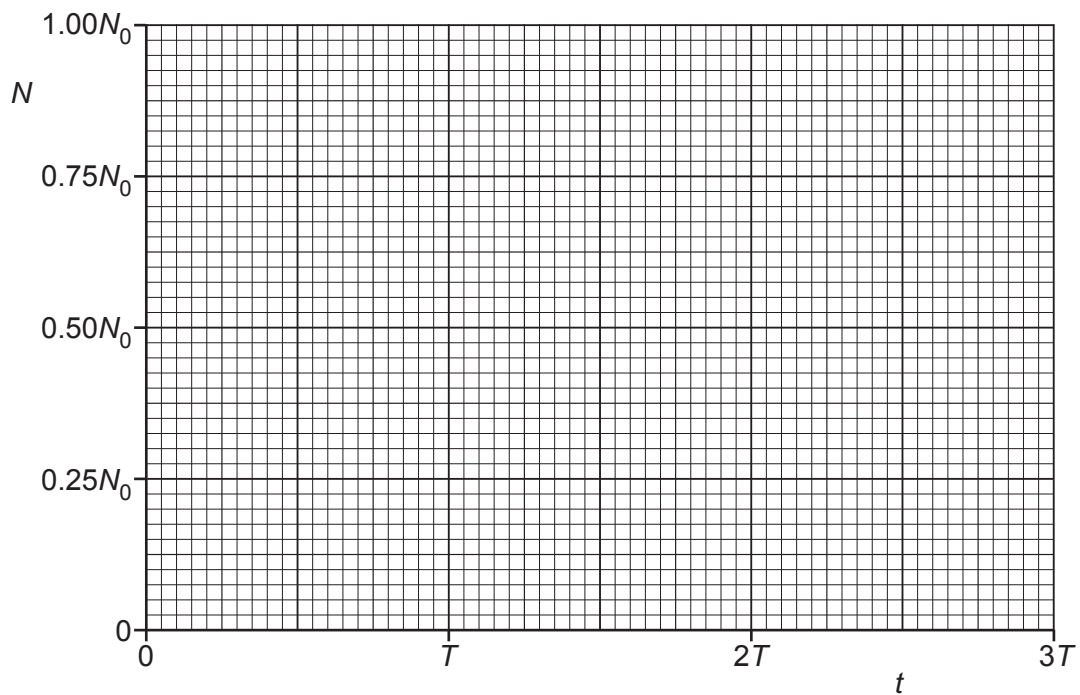


Fig. 10.1

[3]

- (ii) On Fig. 10.2, sketch the variation with N of the activity A of the sample for values of N between $N = 0$ and $N = N_0$.

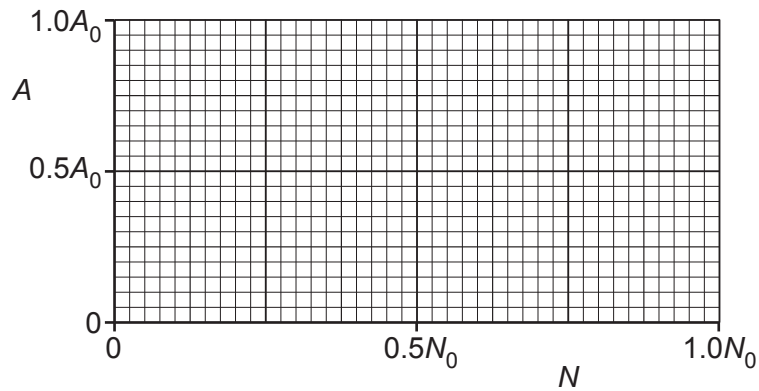


Fig. 10.2

[2]

- (c) State the name of the quantity represented by the gradient of your line in:

- (i) Fig. 10.1

..... [1]

- (ii) Fig. 10.2.

..... [1]

- (d) For the sample in (b), calculate the fraction $\frac{N}{N_0}$ at time $t = 1.70T$.

$$\frac{N}{N_0} = \dots\dots\dots [2]$$

[Total: 11]

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PHYSICS

9702/43

Paper 4 A Level Structured Questions

May/June 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) (i) State Newton's law of gravitation.

.....

.....

..... [2]

- (ii) Use Newton's law of gravitation to show that the gravitational field strength g at a distance r away from a point mass M is given by

$$g = \frac{GM}{r^2}.$$

[2]

- (b) The Earth has a mass of 5.98×10^{24} kg and a radius of 6.37×10^6 m.
 The Moon has a mass of 7.35×10^{22} kg and a radius of 1.74×10^6 m.
 The Earth and the Moon can both be considered as point masses at their centres. Their centres are a distance of 3.84×10^8 m apart.

- (i) Show that the gravitational field strength at the surface of the Moon due to the mass of the Moon is 1.62 N kg^{-1} .

[1]

- (ii) Explain why there is a point X on the line between the centres of the Earth and the Moon where the resultant gravitational field strength due to the Earth and the Moon is zero.

.....

.....

..... [2]

- (iii) Calculate the distance x of point X from the centre of the Moon.

$x = \dots\dots\dots$ m [3]

[Total: 10]

- 2 A sphere of mass $1.6 \times 10^{-10} \text{ kg}$ has a charge of $+0.27 \text{ nC}$. The sphere is in a uniform electric field that acts vertically upwards, as shown in the side view in Fig. 2.1.

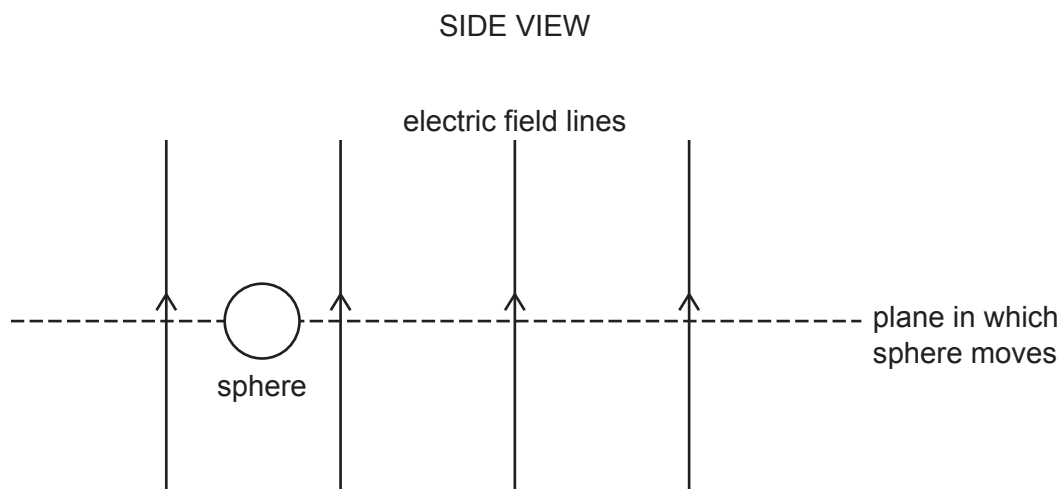


Fig. 2.1

The force exerted on the sphere by the electric field causes the sphere to remain at a fixed vertical height in a horizontal plane.

There is a uniform magnetic field in the region of the electric field. The sphere moves at a speed of 0.78 m s^{-1} in the horizontal plane. The magnetic field causes the sphere to move in a circular path of radius 3.4 m , as shown in the view from above in Fig. 2.2.

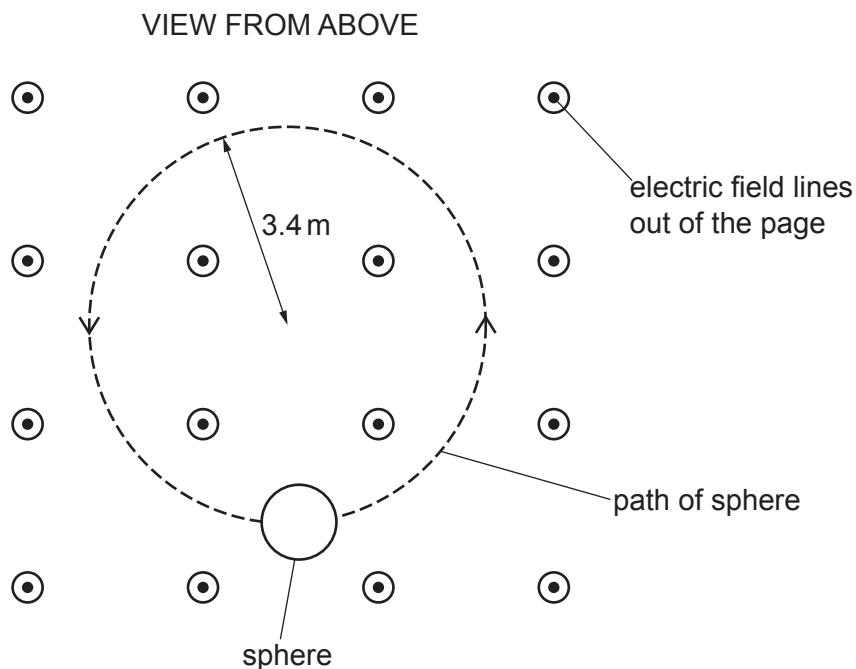


Fig. 2.2

- (a) (i) Determine the direction of the uniform magnetic field.

..... [1]

- (ii) Explain why the motion of the sphere in the horizontal plane is circular.

.....

.....

..... [2]

- (b) Calculate the strength of the uniform electric field.

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

- (c) By considering the magnetic force on the sphere, show that the flux density of the uniform magnetic field is 0.14 T.

[3]

[Total: 8]

- 3 A fixed mass of an ideal gas is initially at a temperature of 17°C . The gas has a volume of 0.24 m^3 and a pressure of $1.2 \times 10^5\text{ Pa}$.

(a) (i) State what is meant by an ideal gas.

.....

 [2]

(ii) Calculate the amount n of gas.

$n = \dots\dots\dots$ mol [2]

(b) The gas undergoes three successive changes, as shown in Fig. 3.1.

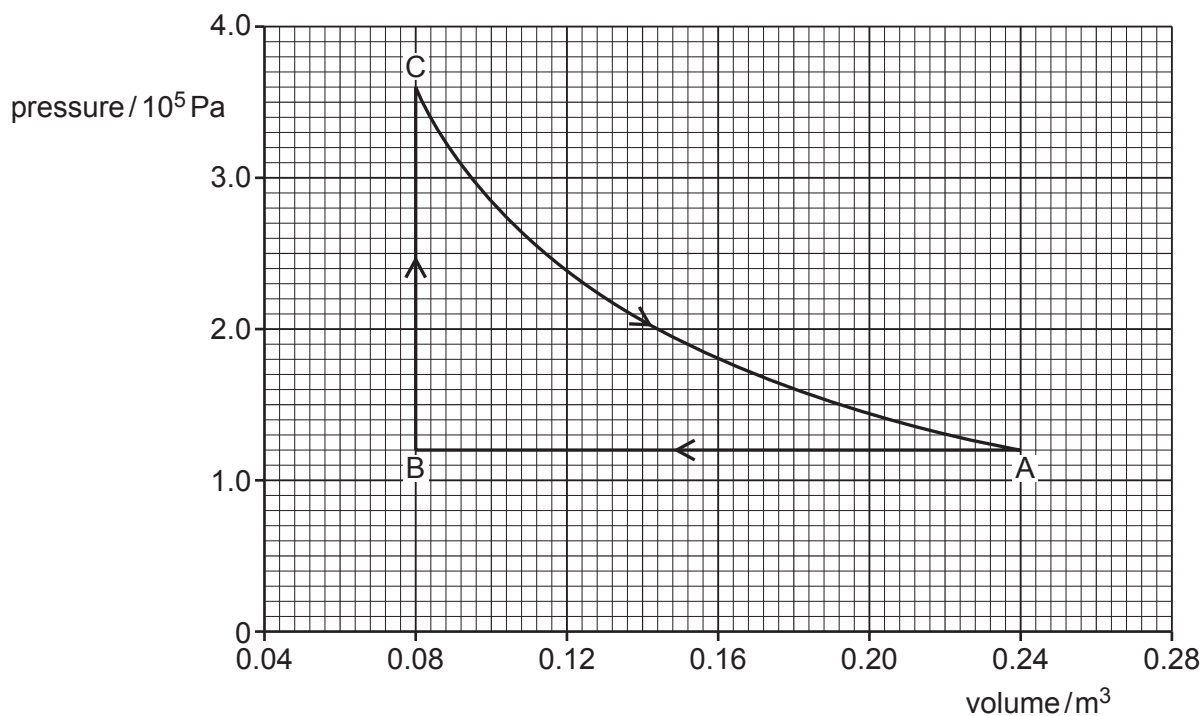


Fig. 3.1

The initial state is represented by point A. The gas is cooled at constant pressure to point B by the removal of 48.0 kJ of thermal energy.

The gas is then heated at constant volume to point C.

Finally, the gas expands at constant temperature back to its original pressure and volume at point A. During this expansion, the gas does 31.6 kJ of work.

- (i) Show that the magnitude of the work done during the change AB is 19.2 kJ.

[2]

- (ii) Complete Table 3.1 to show the work done on the gas, the thermal energy supplied to the gas and the increase in internal energy of the gas, for each of the changes AB, BC and CA.

Table 3.1

change	work done on gas / kJ	thermal energy supplied to gas / kJ	increase in internal energy of gas / kJ
AB		-48.0	
BC			
CA	-31.6		

[5]

[Total: 11]

- 4 A pendulum consists of a bob (small metal sphere) attached to the end of a piece of string. The other end of the string is attached to a fixed point. The bob oscillates with small oscillations about its equilibrium position, as shown in Fig. 4.1.

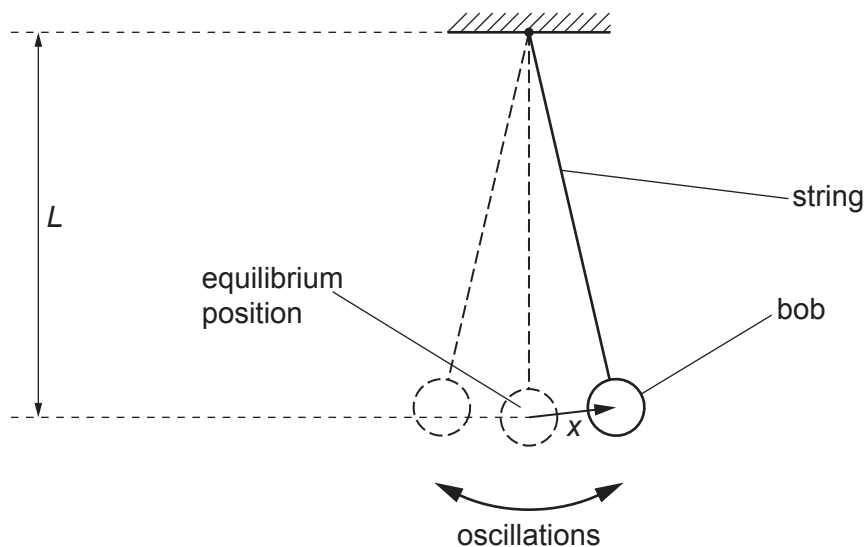


Fig. 4.1 (not to scale)

The length L of the pendulum, measured from the fixed point to the centre of the bob, is 1.24 m.

The acceleration a of the bob varies with its displacement x from the equilibrium position as shown in Fig. 4.2.

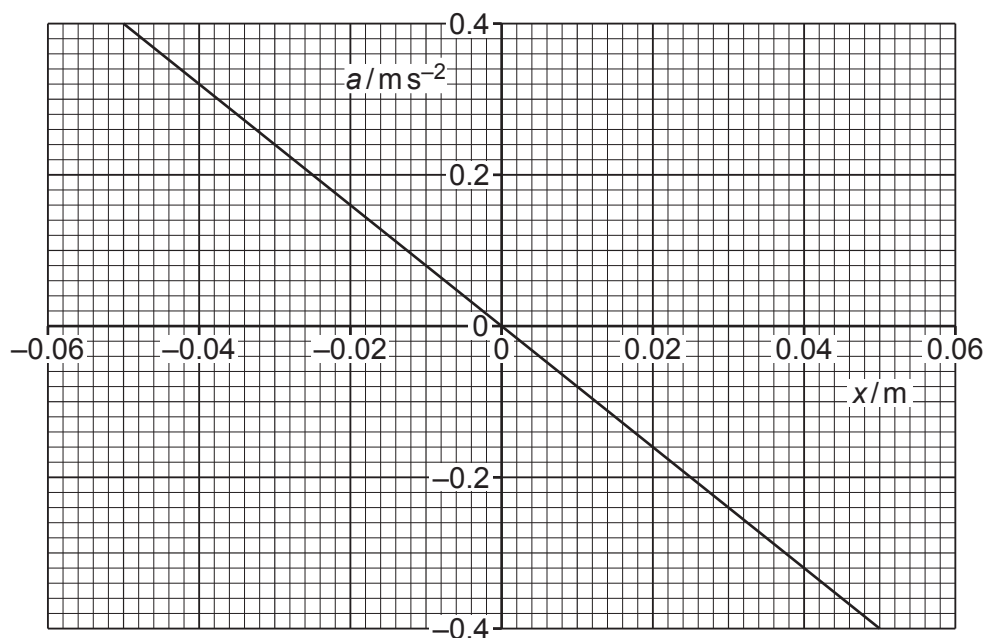


Fig. 4.2

- (a) State how Fig. 4.2 shows that the motion of the pendulum is simple harmonic.

.....

.....

..... [2]

- (b) (i) Use Fig. 4.2 to determine the angular frequency ω of the oscillations.

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

- (ii) The angular frequency ω is related to the length L of the pendulum by

$$\omega = \sqrt{\frac{k}{L}}$$

where k is a constant.

Use your answer in (b)(i) to determine k . Give a unit with your answer.

$$k = \dots\dots\dots \text{unit} \dots\dots\dots [2]$$

- (c) While the pendulum is oscillating, the length of the string is increased in such a way that the total energy of the oscillations remains constant.

Suggest and explain the qualitative effect of this change on the amplitude of the oscillations.

.....

.....

..... [2]

[Total: 8]

- 5 Fig. 5.1 shows four diodes and a load resistor of resistance $1.2\text{ k}\Omega$, connected in a circuit that is used to produce rectification of an alternating voltage.

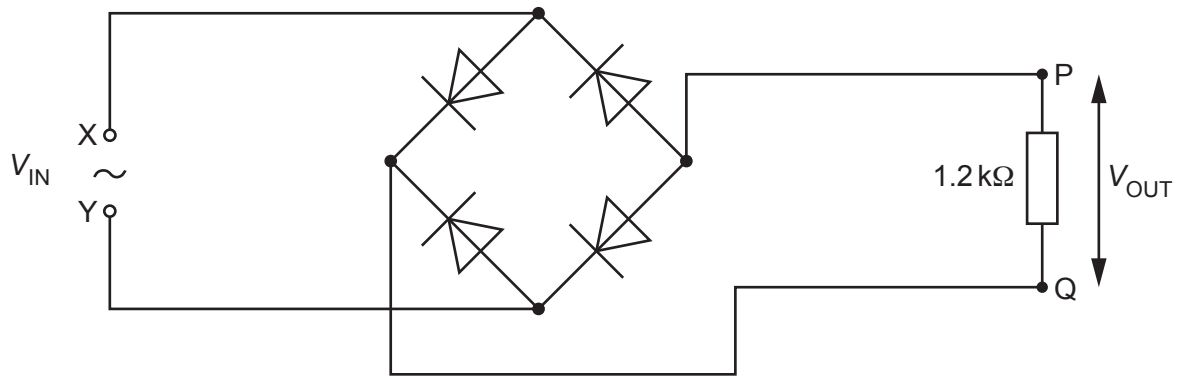


Fig. 5.1

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

.....
 [1]

- (ii) State the type of rectification produced by the circuit in Fig. 5.1.

..... [1]

- (b) A sinusoidal alternating voltage V_{IN} is applied across the input terminals X and Y. The variation with time t of V_{IN} is given by the equation

$$V_{IN} = 6.0 \sin 25\pi t$$

where V_{IN} is in volts and t is in seconds.

- (i) On Fig. 5.1, label the output terminals P and Q with the appropriate symbols to indicate the polarity of the output voltage V_{OUT} . [1]

- (ii) The magnitude of the output voltage V_{OUT} varies with t as shown in Fig. 5.2.

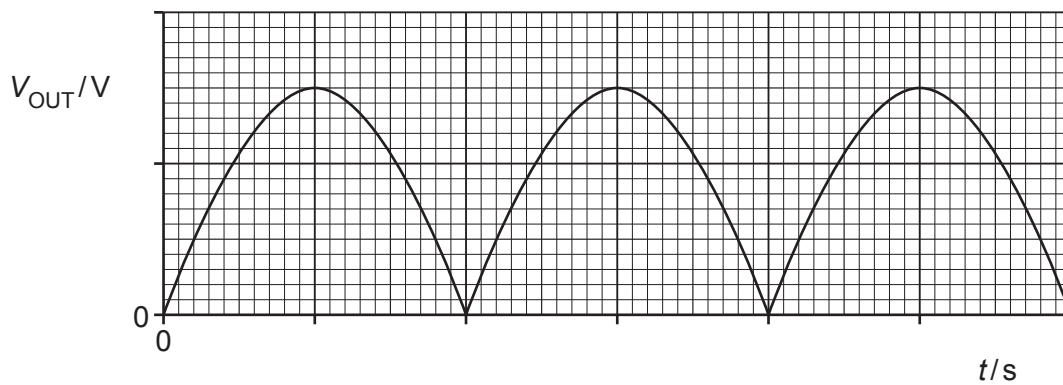


Fig. 5.2

On Fig. 5.2, label both of the axes with the correct scales. Use the space below for any working that you need.

[3]

- (c) The output voltage in (b) is smoothed by adding a capacitor to the circuit in Fig. 5.1. The difference between the maximum and minimum values of the smoothed output voltage is 10% of the peak voltage.

- (i) On Fig. 5.1, draw the circuit symbol for a capacitor showing the capacitor correctly connected into the circuit. [1]

- (ii) On Fig. 5.2, sketch the variation with t of the smoothed output voltage. [2]

- (iii) Calculate the capacitance C of the capacitor.

$C = \dots\dots\dots$ F [3]

[Total: 12]

- 6 (a) Define magnetic flux.

.....

.....

..... [2]

- (b) A square coil of wire of side length 12 cm consists of 8 insulated turns. The coil is stationary in a uniform magnetic field. The plane of the coil is perpendicular to the magnetic field, as shown in Fig. 6.1.

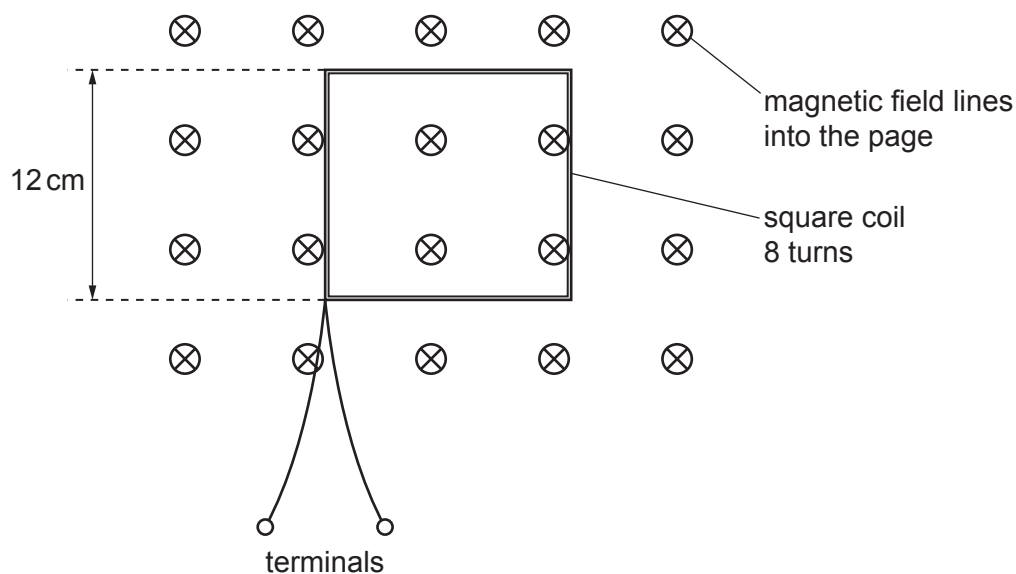


Fig. 6.1

The flux density B of the magnetic field varies with time t as shown in Fig. 6.2.

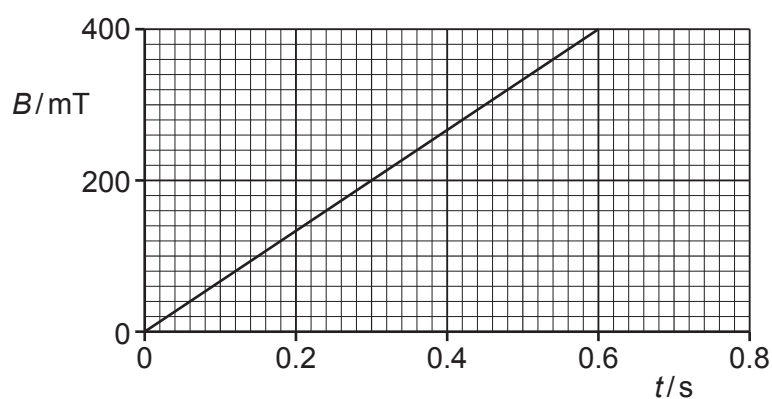


Fig. 6.2

- (i) Determine the magnetic flux linkage inside the coil at time $t = 0.60\text{ s}$. Give a unit with your answer.

magnetic flux linkage = ... unit [3]

- (ii) State how Fig. 6.2 shows that the electromotive force (e.m.f.) E induced across the terminals between $t = 0$ and $t = 0.60\text{ s}$ is constant.

..... [1]

- (iii) Calculate the magnitude of E .

$E = \dots\dots\dots \text{ V}$ [2]

- (c) The procedure in (b) is repeated, but this time the terminals of the coil are connected together.

State and explain the effect on the coil of connecting the terminals together during the change of magnetic flux density shown in Fig. 6.2.

.....

 [3]

[Total: 11]

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

.....

 [2]

- (b) Electromagnetic radiation of a varying frequency f and constant intensity I is used to illuminate a metal surface. At certain frequencies, electrons are emitted from the surface of the metal. The variation with f of the maximum kinetic energy E_{MAX} of the emitted electrons is shown in Fig. 7.1.

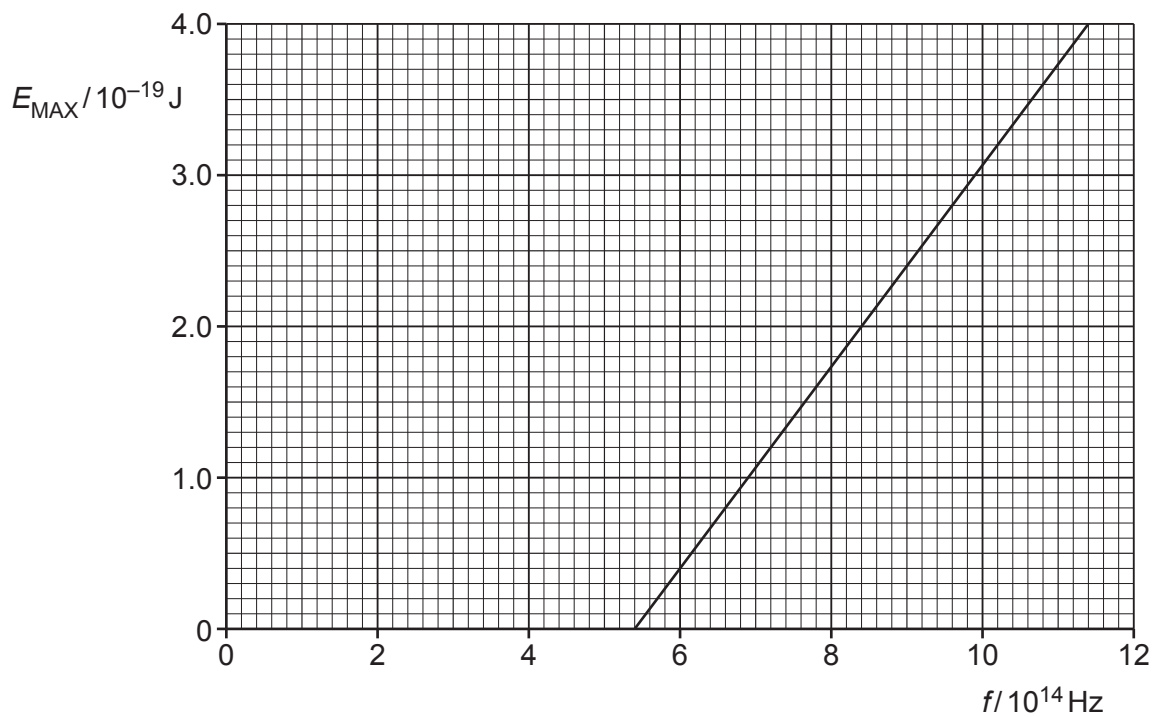


Fig. 7.1

- (i) State the name of this phenomenon.

..... [1]

- (ii) Describe **three** conclusions that can be drawn from the graph in Fig. 7.1. The conclusions may be qualitative or quantitative.

1

.....

2

.....

3

.....

[3]

- (c) The experiment in (b) is repeated twice, each time making one change.

State, with a reason, how the graph obtained would compare with Fig. 7.1 when:

- (i) a different metal is used, but keeping the intensity I of the radiation the same

.....

.....

..... [2]

- (ii) the same metal is used, but with electromagnetic radiation of intensity $2I$.

.....

.....

..... [2]

[Total: 10]

- 8 (a) (i) State what is meant by nuclear binding energy.

.....

 [2]

- (ii) On Fig. 8.1, sketch a line to show the variation with nucleon number A of the binding energy per nucleon E of a nucleus.

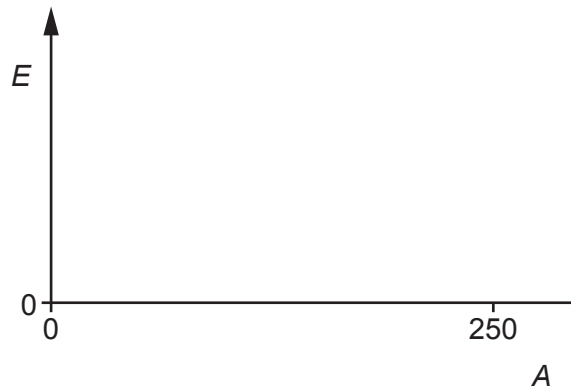


Fig. 8.1

[2]

- (b) In one type of nuclear process, deuterium (${}^2_1\text{H}$) undergoes the reaction



- (i) State the name of this type of nuclear process.

..... [1]

- (ii) Explain, with reference to your line in (a)(ii), why this reaction results in the release of energy.

.....

 [2]

(c) Table 8.1 shows the masses of the particles involved in the reaction in (b).

Table 8.1

particle	mass/u
${}_0^1\text{n}$	1.008 665
${}_1^2\text{H}$	2.014 102
${}_2^3\text{He}$	3.016 029

Calculate the energy released when 1.00 mol of deuterium undergoes the reaction.

energy = ... J [5]

[Total: 12]

- 9 (a) (i) Explain how X-rays are produced for use in medical diagnosis.

.....

 [3]

- (ii) State why X-ray images are taken of multiple sections of the body during computed tomography (CT) scanning.

.....
 [1]

- (b) An X-ray image is taken of the structure shown in Fig. 9.1.

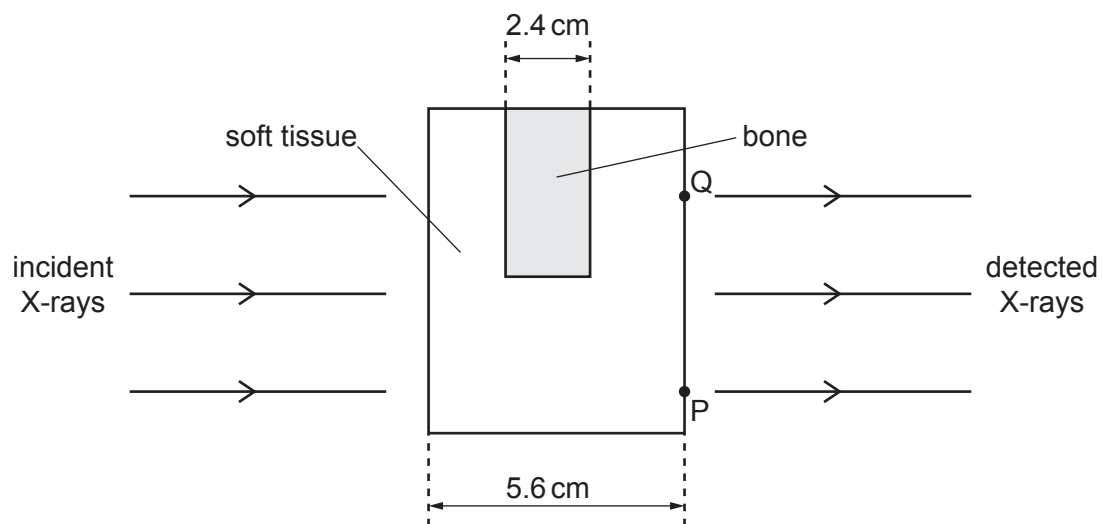


Fig. 9.1

The linear attenuation coefficient of bone is 3.4 cm^{-1} .

The linear attenuation coefficient of soft tissue is 0.89 cm^{-1} .

The incident X-rays are parallel and have a uniform intensity I_0 across the structure.

Determine, in terms of I_0 , the intensity of the detected X-rays from:

(i) point P

detected intensity = ... I_0 [2]

(ii) point Q.

detected intensity = ... I_0 [2]

(c) Explain, with reference to your answers in (b), whether the X-ray image of the structure in Fig. 9.1 has good contrast.

.....

 [1]

[Total: 9]

10 (a) State Wien's displacement law.

.....
 [1]

(b) Fig. 10.1 shows the wavelength distributions of electromagnetic radiation emitted by two stars A and B.

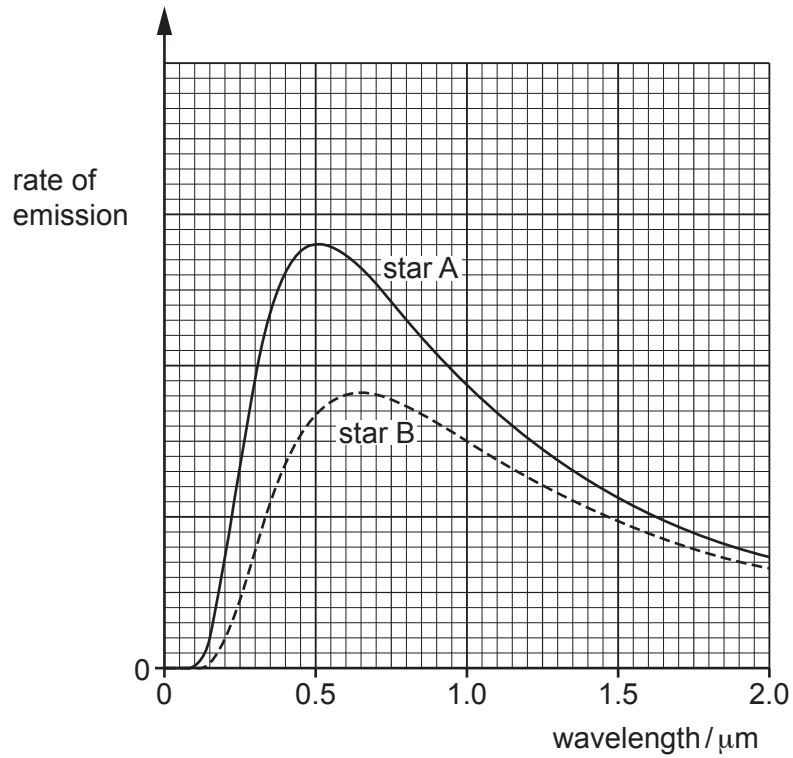


Fig. 10.1

The surface temperature of star A is known to be 5800 K.

(i) Determine the surface temperature of star B.

surface temperature = ... K [2]

- (ii) Star B appears less bright than star A when viewed from the Earth.

Use Fig. 10.1 to suggest, with a reason, how else the physical appearance of star B compares with that of star A.

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

- (c) The lines in Fig. 10.1 have been corrected for redshift.

- (i) State what is meant by redshift.

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

- (ii) Explain how cosmologists are able to determine that light from a distant star has undergone redshift.

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

[Total: 9]

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