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PHYSICS

9702/41

Paper 4 A Level Structured Questions

October/November 2019

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your centre number, candidate number and name on all the work you hand in.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

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

DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.

You may lose marks if you do not show your working or if you do not use appropriate units.

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

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

This document consists of **25** printed pages and **3** blank pages.

Data

speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho gh$
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.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
energy of charged capacitor	$W = \frac{1}{2} QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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

- 1 (a) State Newton's law of gravitation.

.....

.....

..... [2]

- (b) A geostationary satellite orbits the Earth. The orbit of the satellite is circular and the period of the orbit is 24 hours.

- (i) State **two** other features of this orbit.

1.

.....

2.

.....

[2]

- (ii) The radius of the orbit of the satellite is 4.23×10^4 km.

Determine a value for the mass of the Earth. Explain your working.

mass = ... kg [4]

[Total: 8]

- 2 (a) The kinetic theory of gases is based on a number of assumptions about the molecules of a gas.

State the assumption that is related to the volume of the molecules of the gas.

.....

 [2]

- (b) An ideal gas occupies a volume of $2.40 \times 10^{-2} \text{ m}^3$ at a pressure of $4.60 \times 10^5 \text{ Pa}$ and a temperature of 23°C .

- (i) Calculate the number of molecules in the gas.

number = ... [3]

- (ii) Each molecule has a diameter of approximately $3 \times 10^{-10} \text{ m}$.

Estimate the total volume of the gas molecules.

volume = ... m^3 [3]

- (c) By reference to your answer in (b)(ii), suggest why the assumption in (a) is justified.

.....
 [1]

[Total: 9]

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- 3 (a) State what is meant by *specific latent heat*.

.....

.....

..... [2]

- (b) A student determines the specific latent heat of vaporisation of a liquid using the apparatus illustrated in Fig. 3.1.

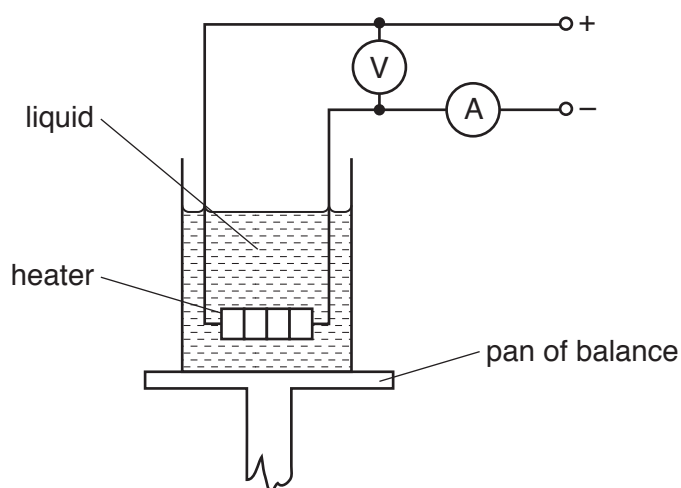


Fig. 3.1

The heater is switched on. When the liquid is boiling at a constant rate, the balance reading is noted at 2.0 minute intervals.

After 10 minutes, the current in the heater is reduced and the balance readings are taken for a further 12 minutes.

The readings of the ammeter and of the voltmeter are given in Fig. 3.2.

	ammeter reading /A	voltmeter reading /V
from time 0 to time 10 minutes	1.2	230
after time 10 minutes	1.0	190

Fig. 3.2

The variation with time of the balance reading is shown in Fig. 3.3.

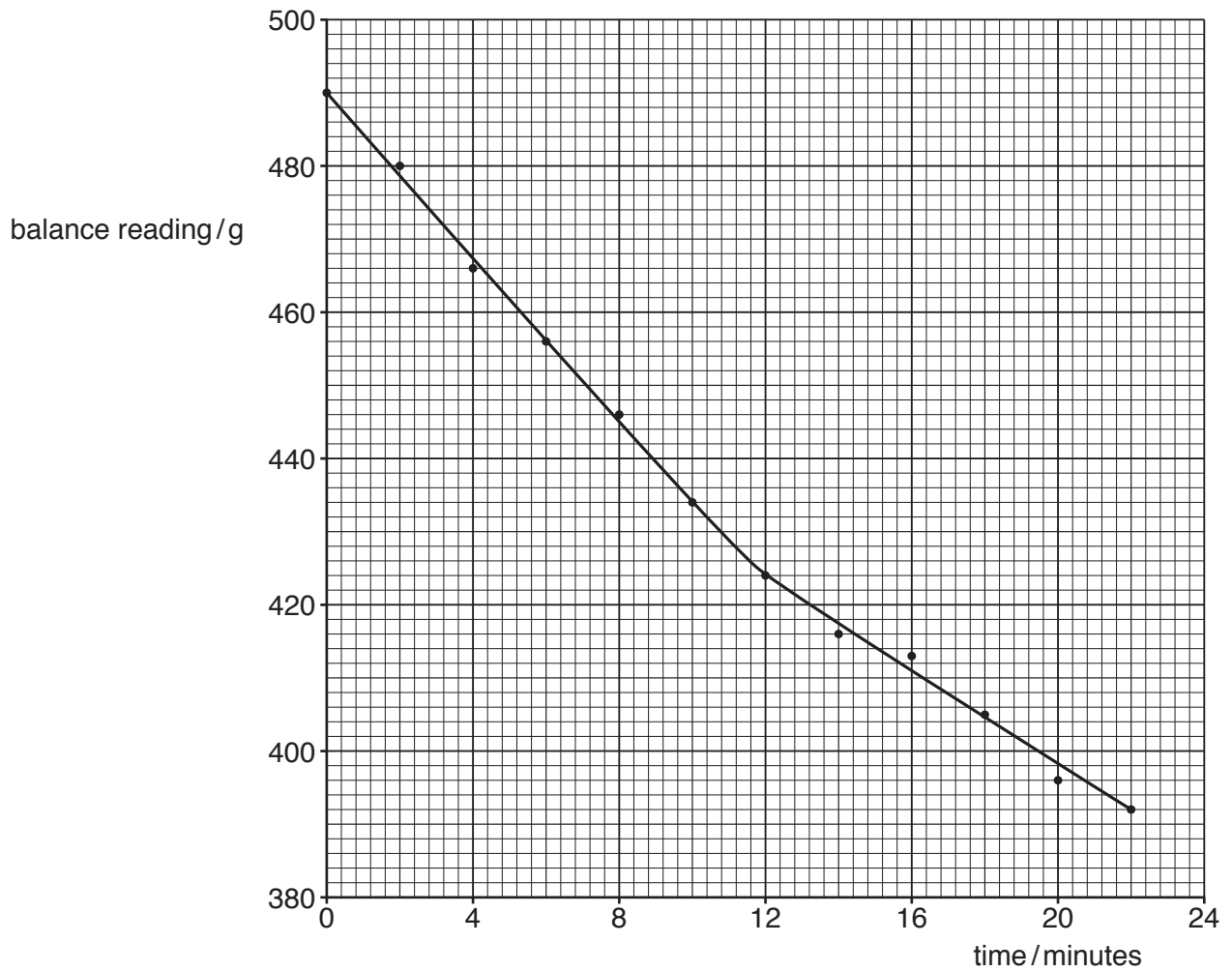


Fig. 3.3

- (i) From time 0 to time 10.0 minutes, the mass of liquid evaporated is 56 g.

Use Fig. 3.3 to determine the mass of liquid evaporated from time 12.0 minutes to time 22.0 minutes.

mass = ...g [1]

- (ii) Explain why, although the power of the heater is changed, the rate of loss of thermal energy to the surroundings may be assumed to be constant.

.....

..... [1]

- (iii) Determine a value for the specific latent heat of vaporisation L of the liquid.

$L = \dots\dots\dots \text{Jg}^{-1}$ [4]

- (iv) Calculate the rate at which thermal energy is transferred to the surroundings.

rate = ... W [2]

[Total: 10]

- 4 A mass is suspended vertically from a fixed point by means of a spring, as illustrated in Fig. 4.1.

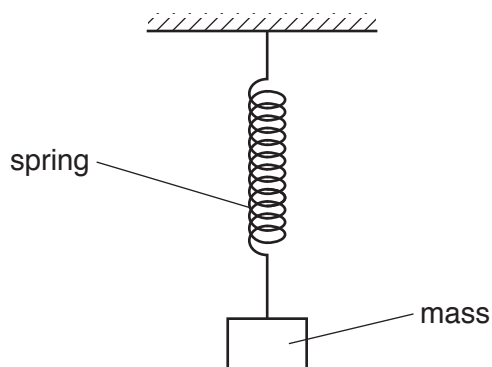


Fig. 4.1

The mass is oscillating vertically. The variation with displacement x of the acceleration a of the mass is shown in Fig. 4.2.

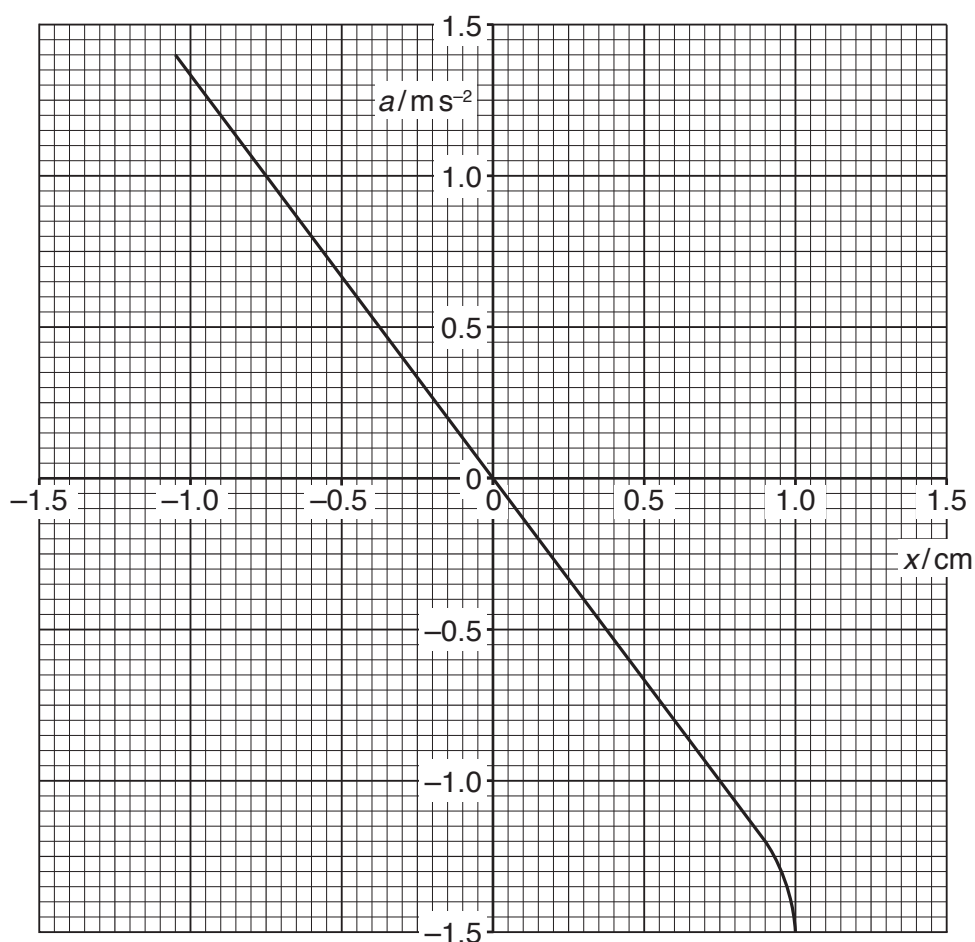


Fig. 4.2

- (a) (i) State what is meant by the *displacement* of the mass on the spring.

.....
 [1]

- (ii) Suggest how Fig. 4.2 shows that the mass is not performing simple harmonic motion.

.....
 [1]

- (b) (i) The amplitude of oscillation of the mass may be changed.

State the maximum amplitude x_0 for which the oscillations are simple harmonic.

$x_0 =$ cm [1]

- (ii) For the simple harmonic oscillations of the mass, use Fig. 4.2 to determine the frequency of the oscillations.

frequency = ... Hz [3]

- (c) The maximum speed of the mass when oscillating with simple harmonic motion of amplitude x_0 is v_0 .

On Fig. 4.3, show the variation with displacement x of the velocity v of the mass for displacements from $+x_0$ to $-x_0$.

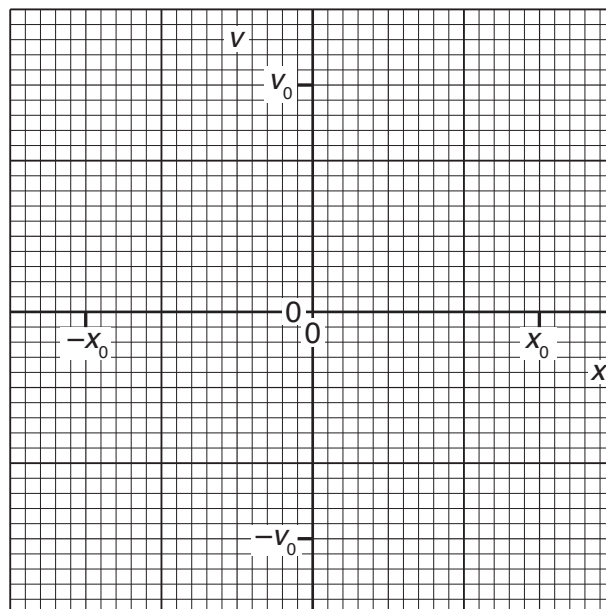


Fig. 4.3

[2]

[Total: 8]

- 5 (a) A section of a coaxial cable is shown in Fig. 5.1.

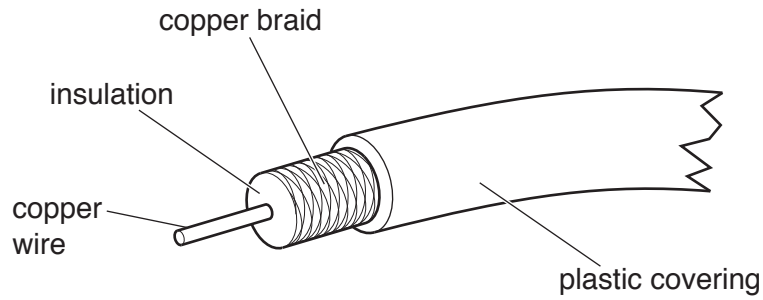


Fig. 5.1

- (i) Suggest **two** functions of the copper braid.

1.

.....

2.

.....

[2]

- (ii) Suggest **one** application of a coaxial cable for the transmission of electrical signals.

.....

..... [1]

- (b) (i) The constant noise power in a transmission cable is $7.6\mu\text{W}$. The minimum acceptable signal-to-noise ratio is 32 dB.

Calculate the minimum acceptable signal power P_{MIN} in the cable.

$$P_{\text{MIN}} = \dots\dots\dots\text{W} \quad [2]$$

- (ii) The input power of the signal to the transmission cable is 2.6 W. The attenuation per unit length of the cable is 6.3 dB km^{-1} .

Use your answer in (i) to determine the maximum uninterrupted length L of cable along which the signal may be transmitted.

$L = \dots\dots\dots \text{ km [2]}$

[Total: 7]

- 6 (a) State an expression for the electric field strength E at a distance r from a point charge Q in a vacuum.
State the name of any other symbol used.

.....

 [2]

- (b) Two point charges A and B are situated a distance 10.0 cm apart in a vacuum, as illustrated in Fig. 6.1.

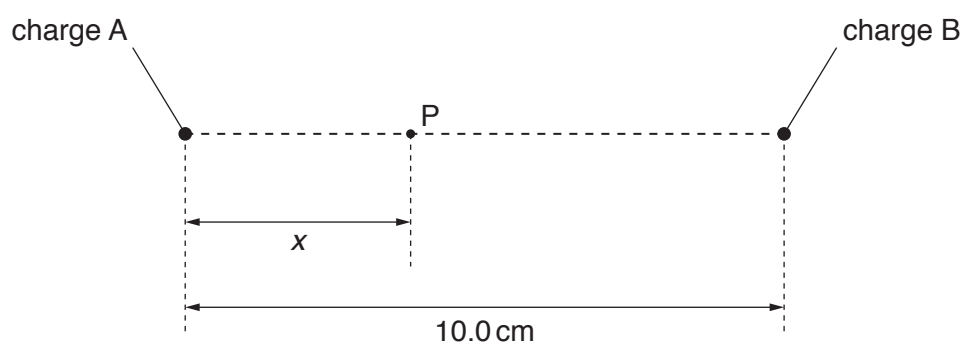


Fig. 6.1

A point P lies on the line joining the charges A and B. Point P is a distance x from A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 6.2.

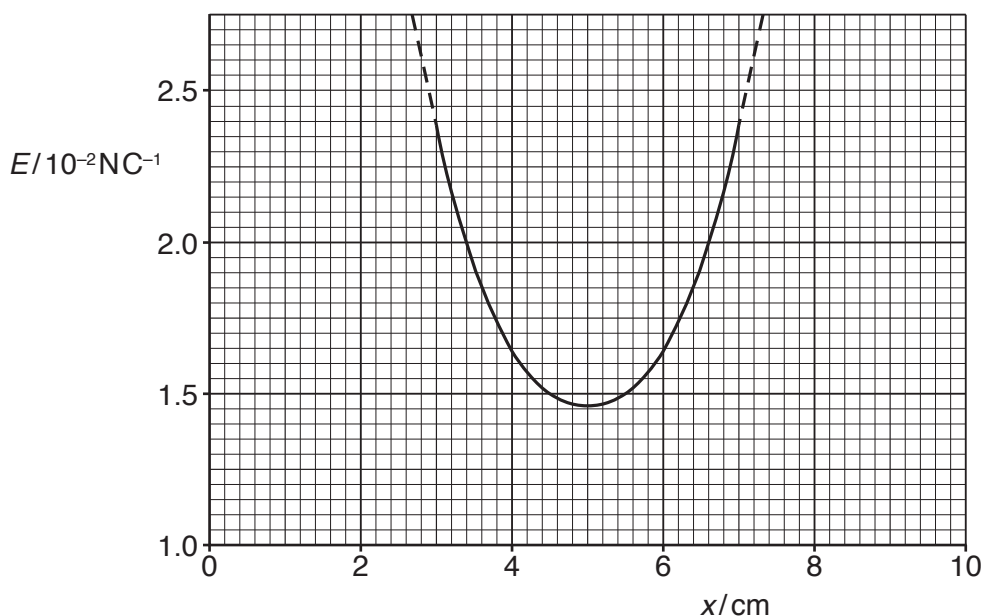


Fig. 6.2

State and explain whether the charges A and B:

(i) have the same, or opposite, signs

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

(ii) have the same, or different, magnitudes.

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

(c) An electron is situated at point P.

Without calculation, state and explain the variation in the magnitude of the acceleration of the electron as it moves from the position where $x = 3\text{ cm}$ to the position where $x = 7\text{ cm}$.

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

[Total: 10]

- 7 (a) An ideal operational amplifier (op-amp) has infinite bandwidth and zero output impedance.

State what is meant by:

- (i) *infinite bandwidth*

.....
 [1]

- (ii) *zero output impedance.*

.....
 [1]

- (b) The circuit for a non-inverting amplifier incorporating an ideal op-amp is shown in Fig. 7.1.

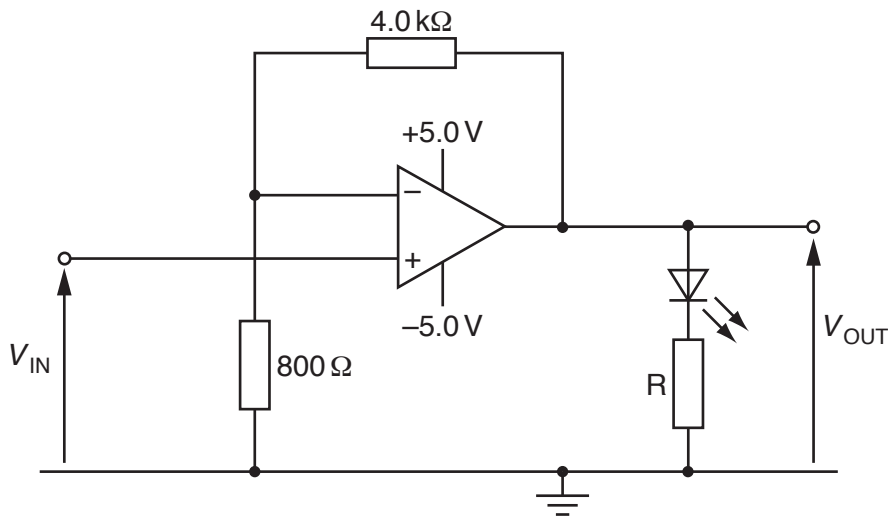


Fig. 7.1

The light-emitting diode (LED) emits light when the potential difference across it is at least 2.0 V.

The current in the LED must not be greater than 20 mA.

- (i) Calculate the gain of the amplifier circuit.

gain = ... [2]

- (ii) Determine the value of V_{IN} for which the value of V_{OUT} is +2.0 V.

$$V_{IN} = \dots\dots\dots \text{ V [1]}$$

- (iii) State the maximum value of the output potential V_{OUT} .

$$\text{maximum potential} = \dots\dots\dots \text{ V [1]}$$

- (iv) When the op-amp is saturated, the potential difference across the LED is 2.2 V.

Calculate the minimum resistance of resistor R so that the current in the LED is limited to 20 mA.

$$\text{resistance} = \dots\dots\dots \Omega \text{ [2]}$$

[Total: 8]

- 8 (a) A long straight vertical wire carries a current I . The wire passes through a horizontal card EFGH, as shown in Fig. 8.1 and Fig. 8.2.

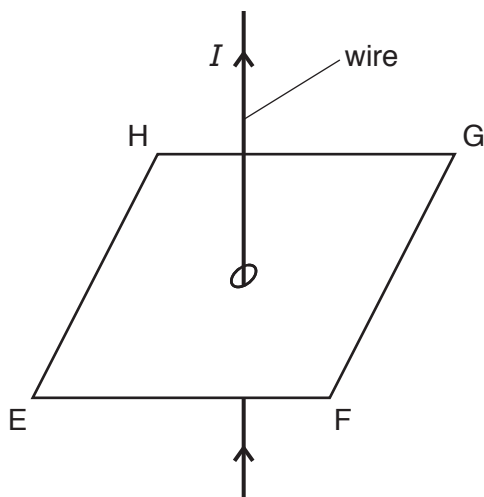


Fig. 8.1

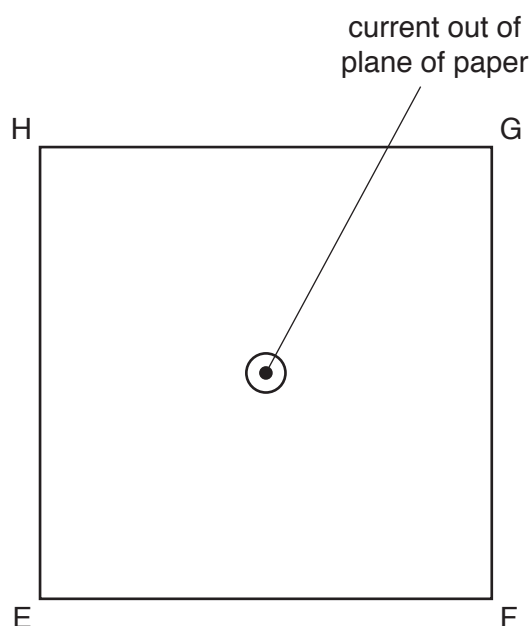


Fig. 8.2 (view from above)

On Fig. 8.2, draw the pattern of the magnetic field produced by the current-carrying wire on the plane EFGH. [3]

- (b) Two long straight parallel wires P and Q are situated a distance 3.1 cm apart, as illustrated in Fig. 8.3.

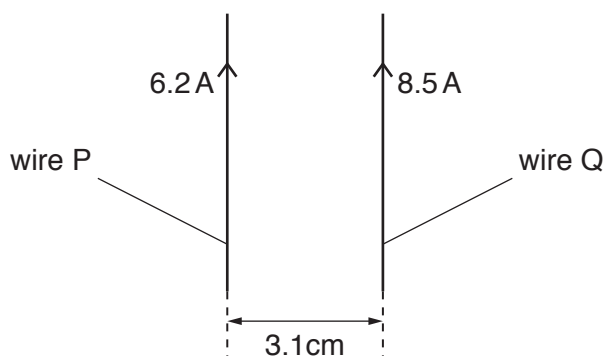


Fig. 8.3

The current in wire P is 6.2 A. The current in wire Q is 8.5 A.

The magnetic flux density B at a distance x from a long straight wire carrying current I is given by the expression

$$B = \frac{\mu_0 I}{2\pi x}$$

where μ_0 is the permeability of free space.

Calculate:

- (i) the magnetic flux density at wire Q due to the current in wire P

flux density = ... T [2]

- (ii) the force per unit length, in N m^{-1} , acting on wire Q due to the current in wire P.

force per unit length = ... N m^{-1} [2]

- (c) The currents in wires P and Q are different in magnitude.

State and explain whether the forces per unit length on the two wires will be different.

.....

 [2]

[Total: 9]

- 9 Diagnosis using nuclear magnetic resonance imaging (NMRI) requires the use of a non-uniform magnetic field superimposed on a constant magnetic field of large magnitude.

Explain the purpose of:

- (a) the large constant magnetic field

.....

.....

.....

.....

..... [2]

- (b) the non-uniform magnetic field.

.....

.....

.....

.....

..... [2]

[Total: 4]

10 A bridge rectifier using four ideal diodes is shown in Fig. 10.1.

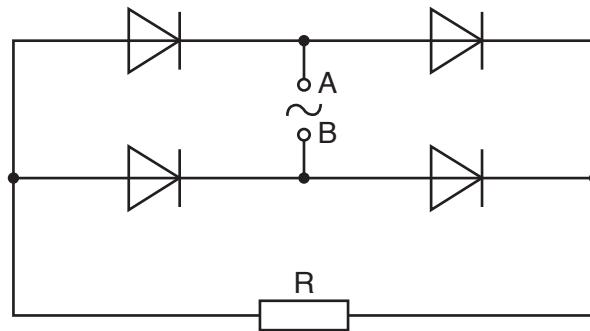


Fig. 10.1

The sinusoidal alternating electromotive force (e.m.f.) applied between points A and B has a root-mean-square (r.m.s.) value of 7.0 V.

- (a) (i) On Fig. 10.1, circle the diodes that conduct when point B is positive with respect to point A. [1]
- (ii) Calculate the maximum potential difference V_{MAX} across resistor R.

$$V_{\text{MAX}} = \dots\dots\dots \text{ V [1]}$$

- (b) A capacitor is connected into the circuit to produce smoothing of the potential difference across resistor R.

The variation with time t of the potential difference V across resistor R is shown in Fig. 10.2.

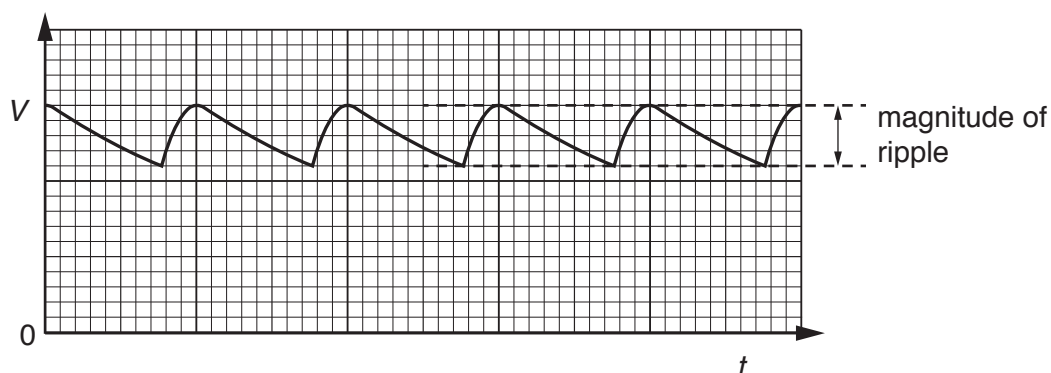


Fig. 10.2

- (i) On Fig. 10.1, draw the symbol for a capacitor, connected so as to produce smoothing. [1]

- (ii) State the effect, if any, on the magnitude of the ripple on V when, separately:

1. a capacitor of larger capacitance is used

.....

2. the resistor R has a smaller resistance.

.....

[2]

[Total: 5]

- 11 (a) With reference to the photoelectric effect, state what is meant by *work function energy*.

.....

.....

..... [2]

- (b) The work function energy of a clean metal surface is $5.5 \times 10^{-19} \text{ J}$.

Electromagnetic radiation of wavelength 280 nm is incident on the metal surface. The metal is in a vacuum.

- (i) Calculate:

1. the photon energy

photon energy = ... J [2]

2. the maximum speed v_{MAX} of the electrons emitted from the surface.

$v_{\text{MAX}} = \dots \text{ ms}^{-1}$ [3]

- (ii) Explain why most of the emitted electrons will have a speed lower than v_{MAX} .

.....

..... [1]

- (c) The electromagnetic radiation incident on the metal surface may change in intensity or in frequency.

Complete Fig. 11.1 by inserting either '*increases*' or '*decreases*' or '*no change*' to describe the effects of the changes shown on the maximum speed and on the rate of emission of electrons.

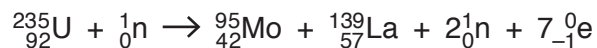
change	maximum speed of electrons	rate of emission of electrons
reduced intensity at constant frequency		
increased frequency at constant intensity		

Fig. 11.1

[4]

[Total: 12]

12 One possible nuclear reaction that takes place is



Data for nuclei in this reaction are given in Fig. 12.1.

nucleus	mass/u	total mass of separate nucleons/u	mass defect/u	binding energy per nucleon/MeV
${}_{42}^{95}\text{Mo}$	94.906	95.765	0.859	8.443
${}_{57}^{139}\text{La}$	138.906	140.125	1.219	8.189
${}_{92}^{235}\text{U}$	235.044	236.909	1.865	

Fig. 12.1

(a) Show that the energy equivalent to a mass of 1.00 u is 934 MeV.

[2]

(b) (i) Use data from Fig. 12.1 to calculate the binding energy per nucleon of a nucleus of uranium-235 (${}_{92}^{235}\text{U}$). Complete Fig. 12.1.

[2]

(ii) The nucleon number of an isotope of the element rutherfordium is 267.

State whether the binding energy per nucleon of this isotope will be greater than, equal to or less than the binding energy per nucleon of uranium-235.

..... [1]

- (c) Calculate the total energy, in MeV, released in this nuclear reaction.

energy = ... MeV [2]

- (d) The nuclei in 1.2×10^{-7} mol of uranium-235 all undergo this reaction in a time of 25 ms.

Calculate the average power release during the time of 25 ms.

power = ... W [3]

[Total: 10]

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gravitational potential

$$\phi = -\frac{Gm}{r}$$

hydrostatic pressure

$$p = \rho gh$$

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.

$$v = v_0 \cos \omega t$$

$$v = \pm \omega \sqrt{(x_0^2 - x^2)}$$

Doppler effect

$$f_o = \frac{f_s v}{v \pm v_s}$$

electric potential

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

capacitors in series

$$1/C = 1/C_1 + 1/C_2 + \dots$$

capacitors in parallel

$$C = C_1 + C_2 + \dots$$

energy of charged capacitor

$$W = \frac{1}{2} QV$$

electric current

$$I = Anvq$$

resistors in series

$$R = R_1 + R_2 + \dots$$

resistors in parallel

$$1/R = 1/R_1 + 1/R_2 + \dots$$

Hall voltage

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

alternating current/voltage

$$x = x_0 \sin \omega t$$

radioactive decay

$$x = x_0 \exp(-\lambda t)$$

decay constant

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$$

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

- 1 (a) State Newton's law of gravitation.

.....

.....

..... [2]

- (b) The astronomer Johannes Kepler showed that the period T of rotation of a planet about the Sun is related to its mean distance R from the centre of the Sun by the expression

$$\frac{R^3}{T^2} = k$$

where k is a constant.

Use Newton's law to show that, for planets in circular orbits about the Sun of mass M , the constant k is given by

$$k = \frac{GM}{4\pi^2}$$

where G is the gravitational constant. Explain your working.

[4]

- (c) A satellite is in a circular orbit about Mars.
The radius of the orbit of the satellite is 4.38×10^6 m. The orbital period is 2.44 hours.

Use the expressions in (b) to calculate a value for the mass of Mars.

mass = ... kg [2]

[Total: 8]

- 2 (a) Smoke particles are suspended in still air. Brownian motion of the smoke particles is seen through a microscope.

Describe:

- (i) what is seen through the microscope

.....
 [1]

- (ii) how Brownian motion provides evidence for the nature of the movement of gas molecules.

.....

 [2]

- (b) A fixed mass of an ideal gas has volume $2.40 \times 10^3 \text{ cm}^3$ at pressure $3.51 \times 10^5 \text{ Pa}$ and temperature 290 K. The gas is heated at constant volume until the temperature is 310 K at pressure $3.75 \times 10^5 \text{ Pa}$, as illustrated in Fig. 2.1.

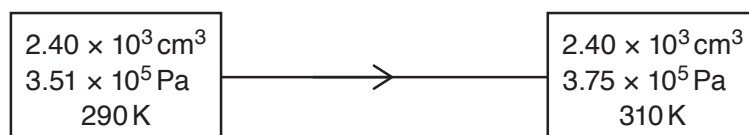


Fig. 2.1

The quantity of thermal energy required to raise the temperature of 1.00 mol of the gas by 1.00 K at constant volume is 12.5 J.

Calculate, to three significant figures:

- (i) the amount, in mol, of the gas

amount = ... mol [3]

- (ii) the thermal energy transfer during the change.

energy transfer = ... J [2]

- (c) For the change in the gas in (b), state:

- (i) the quantity of external work done on the gas

work done = ... J [1]

- (ii) the change in internal energy, with the direction of this change.

change = ... J

direction [2]

[Total: 11]

- 3 (a) State what is meant by *specific latent heat*.

.....

.....

..... [2]

- (b) A student uses the apparatus illustrated in Fig. 3.1 to determine a value for the specific latent heat of fusion of ice.

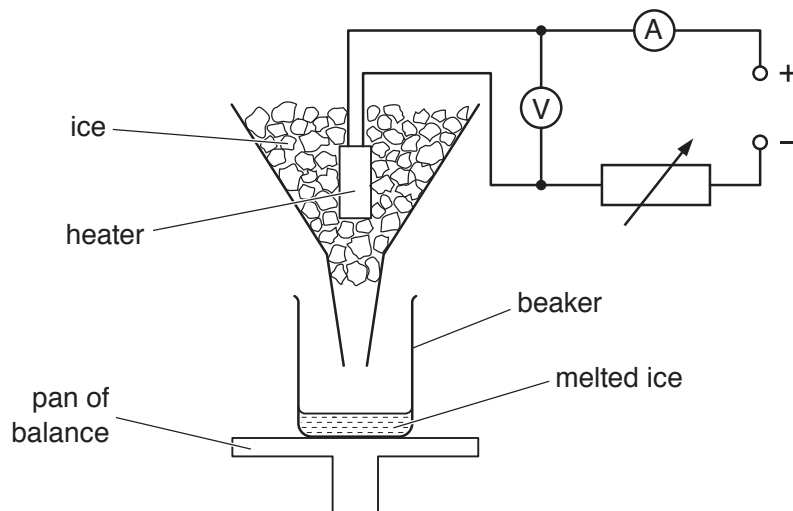


Fig. 3.1

The balance reading measures the mass of the beaker and the melted ice (water) in the beaker.

The heater is switched on and pieces of ice at 0°C are added continuously to the funnel so that the heater is always surrounded by ice.

When water drips out of the funnel at a constant rate, the balance reading is noted at 2.0 minute intervals. After 10 minutes, the current in the heater is increased and the balance readings are taken for a further 12 minutes.

The variation with time of the balance reading is shown in Fig. 3.2.

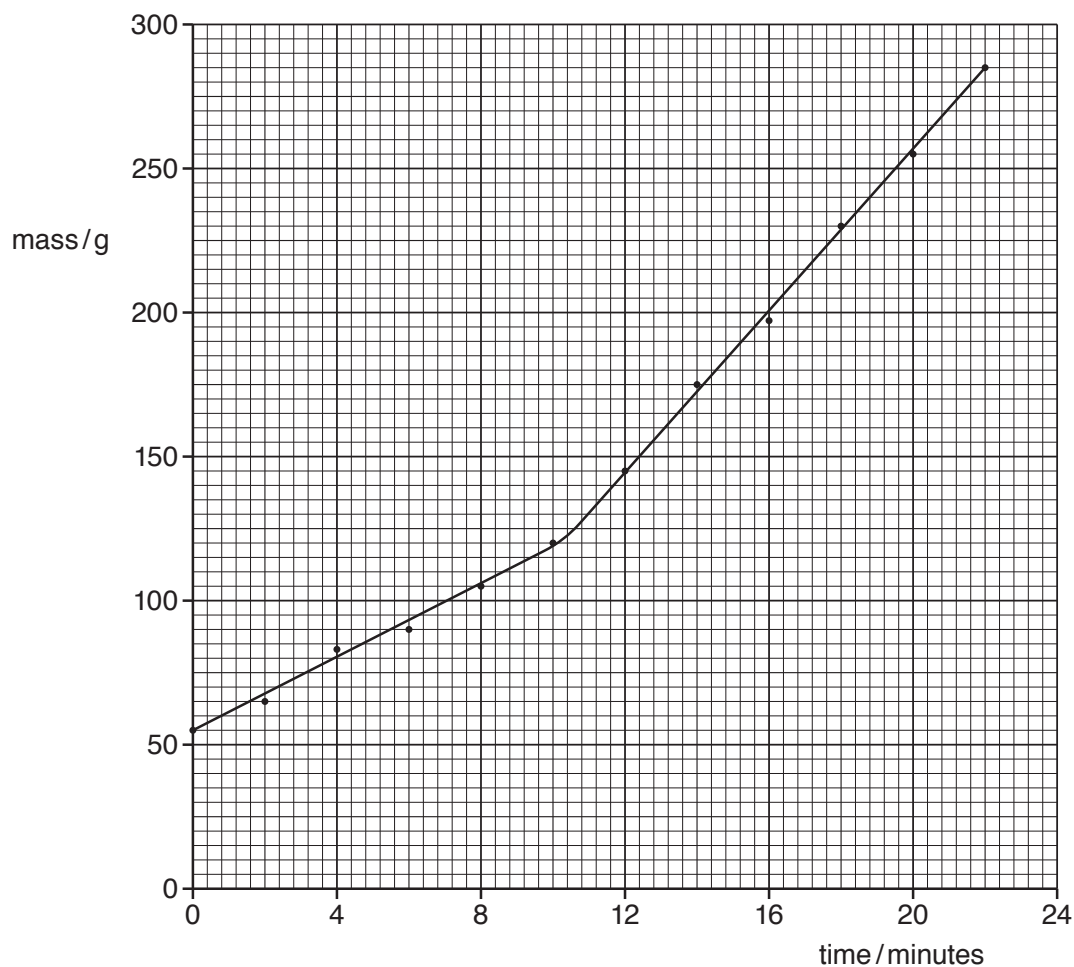


Fig. 3.2

The readings of the ammeter and of the voltmeter are shown in Fig. 3.3.

	ammeter reading /A	voltmeter reading /V
from time 0 to time 10 minutes	1.8	7.3
after time 10 minutes	3.6	15.1

Fig. 3.3

- (i) From time 0 to time 10.0 minutes, 65 g of ice is melted.

Use Fig. 3.2 to determine the mass of ice melted from time 12.0 minutes to time 22.0 minutes.

mass = ... g [1]

- (ii) Explain why, although the power of the heater is changed, the rate at which thermal energy is transferred from the surroundings to the ice is constant.

.....

..... [1]

- (iii) Determine a value for the specific latent heat of fusion L of ice.

$L = \dots\dots\dots \text{Jg}^{-1}$ [4]

- (iv) Calculate the rate at which thermal energy is transferred from the surroundings to the ice.

rate = ... W [2]

[Total: 10]

- 4 A ball of mass M is held on a horizontal surface by two identical extended springs, as illustrated in Fig. 4.1.

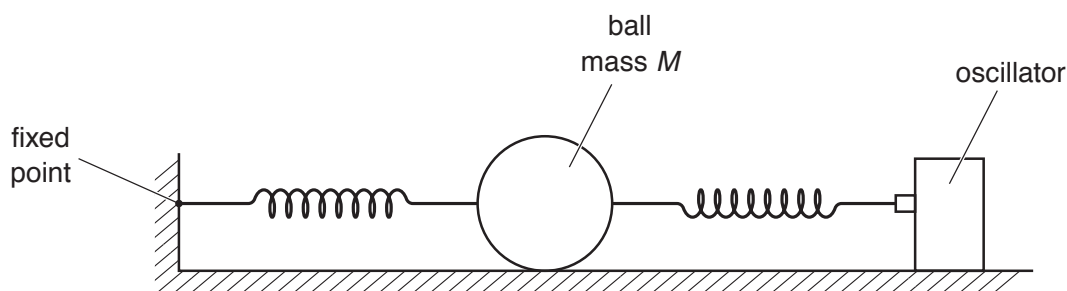


Fig. 4.1

One spring is attached to a fixed point. The other spring is attached to an oscillator.

The oscillator is switched off. The ball is displaced sideways along the axis of the springs and is then released. The variation with time t of the displacement x of the ball is shown in Fig. 4.2.

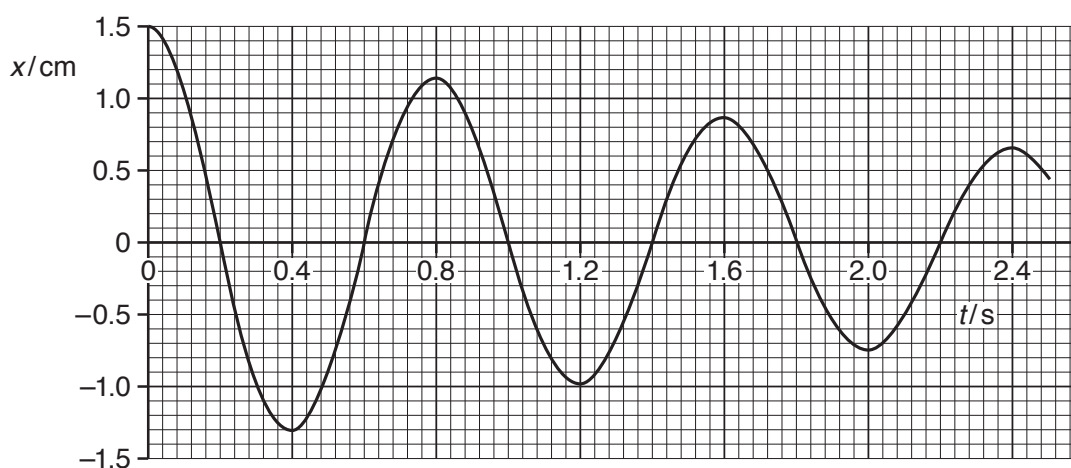


Fig. 4.2

(a) State:

- (i) what is meant by *damping*

.....
 [1]

- (ii) the evidence provided by Fig. 4.2 that the motion of the ball is damped.

.....
 [1]

- (b) The acceleration a and the displacement x of the ball are related by the expression

$$a = -\left(\frac{2k}{M}\right)x$$

where k is the spring constant of one of the springs.

The mass M of the ball is 1.2 kg.

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

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

- (ii) Use your answer in (i) to determine the value of k .

$$k = \dots\dots\dots \text{Nm}^{-1} \quad [2]$$

- (c) The oscillator is switched on. The amplitude of oscillation of the oscillator is constant.

The angular frequency of the oscillations is gradually increased from 0.7ω to 1.3ω , where ω is the angular frequency calculated in (b)(i).

- (i) On the axes of Fig. 4.3, show the variation with angular frequency of the amplitude A of oscillation of the ball.

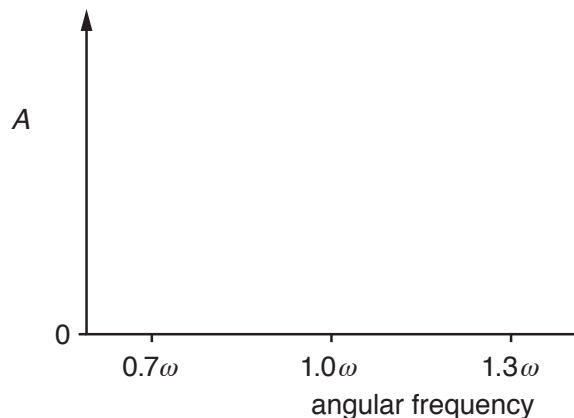


Fig. 4.3

[2]

- (ii) Some sand is now sprinkled on the horizontal surface.

The angular frequency of the oscillations is again gradually increased from 0.7ω to 1.3ω .

State **two** changes that occur to the line you have drawn on Fig. 4.3.

1.

.....

2.

.....

[2]

[Total: 10]

- 5 (a) (i) State what is meant by the *specific acoustic impedance* of a medium.

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

- (ii) The density of a sample of bone is 1.8 g cm^{-3} and the speed of ultrasound in the bone is $4.1 \times 10^3 \text{ m s}^{-1}$.

Calculate the specific acoustic impedance Z_B of the sample of bone.

$$Z_B = \dots\dots\dots \text{ kg m}^{-2} \text{ s}^{-1} \quad [1]$$

- (b) A parallel beam of ultrasound passes normally through a layer of fat and of muscle, as illustrated in Fig. 5.1.

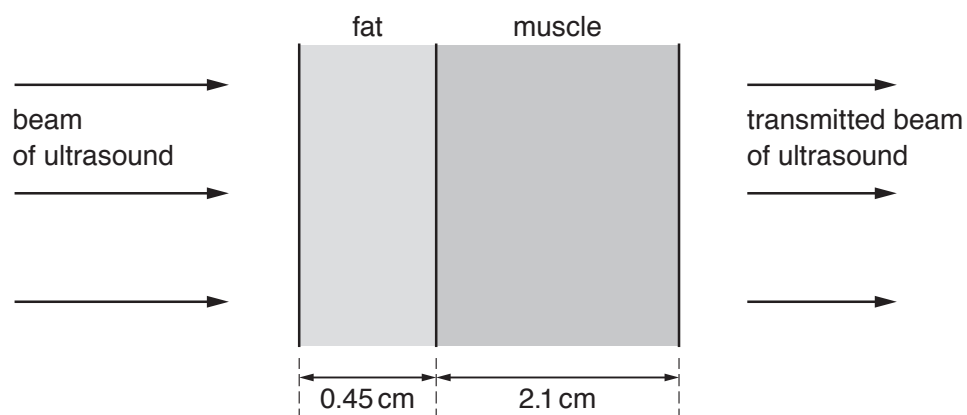


Fig. 5.1 (not to scale)

The fat has thickness 0.45 cm and the muscle has thickness 2.1 cm.

Data for fat and for muscle are given in Fig. 5.2.

	specific acoustic impedance $Z/10^6 \text{ kg m}^{-2} \text{ s}^{-1}$	linear attenuation (absorption) coefficient μ/cm^{-1}
fat	1.3	0.24
muscle	1.7	0.23

Fig. 5.2

The intensity reflection coefficient α at a boundary between two media of specific acoustic impedances Z_1 and Z_2 is given by the expression

$$\alpha = \frac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}.$$

Calculate the fraction of the intensity of the ultrasound that is **transmitted** through the boundary between the fat and the muscle.

fraction transmitted = ... [1]

- (c) (i) State what is meant by *attenuation* of an ultrasound wave.

.....

.....

..... [2]

- (ii) Data for linear attenuation coefficients are given in Fig. 5.2.

Determine the ratio

$$\frac{\text{intensity of ultrasound transmitted through the medium}}{\text{intensity of ultrasound entering the medium}}$$

for:

1. the layer of fat of thickness 0.45 cm

ratio = ...

2. the layer of muscle of thickness 2.1 cm.

ratio = ... [3]

- (d) Use your answers in (b) and (c)(ii) to determine the fraction of the intensity entering the layer of fat that is transmitted through the layer of muscle.

fraction transmitted = ... [1]

[Total: 10]

- 6 The variation with time of the displacement of an amplitude-modulated (AM) wave is shown in Fig. 6.1.

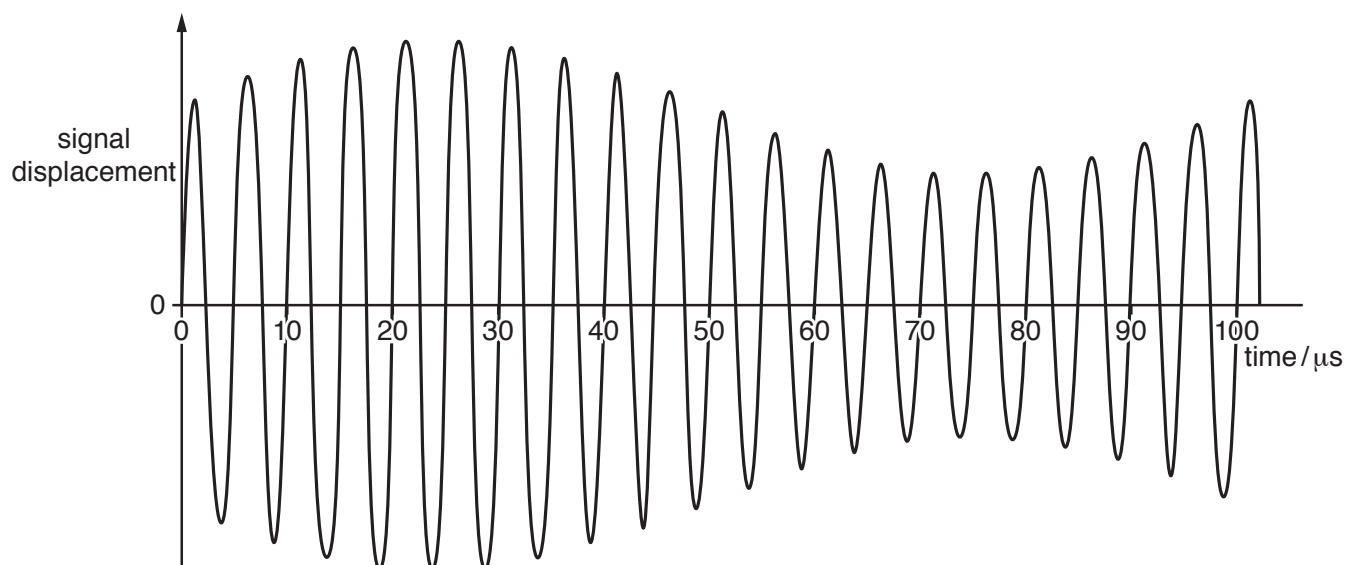


Fig. 6.1

The sinusoidal information signal has frequency 10 kHz.

- (a) Determine the frequency of the carrier wave.

frequency = ... Hz [1]

- (b) On the axes of Fig. 6.2, sketch the frequency spectrum of the modulated wave.

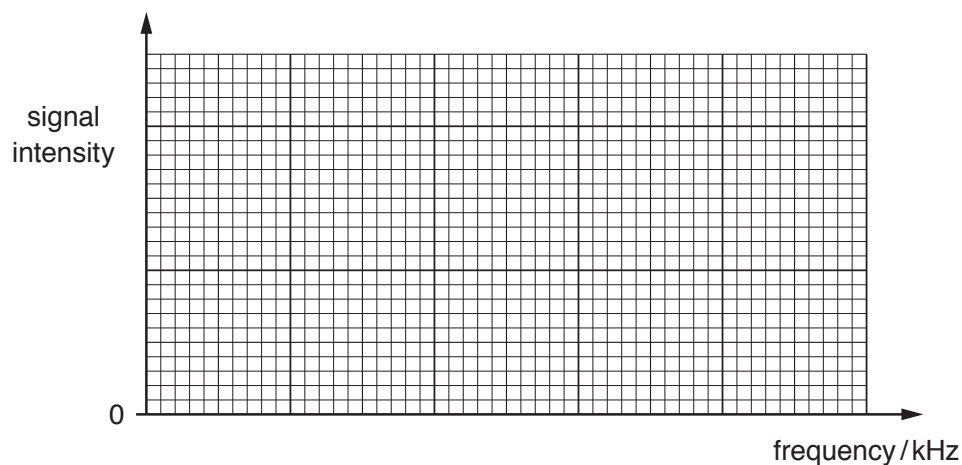


Fig. 6.2

[3]

[Total: 4]

7 Describe the principles of computed tomography (CT) scanning.

.....

.....

.....

.....

.....

.....

.....

..... [5]

- 8 Electrons enter a rectangular slice PQRSEFGH of a semiconductor material at right-angles to face PQFE, as shown in Fig. 8.1.

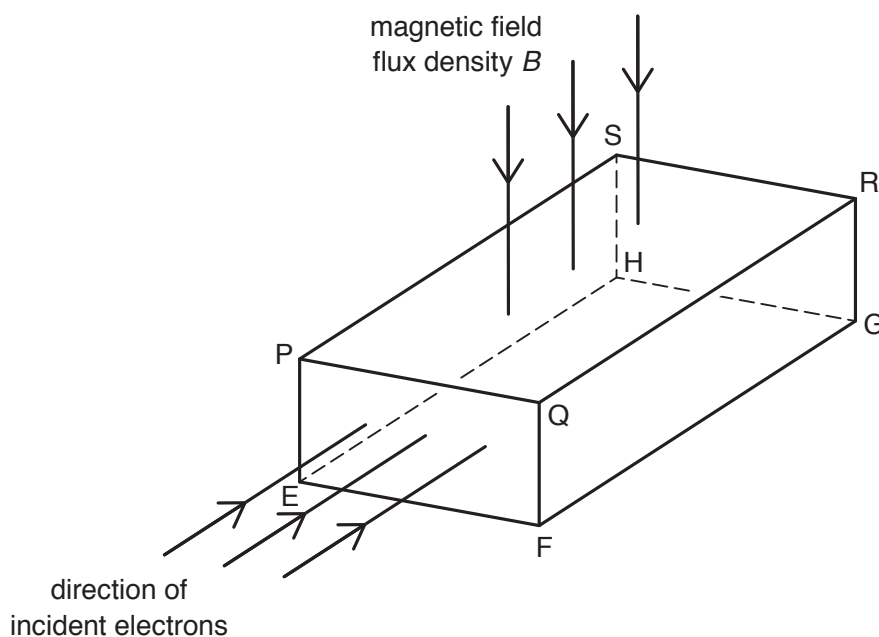


Fig. 8.1

A uniform magnetic field of flux density B is directed into the slice, at right-angles to face PQRS.

- (a) The electrons each have charge $-q$ and drift speed v in the slice.

State the magnitude and the direction of the force due to the magnetic field on each electron as it enters the slice.

.....

 [2]

- (b) The force on the electrons causes a voltage V_H to be established across the semiconductor slice given by the expression

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

where I is the current in the slice.

- (i) State the two faces between which the voltage V_H is established.

face and face [1]

- (ii) Use letters from Fig. 8.1 to identify the distance t .

..... [1]

(c) Aluminium (${}^{27}_{13}\text{Al}$) has a density of 2.7 g cm^{-3} . Assume that there is one free electron available to carry charge per atom of aluminium.

(i) Show that the number of charge carriers per unit volume in aluminium is $6.0 \times 10^{28}\text{ m}^{-3}$.

[2]

(ii) A sample of aluminium foil has a thickness of 0.090 mm . The current in the foil is 4.6 A .

A uniform magnetic field of flux density 0.15 T acts at right-angles to the foil.

Use the value in (i) to calculate the voltage V_H that is generated.

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

[Total: 8]

- 9 (a) Define what is meant by *electric potential* at a point.

.....

.....

..... [2]

- (b) In an α -particle scattering experiment, α -particles are directed towards a thin film of gold, as illustrated in Fig. 9.1.

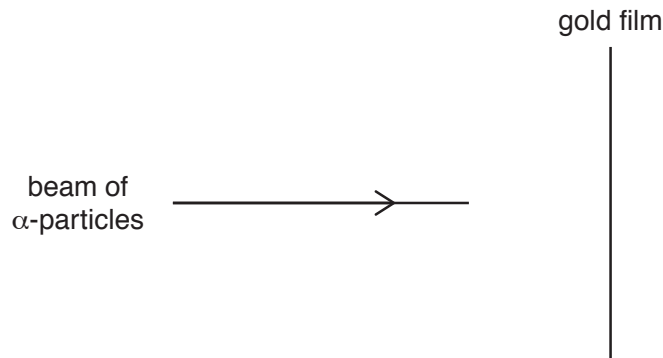


Fig. 9.1

The apparatus is in a vacuum.

The gold-197 ($^{197}_{79}\text{Au}$) nuclei in the film may be considered to be fixed point charges.

The α -particles emitted from the source each have an energy of 4.8 MeV.

Calculate:

- (i) the initial kinetic energy E_K , in J, of an α -particle emitted from the source

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

- (ii) the distance d of closest approach of an α -particle to a gold nucleus.

$d = \dots\dots\dots$ m [4]

- (c) Use your answer in (b)(ii) to comment on the possible diameter of a gold nucleus.

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

[Total: 8]

- 10 (a) The upper electron energy bands in an intrinsic semiconductor material are illustrated in Fig. 10.1.

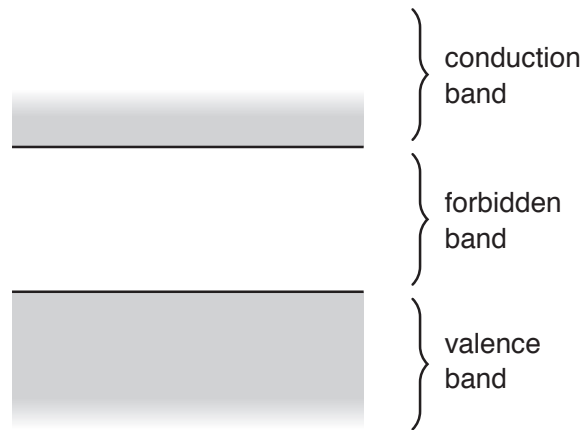


Fig. 10.1

Use band theory to explain why the resistance of an intrinsic semiconductor material decreases as its temperature increases.

.....

.....

.....

.....

.....

.....

.....

..... [4]

- (b) A comparator circuit incorporating an ideal operational amplifier (op-amp) is shown in Fig. 10.2.

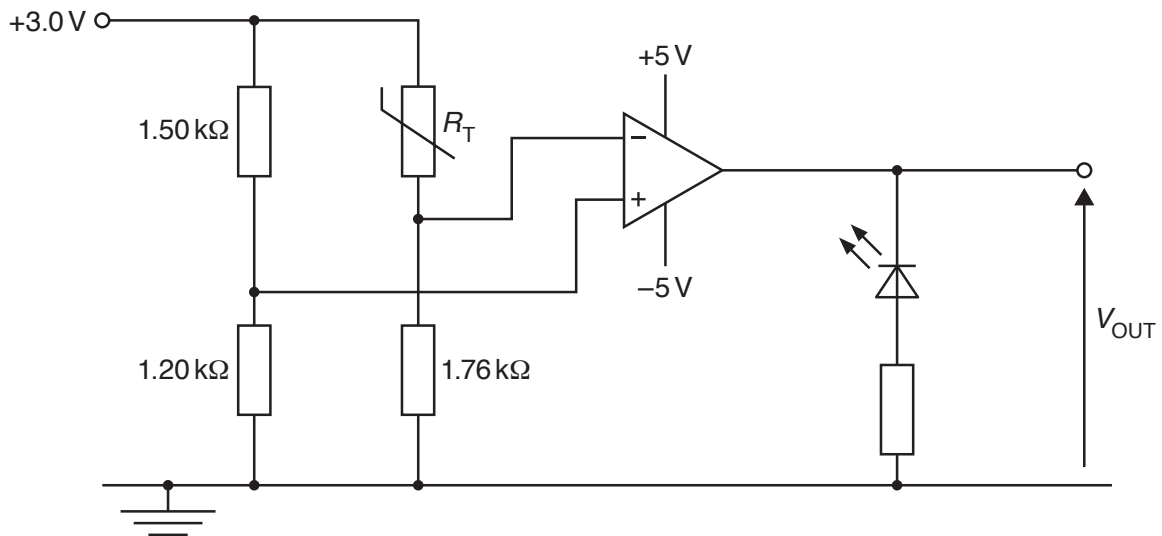


Fig. 10.2

The variation with temperature θ of the resistance R_T of the thermistor is shown in Fig. 10.3.

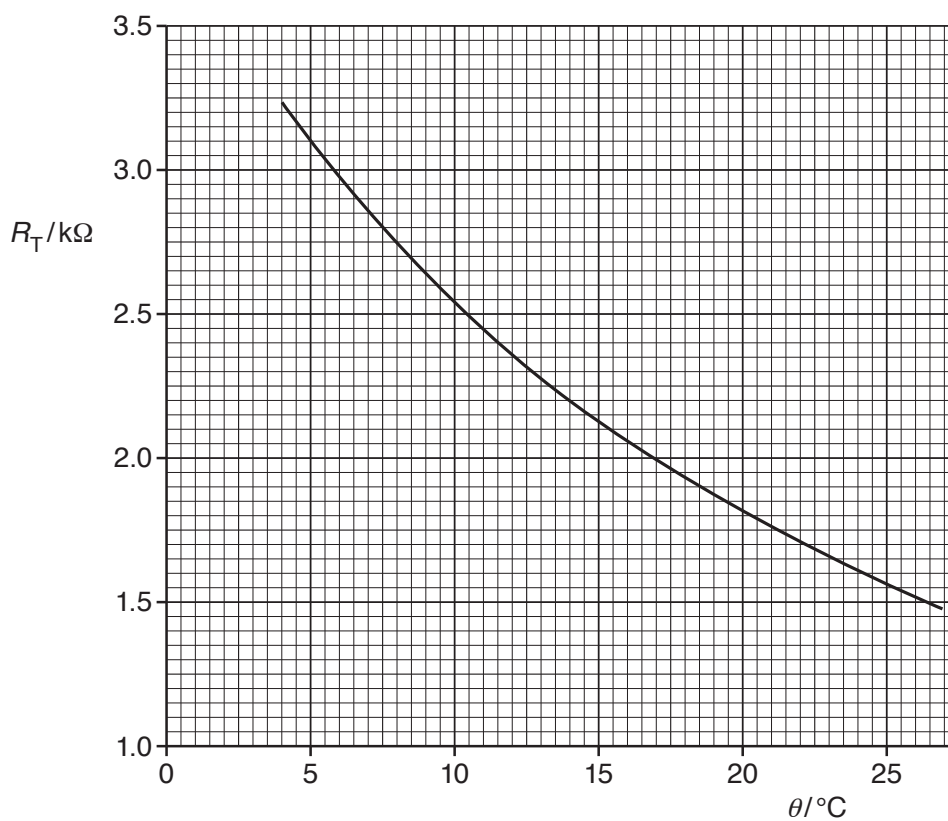


Fig. 10.3

- (i) Determine the temperature at which the light-emitting diode (LED) in Fig. 10.2 switches on or off.

temperature = ... °C [4]

- (ii) State and explain whether the thermistor is above or below the temperature calculated in (i) for the LED to emit light.

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

[Total: 11]

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

.....

.....

..... [2]

(b) A solenoid S has a small coil C placed near to one of its ends, as shown in Fig. 11.1.

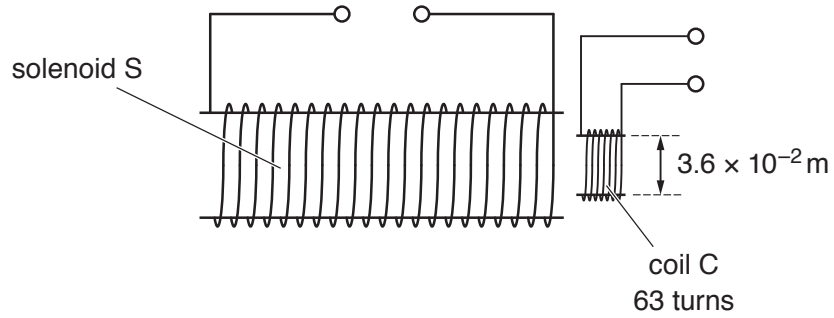


Fig. 11.1

The coil C has a circular cross-section of diameter $3.6 \times 10^{-2} \text{ m}$ and contains 63 turns of wire.

The solenoid S produces a uniform magnetic field of flux density B , in tesla, in the region of coil C given by the expression

$$B = 9.4 \times 10^{-4} I$$

where I is the current, in ampere, in the solenoid S.

The variation with time t of the current I in solenoid S is shown in Fig. 11.2.

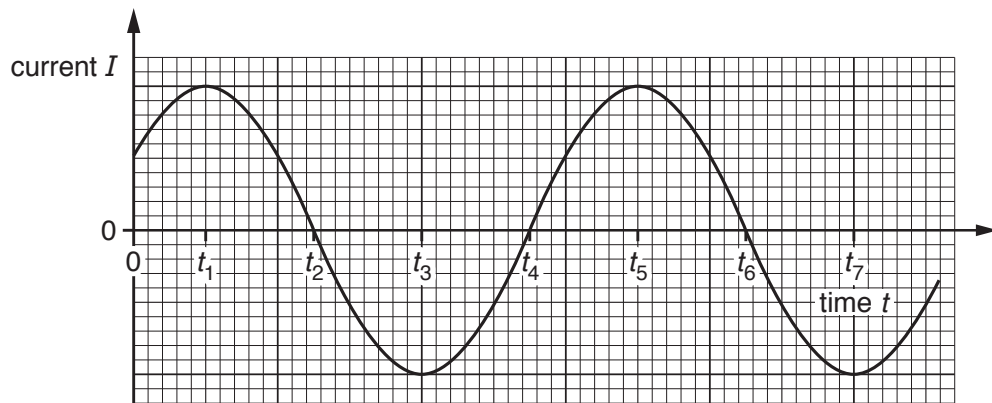


Fig. 11.2

State two times at which:

- (i) there is no electromotive force (e.m.f.) induced in coil C

time and time [1]

- (ii) the induced e.m.f. in coil C is a maximum but with opposite polarities.

time and time [1]

- (c) The alternating current in the solenoid S in (b) is replaced by a constant current of 5.0 A.

Calculate the average e.m.f. induced in coil C when the current in solenoid S is reversed in a time of 6.0 ms.

e.m.f. induced = ... V [3]

[Total: 7]

- 12 Radon-222 ($^{222}_{86}\text{Ra}$) is a radioactive gas that decays randomly with a decay constant of $7.55 \times 10^{-3} \text{ hour}^{-1}$.

(a) State what is meant by:

(i) *random decay*

.....
 [1]

(ii) *decay constant.*

.....

 [2]

(b) The activity of radon gas in a sample of $4.80 \times 10^{-3} \text{ m}^3$ of air taken from a building is 0.600 Bq.

There are 2.52×10^{25} air molecules in a volume of 1.00 m^3 of air.

Calculate, for 1.00 m^3 of the air, the ratio

$$\frac{\text{number of air molecules}}{\text{number of radon atoms}}$$

ratio = ... [5]

[Total: 8]

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PHYSICS

9702/43

Paper 4 A Level Structured Questions

October/November 2019

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your centre number, candidate number and name on all the work you hand in.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

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

DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.

You may lose marks if you do not show your working or if you do not use appropriate units.

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

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

This document consists of **25** printed pages and **3** blank pages.

Data

speed of light in free space	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$
permittivity of free space	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall	$g = 9.81 \text{ m s}^{-2}$

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
hydrostatic pressure	$p = \rho gh$
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.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \dots$
capacitors in parallel	$C = C_1 + C_2 + \dots$
energy of charged capacitor	$W = \frac{1}{2} QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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

- 1 (a) State Newton's law of gravitation.

.....

.....

..... [2]

- (b) A geostationary satellite orbits the Earth. The orbit of the satellite is circular and the period of the orbit is 24 hours.

- (i) State **two** other features of this orbit.

1.

.....

2.

..... [2]

- (ii) The radius of the orbit of the satellite is 4.23×10^4 km.

Determine a value for the mass of the Earth. Explain your working.

mass = ... kg [4]

[Total: 8]

- 2 (a) The kinetic theory of gases is based on a number of assumptions about the molecules of a gas.

State the assumption that is related to the volume of the molecules of the gas.

.....

 [2]

- (b) An ideal gas occupies a volume of $2.40 \times 10^{-2} \text{ m}^3$ at a pressure of $4.60 \times 10^5 \text{ Pa}$ and a temperature of 23°C .

- (i) Calculate the number of molecules in the gas.

number = ... [3]

- (ii) Each molecule has a diameter of approximately $3 \times 10^{-10} \text{ m}$.

Estimate the total volume of the gas molecules.

volume = ... m^3 [3]

- (c) By reference to your answer in (b)(ii), suggest why the assumption in (a) is justified.

.....
 [1]

[Total: 9]

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- 3 (a) State what is meant by *specific latent heat*.

.....

.....

..... [2]

- (b) A student determines the specific latent heat of vaporisation of a liquid using the apparatus illustrated in Fig. 3.1.

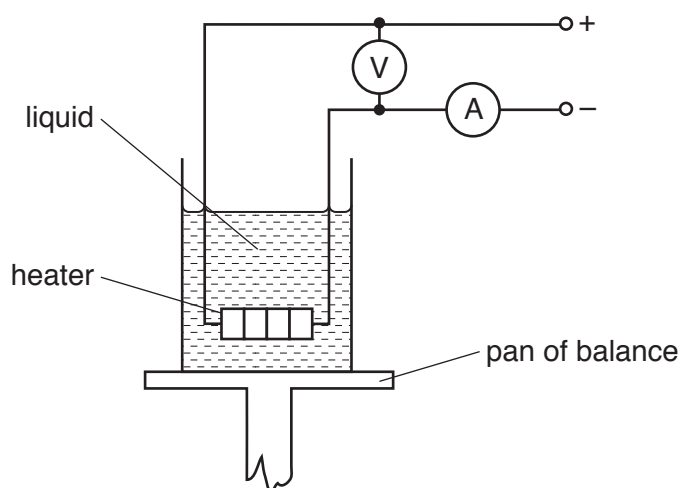


Fig. 3.1

The heater is switched on. When the liquid is boiling at a constant rate, the balance reading is noted at 2.0 minute intervals.

After 10 minutes, the current in the heater is reduced and the balance readings are taken for a further 12 minutes.

The readings of the ammeter and of the voltmeter are given in Fig. 3.2.

	ammeter reading /A	voltmeter reading /V
from time 0 to time 10 minutes	1.2	230
after time 10 minutes	1.0	190

Fig. 3.2

The variation with time of the balance reading is shown in Fig. 3.3.

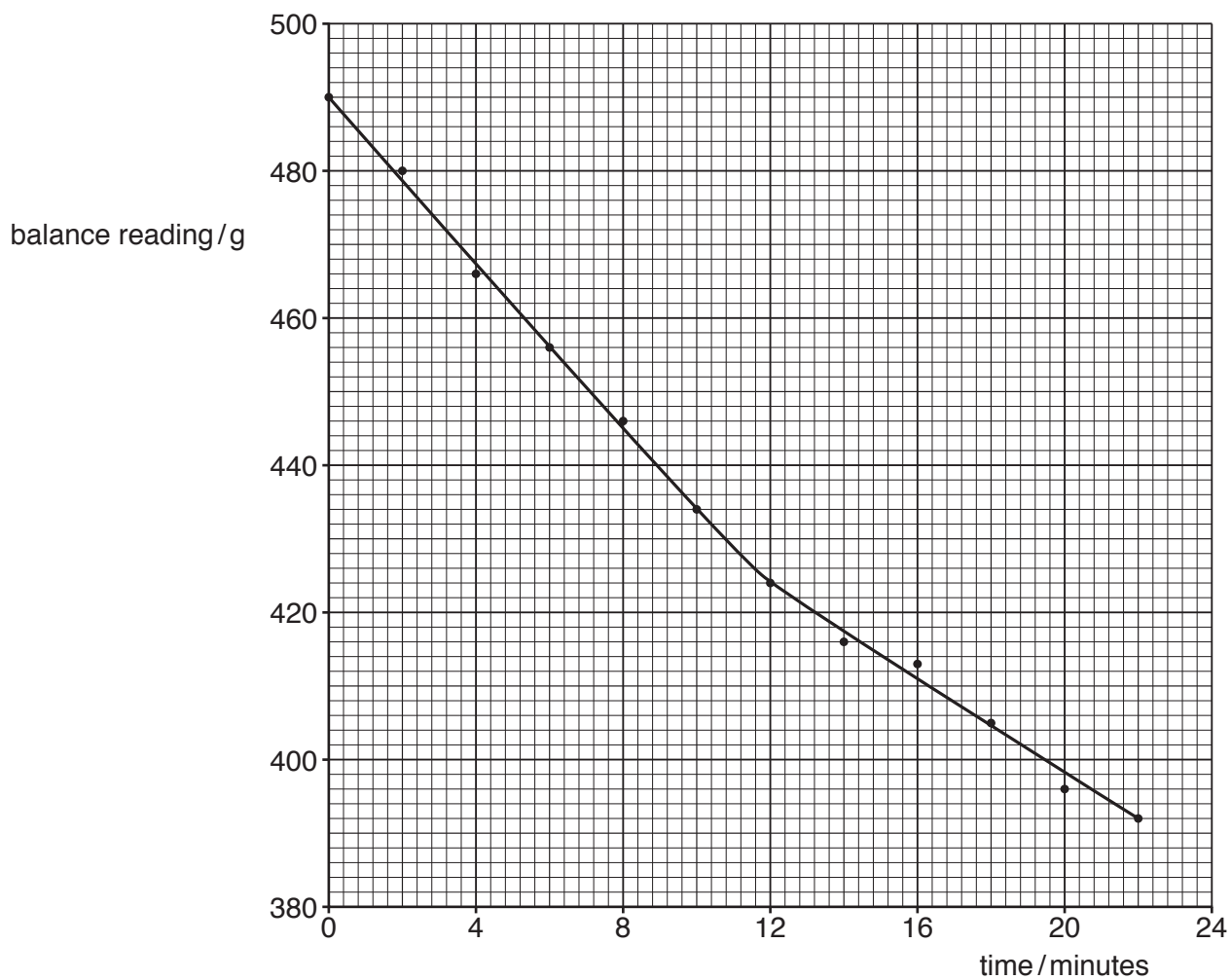


Fig. 3.3

- (i) From time 0 to time 10.0 minutes, the mass of liquid evaporated is 56 g.

Use Fig. 3.3 to determine the mass of liquid evaporated from time 12.0 minutes to time 22.0 minutes.

mass = ...g [1]

- (ii) Explain why, although the power of the heater is changed, the rate of loss of thermal energy to the surroundings may be assumed to be constant.

.....

..... [1]

- (iii) Determine a value for the specific latent heat of vaporisation L of the liquid.

$L = \dots\dots\dots \text{Jg}^{-1}$ [4]

- (iv) Calculate the rate at which thermal energy is transferred to the surroundings.

rate = ... W [2]

[Total: 10]

- 4 A mass is suspended vertically from a fixed point by means of a spring, as illustrated in Fig. 4.1.

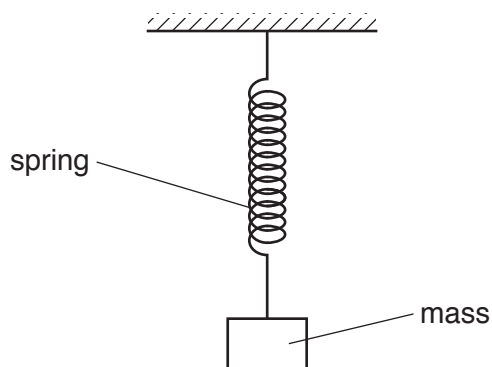


Fig. 4.1

The mass is oscillating vertically. The variation with displacement x of the acceleration a of the mass is shown in Fig. 4.2.

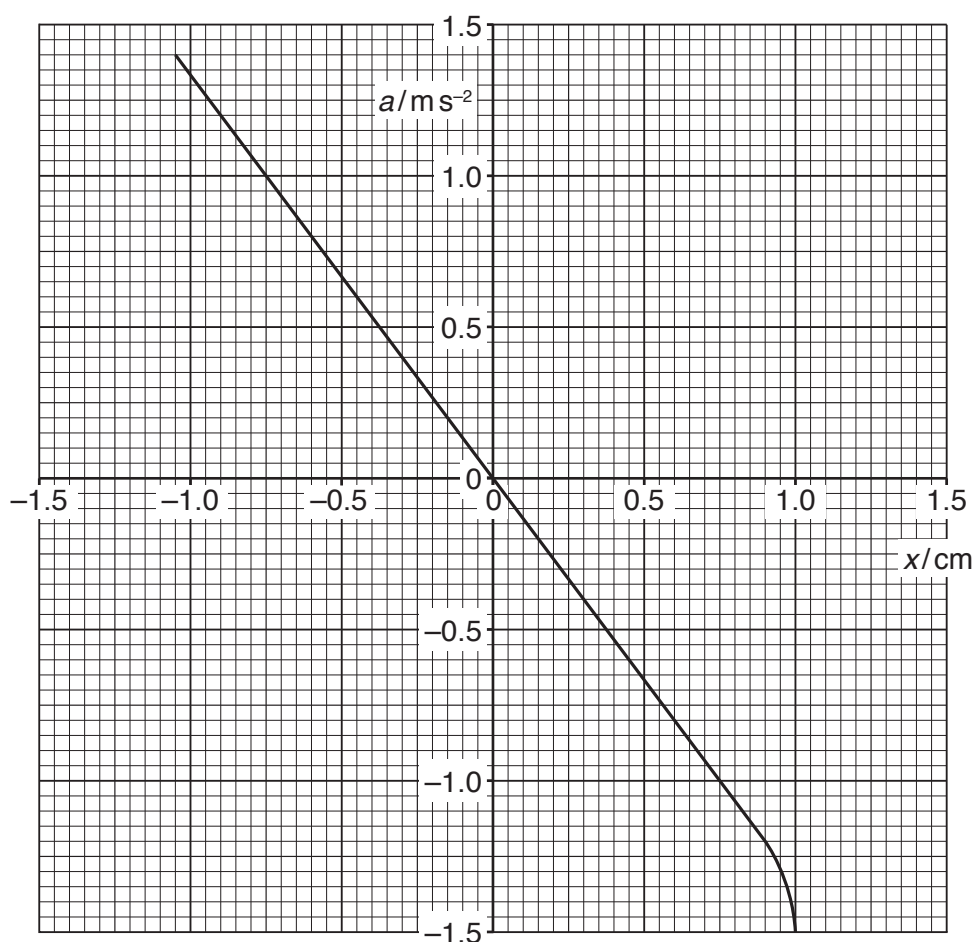


Fig. 4.2

- (a) (i) State what is meant by the *displacement* of the mass on the spring.

.....
 [1]

- (ii) Suggest how Fig. 4.2 shows that the mass is not performing simple harmonic motion.

.....
 [1]

- (b) (i) The amplitude of oscillation of the mass may be changed.

State the maximum amplitude x_0 for which the oscillations are simple harmonic.

$x_0 =$ cm [1]

- (ii) For the simple harmonic oscillations of the mass, use Fig. 4.2 to determine the frequency of the oscillations.

frequency = ... Hz [3]

- (c) The maximum speed of the mass when oscillating with simple harmonic motion of amplitude x_0 is v_0 .

On Fig. 4.3, show the variation with displacement x of the velocity v of the mass for displacements from $+x_0$ to $-x_0$.

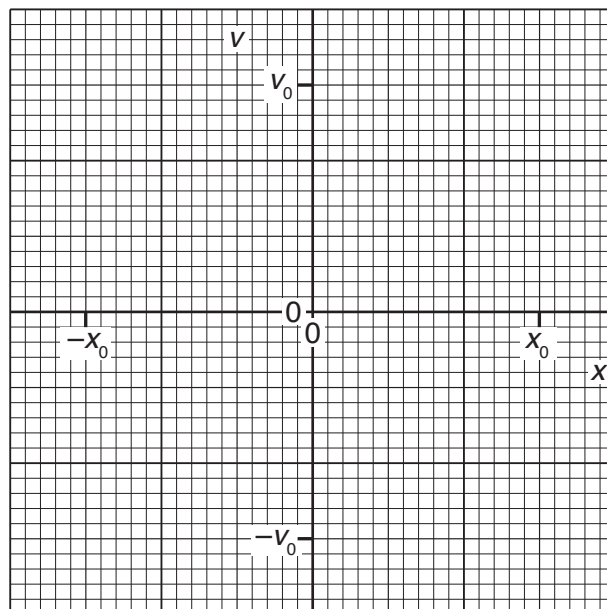


Fig. 4.3

[2]

[Total: 8]

- 5 (a) A section of a coaxial cable is shown in Fig. 5.1.

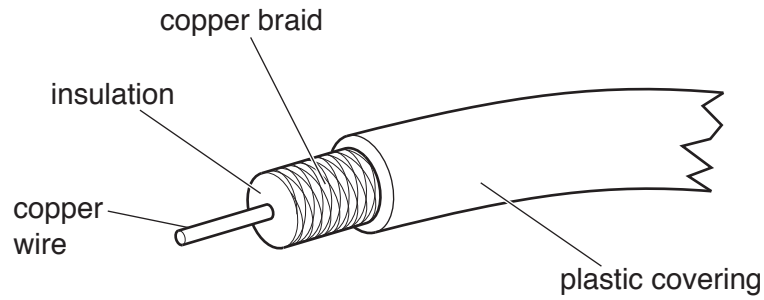


Fig. 5.1

- (i) Suggest **two** functions of the copper braid.

1.

.....

2.

.....

[2]

- (ii) Suggest **one** application of a coaxial cable for the transmission of electrical signals.

.....

..... [1]

- (b) (i) The constant noise power in a transmission cable is $7.6\mu\text{W}$. The minimum acceptable signal-to-noise ratio is 32 dB.

Calculate the minimum acceptable signal power P_{MIN} in the cable.

$$P_{\text{MIN}} = \dots\dots\dots\text{W} \quad [2]$$

- (ii) The input power of the signal to the transmission cable is 2.6 W. The attenuation per unit length of the cable is 6.3 dB km^{-1} .

Use your answer in (i) to determine the maximum uninterrupted length L of cable along which the signal may be transmitted.

$L = \dots\dots\dots \text{ km [2]}$

[Total: 7]

- 6 (a) State an expression for the electric field strength E at a distance r from a point charge Q in a vacuum.
State the name of any other symbol used.

.....

 [2]

- (b) Two point charges A and B are situated a distance 10.0 cm apart in a vacuum, as illustrated in Fig. 6.1.

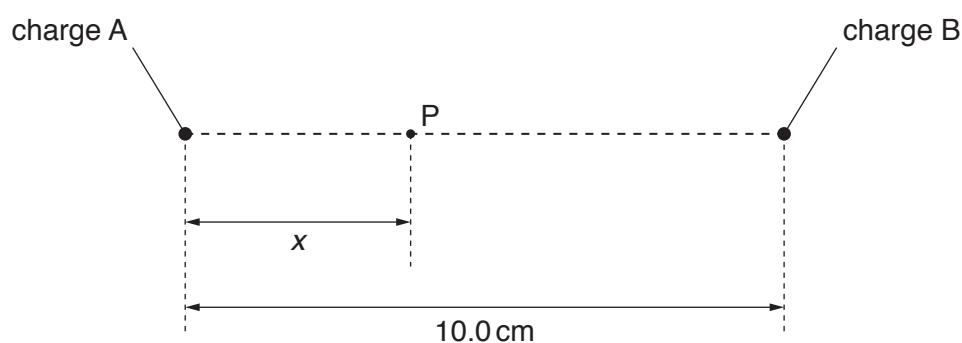


Fig. 6.1

A point P lies on the line joining the charges A and B. Point P is a distance x from A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 6.2.

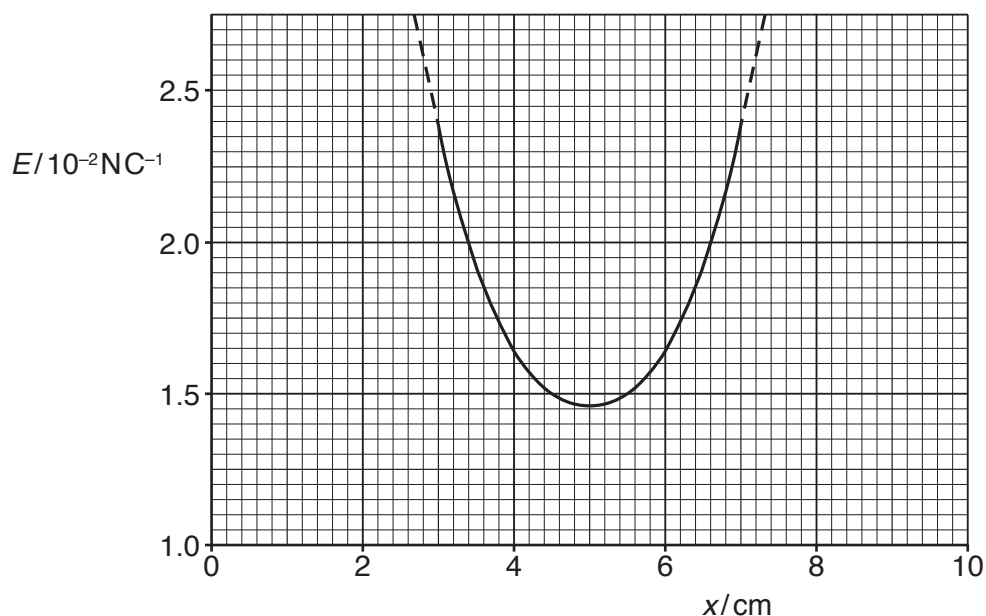


Fig. 6.2

State and explain whether the charges A and B:

(i) have the same, or opposite, signs

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

(ii) have the same, or different, magnitudes.

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

(c) An electron is situated at point P.

Without calculation, state and explain the variation in the magnitude of the acceleration of the electron as it moves from the position where $x = 3\text{ cm}$ to the position where $x = 7\text{ cm}$.

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

[Total: 10]

- 7 (a) An ideal operational amplifier (op-amp) has infinite bandwidth and zero output impedance.

State what is meant by:

- (i) *infinite bandwidth*

.....
 [1]

- (ii) *zero output impedance.*

.....
 [1]

- (b) The circuit for a non-inverting amplifier incorporating an ideal op-amp is shown in Fig. 7.1.

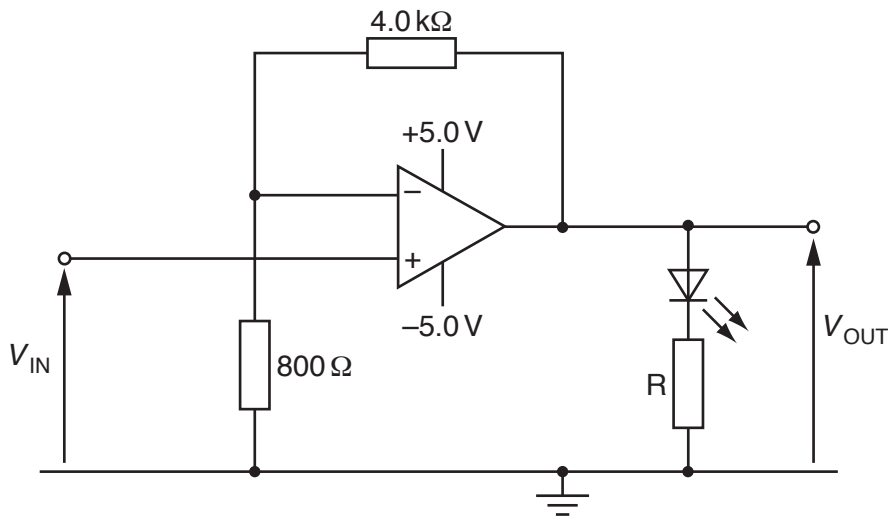


Fig. 7.1

The light-emitting diode (LED) emits light when the potential difference across it is at least 2.0 V.

The current in the LED must not be greater than 20 mA.

- (i) Calculate the gain of the amplifier circuit.

gain = ... [2]

- (ii) Determine the value of V_{IN} for which the value of V_{OUT} is +2.0 V.

$$V_{IN} = \dots\dots\dots \text{ V [1]}$$

- (iii) State the maximum value of the output potential V_{OUT} .

$$\text{maximum potential} = \dots\dots\dots \text{ V [1]}$$

- (iv) When the op-amp is saturated, the potential difference across the LED is 2.2 V.

Calculate the minimum resistance of resistor R so that the current in the LED is limited to 20 mA.

$$\text{resistance} = \dots\dots\dots \Omega \text{ [2]}$$

[Total: 8]

- 8 (a) A long straight vertical wire carries a current I . The wire passes through a horizontal card EFGH, as shown in Fig. 8.1 and Fig. 8.2.

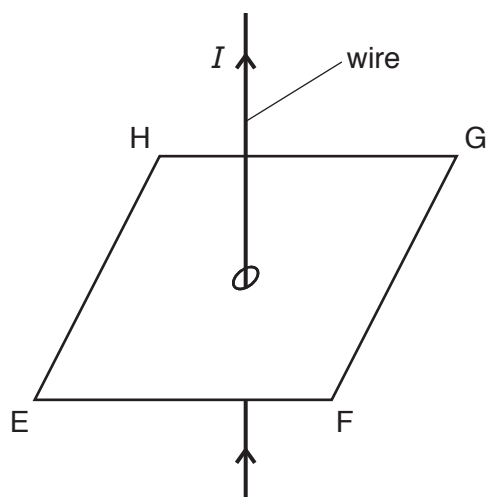


Fig. 8.1

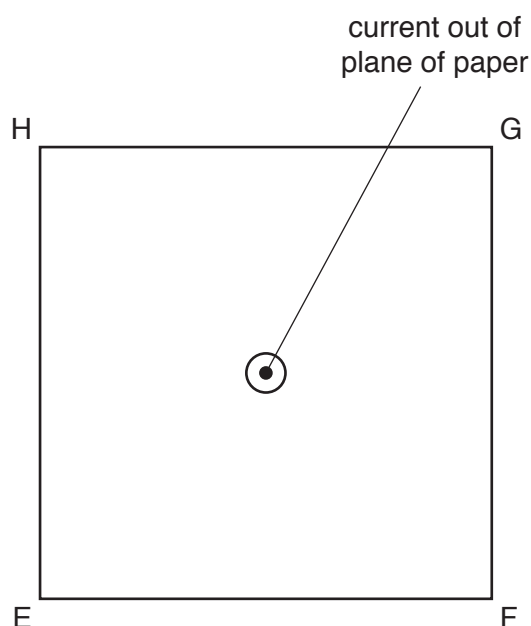


Fig. 8.2 (view from above)

On Fig. 8.2, draw the pattern of the magnetic field produced by the current-carrying wire on the plane EFGH. [3]

- (b) Two long straight parallel wires P and Q are situated a distance 3.1 cm apart, as illustrated in Fig. 8.3.

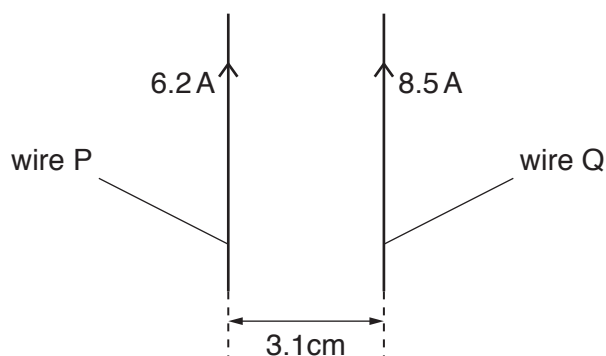


Fig. 8.3

The current in wire P is 6.2 A. The current in wire Q is 8.5 A.

The magnetic flux density B at a distance x from a long straight wire carrying current I is given by the expression

$$B = \frac{\mu_0 I}{2\pi x}$$

where μ_0 is the permeability of free space.

Calculate:

- (i) the magnetic flux density at wire Q due to the current in wire P

flux density = ... T [2]

- (ii) the force per unit length, in N m^{-1} , acting on wire Q due to the current in wire P.

force per unit length = ... N m^{-1} [2]

- (c) The currents in wires P and Q are different in magnitude.

State and explain whether the forces per unit length on the two wires will be different.

.....

 [2]

[Total: 9]

- 9 Diagnosis using nuclear magnetic resonance imaging (NMRI) requires the use of a non-uniform magnetic field superimposed on a constant magnetic field of large magnitude.

Explain the purpose of:

- (a) the large constant magnetic field

.....

.....

.....

.....

..... [2]

- (b) the non-uniform magnetic field.

.....

.....

.....

.....

..... [2]

[Total: 4]

10 A bridge rectifier using four ideal diodes is shown in Fig. 10.1.

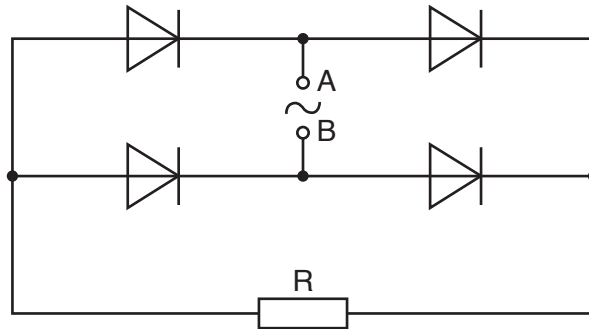


Fig. 10.1

The sinusoidal alternating electromotive force (e.m.f.) applied between points A and B has a root-mean-square (r.m.s.) value of 7.0 V.

- (a) (i) On Fig. 10.1, circle the diodes that conduct when point B is positive with respect to point A. [1]
- (ii) Calculate the maximum potential difference V_{MAX} across resistor R.

$$V_{\text{MAX}} = \dots\dots\dots \text{ V [1]}$$

- (b) A capacitor is connected into the circuit to produce smoothing of the potential difference across resistor R.

The variation with time t of the potential difference V across resistor R is shown in Fig. 10.2.

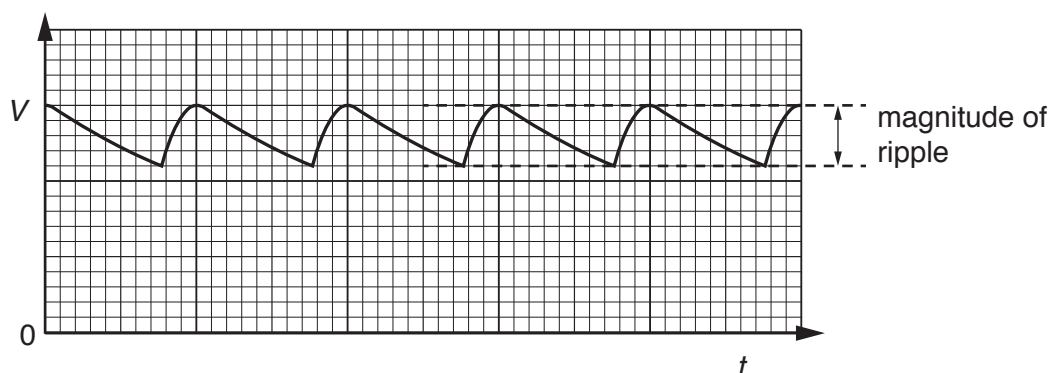


Fig. 10.2

- (i) On Fig. 10.1, draw the symbol for a capacitor, connected so as to produce smoothing. [1]

- (ii) State the effect, if any, on the magnitude of the ripple on V when, separately:

1. a capacitor of larger capacitance is used

.....

2. the resistor R has a smaller resistance.

.....

[2]

[Total: 5]

- 11 (a) With reference to the photoelectric effect, state what is meant by *work function energy*.

.....

.....

..... [2]

- (b) The work function energy of a clean metal surface is $5.5 \times 10^{-19} \text{ J}$.

Electromagnetic radiation of wavelength 280 nm is incident on the metal surface. The metal is in a vacuum.

- (i) Calculate:

1. the photon energy

photon energy = ... J [2]

2. the maximum speed v_{MAX} of the electrons emitted from the surface.

$v_{\text{MAX}} = \dots \text{ ms}^{-1}$ [3]

- (ii) Explain why most of the emitted electrons will have a speed lower than v_{MAX} .

.....

..... [1]

- (c) The electromagnetic radiation incident on the metal surface may change in intensity or in frequency.

Complete Fig. 11.1 by inserting either '*increases*' or '*decreases*' or '*no change*' to describe the effects of the changes shown on the maximum speed and on the rate of emission of electrons.

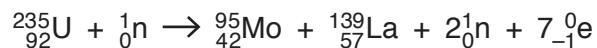
change	maximum speed of electrons	rate of emission of electrons
reduced intensity at constant frequency		
increased frequency at constant intensity		

Fig. 11.1

[4]

[Total: 12]

12 One possible nuclear reaction that takes place is



Data for nuclei in this reaction are given in Fig. 12.1.

nucleus	mass/u	total mass of separate nucleons/u	mass defect/u	binding energy per nucleon/MeV
${}_{42}^{95}\text{Mo}$	94.906	95.765	0.859	8.443
${}_{57}^{139}\text{La}$	138.906	140.125	1.219	8.189
${}_{92}^{235}\text{U}$	235.044	236.909	1.865	

Fig. 12.1

(a) Show that the energy equivalent to a mass of 1.00 u is 934 MeV.

[2]

(b) (i) Use data from Fig. 12.1 to calculate the binding energy per nucleon of a nucleus of uranium-235 (${}_{92}^{235}\text{U}$). Complete Fig. 12.1.

[2]

(ii) The nucleon number of an isotope of the element rutherfordium is 267.

State whether the binding energy per nucleon of this isotope will be greater than, equal to or less than the binding energy per nucleon of uranium-235.

..... [1]

- (c) Calculate the total energy, in MeV, released in this nuclear reaction.

energy = ... MeV [2]

- (d) The nuclei in 1.2×10^{-7} mol of uranium-235 all undergo this reaction in a time of 25 ms.

Calculate the average power release during the time of 25 ms.

power = ... W [3]

[Total: 10]

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