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PHYSICS

Paper 4 A2 Structured Questions

9702/41

May/June 2015

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

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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.

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Total	

This document consists of **23** printed pages and **1** blank page.

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 constant,	$u = 1.66 \times 10^{-27} \text{ kg}$
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.,	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
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,	$W = \frac{1}{2} QV$
resistors in series,	$R = R_1 + R_2 + \dots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \dots$
alternating current/voltage,	$x = x_0 \sin \omega t$
radioactive decay,	$x = x_0 \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

Section A

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

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

.....

.....

..... [2]

- (b) The planet Neptune has eight moons (satellites). Each moon orbits Neptune in a circular path of radius r with a period T .

Assuming that Neptune and each moon behave as point masses, show that r and T are related by the expression

$$GM_N = \frac{4\pi^2 r^3}{T^2}$$

where G is the gravitational constant and M_N is the mass of Neptune.

[3]

- (c) Data for the moon Triton that orbits Neptune and for the moon Oberon that orbits the planet Uranus are given in Fig. 1.1.

planet	moon	radius of orbit $r/10^5 \text{ km}$	period of orbit T/days
Neptune	Triton	3.55	5.9
Uranus	Oberon	5.83	13.5

Fig. 1.1

Use the expression in **(b)** to determine the ratio

$$\frac{\text{mass of Neptune}}{\text{mass of Uranus}} .$$

ratio = ... [3]

- 2 (a) State what is meant by *internal energy*.

.....

.....

..... [2]

- (b) The variation with volume V of the pressure p of an ideal gas as it undergoes a cycle ABCA of changes is shown in Fig. 2.1.

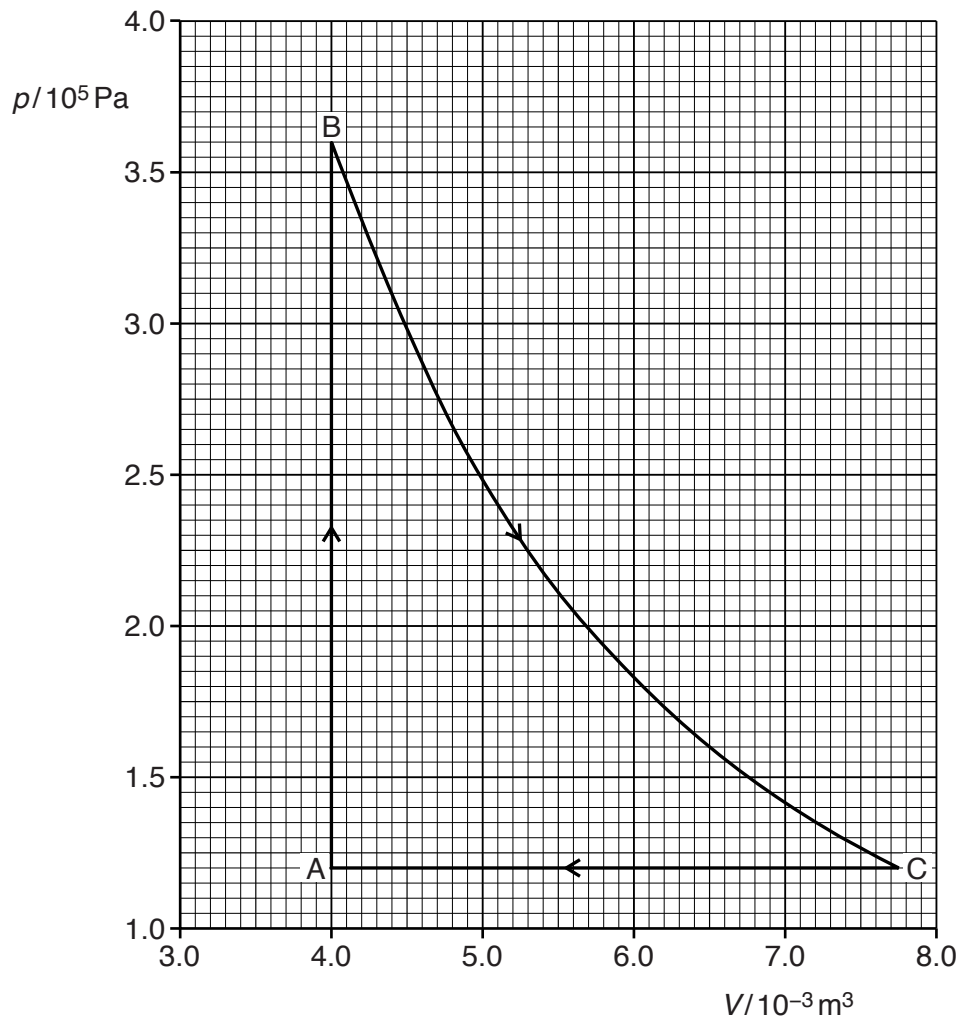


Fig. 2.1

The temperature of the gas at A is 290 K. The temperature at B is 870 K.

Determine

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

amount = ... mol [2]

(ii) the temperature of the gas at C.

temperature = ... K [2]

(c) Explain why the change from C to A involves external work and a change in internal energy.

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

- 3 (a) Define *specific latent heat*.

.....

.....

.....

..... [2]

- (b) An electrical heater is immersed in some melting ice that is contained in a funnel, as shown in Fig. 3.1.

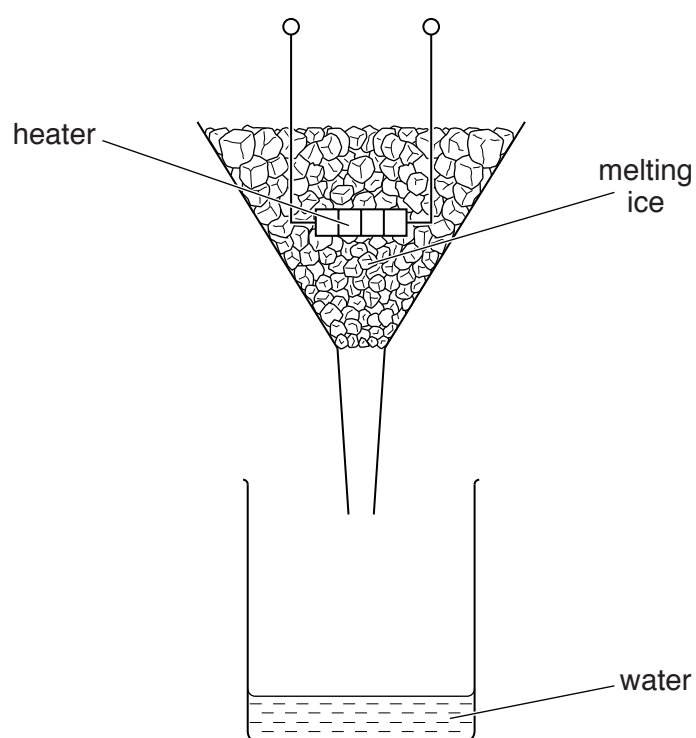


Fig. 3.1

The heater is switched on and, when the ice is melting at a constant rate, the mass m of ice melted in 5.0 minutes is noted, together with the power P of the heater. The power P of the heater is then increased. A new reading for the mass m of ice melted in 5.0 minutes is recorded when the ice is melting at a constant rate.

Data for the power P and the mass m are shown in Fig. 3.2.

power of heater P/W	mass m melted in 5.0 minutes/g	mass m melted per second/ gs^{-1}
70	78	
110	114	

Fig. 3.2

- (i) Complete Fig. 3.2 to determine the mass melted per second for each power of the heater. [2]
- (ii) Use the data in the completed Fig. 3.2 to determine
1. a value for the specific latent heat of fusion L of ice,

$$L = \dots\dots\dots \text{J g}^{-1} \quad [3]$$

2. the rate h of thermal energy gained by the ice from the surroundings.

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

4 (a) For an oscillating body, state what is meant by

(i) forced frequency,

.....
 [1]

(ii) natural frequency of vibration,

.....
 [1]

(iii) resonance.

.....

 [2]

(b) State and explain one situation where resonance is useful.

.....

 [2]

(c) In some situations, resonance should be avoided.

State one such situation and suggest how the effects of resonance are reduced.

.....

 [2]

- 5 A charged metal sphere is isolated in space. Measurements of the electric potential V are made for different distances x from the centre of the sphere.

The variation with distance x of the potential V is shown in Fig. 5.1.

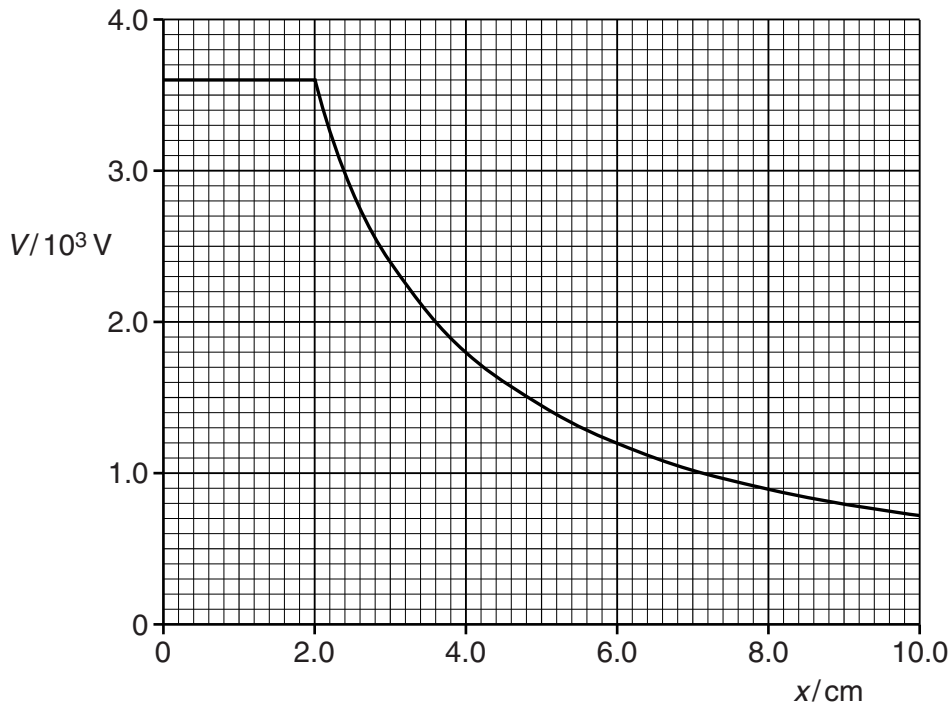


Fig. 5.1

- (a) Use Fig. 5.1 to determine the electric field strength, in NC^{-1} , at a point where $x = 4.0 \text{ cm}$. Explain your working.

electric field strength = ... NC^{-1} [3]

- (b) The charge on the sphere is $8.0 \times 10^{-9} \text{ C}$.

- (i) Use Fig. 5.1 to state the electric potential at the surface of the sphere.

potential = ... V [1]

- (ii) The sphere acts as a capacitor. Determine the capacitance of the sphere.

capacitance = ... F [2]

6 (a) State the type of field, or fields, that may cause a force to be exerted on a particle that is

(i) uncharged and moving,

..... [1]

(ii) charged and stationary,

..... [1]

(iii) charged and moving at right-angles to the field.

..... [2]

(b) A particle X has mass $3.32 \times 10^{-26} \text{ kg}$ and charge $+1.60 \times 10^{-19} \text{ C}$.

The particle is travelling in a vacuum with speed $7.60 \times 10^4 \text{ m s}^{-1}$. It enters a region of uniform magnetic field that is normal to the direction of travel of the particle. The particle travels in a semicircle of diameter 12.2 cm, as shown in Fig. 6.1.

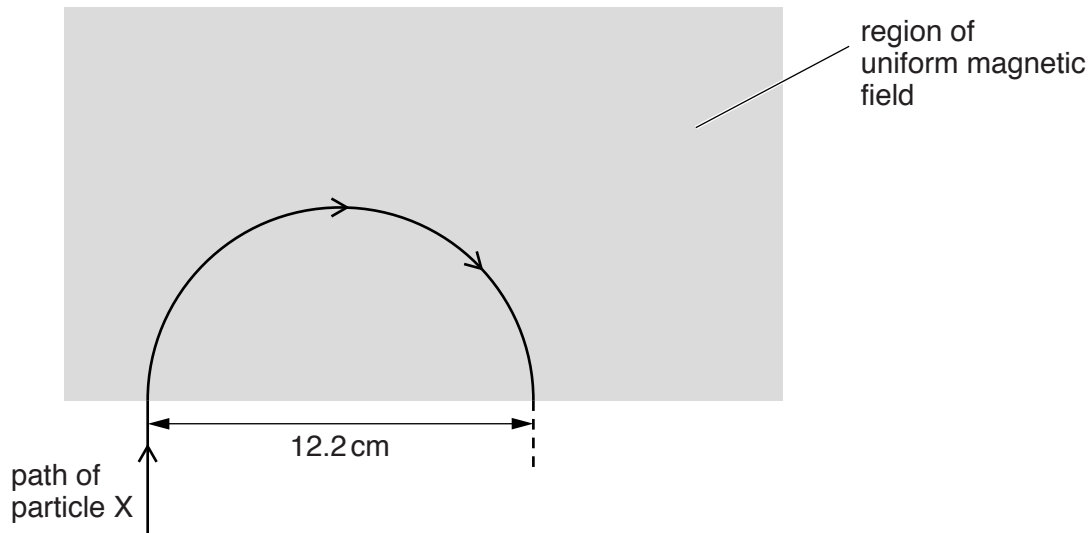


Fig. 6.1

For the uniform magnetic field,

(i) state its direction,

.....
 [1]

(ii) calculate the magnetic flux density.

magnetic flux density = ... T [3]

(c) A second particle Y has mass less than that of particle X in (b) and the same charge.

It enters the region of uniform magnetic field in (b) with the same speed and along the same initial path as particle X.

On Fig. 6.1, draw the path of particle Y in the region of the magnetic field. [1]

7 In many distribution systems for electrical energy, the energy is transmitted using alternating current at high voltages.

Suggest and explain an advantage, one in each case, for the use of

(a) alternating voltages,

.....

 [2]

(b) high voltages.

.....

 [2]

- 8 A photon of wavelength $6.50 \times 10^{-12} \text{ m}$ is incident on an isolated stationary electron, as illustrated in Fig. 8.1.

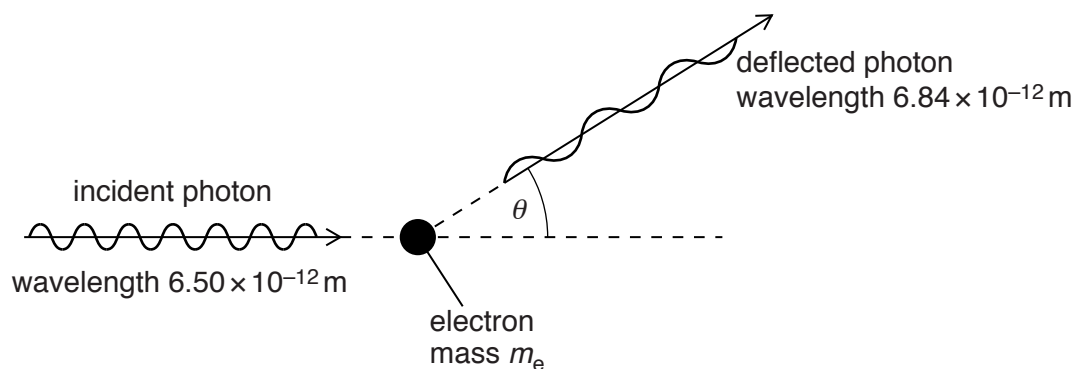


Fig. 8.1

The photon is deflected elastically by the electron of mass m_e . The wavelength of the deflected photon is $6.84 \times 10^{-12} \text{ m}$.

- (a) Calculate, for the incident photon,

- (i) its momentum,

momentum = ... Ns [2]

- (ii) its energy.

energy = ... J [2]

- (b) The angle θ through which the photon is deflected is given by the expression

$$\Delta\lambda = \frac{h}{m_e c} (1 - \cos \theta)$$

where $\Delta\lambda$ is the change in wavelength of the photon, h is the Planck constant and c is the speed of light in free space.

- (i) Calculate the angle θ .

$$\theta = \dots\dots\dots^\circ \quad [2]$$

- (ii) Use energy considerations to suggest why $\Delta\lambda$ must always be positive.

.....

.....

.....

..... [3]

- 9 (a) An isotope of an element is radioactive. Explain what is meant by *radioactive decay*.

.....

.....

.....

..... [3]

- (b) At time t , a sample of a radioactive isotope contains N nuclei. In a short time Δt , the number of nuclei that decay is ΔN .

State expressions, in terms of the symbols t , Δt , N and ΔN for

- (i) the number of undecayed nuclei at time $(t + \Delta t)$,

number = ... [1]

- (ii) the mean activity of the sample during the time interval Δt ,

mean activity = ... [1]

- (iii) the probability of decay of a nucleus during the time interval Δt ,

probability = ... [1]

- (iv) the decay constant.

decay constant = ... [1]

- (c) The variation with time t of the activity A of a sample of a radioactive isotope is shown in Fig. 9.1.

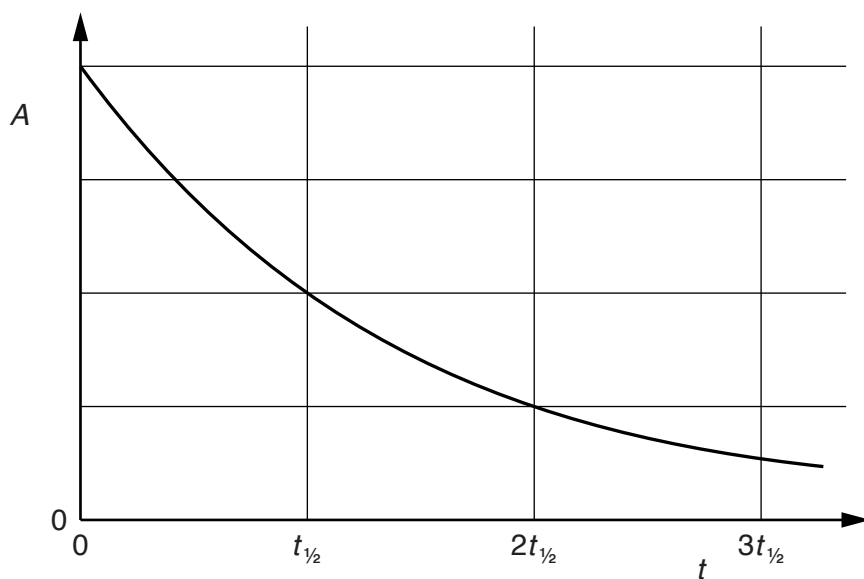


Fig. 9.1

The radioactive isotope decays to form a stable isotope S. At time $t = 0$, there are no nuclei of S in the sample.

On the axes of Fig. 9.2, sketch a graph to show the variation with time t of the number n of nuclei of S in the sample.

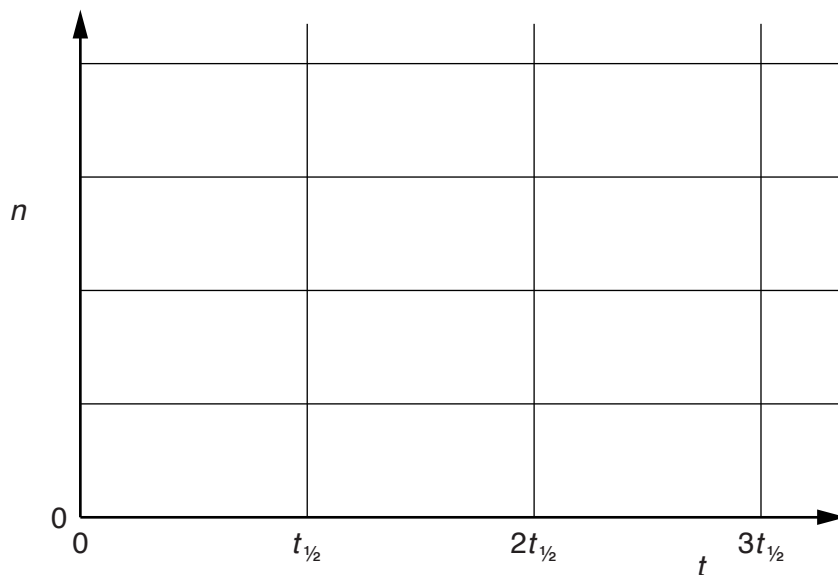


Fig. 9.2

[2]

Section B

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

- 10 An operational amplifier (op-amp) is used in the comparator circuit of Fig. 10.1.

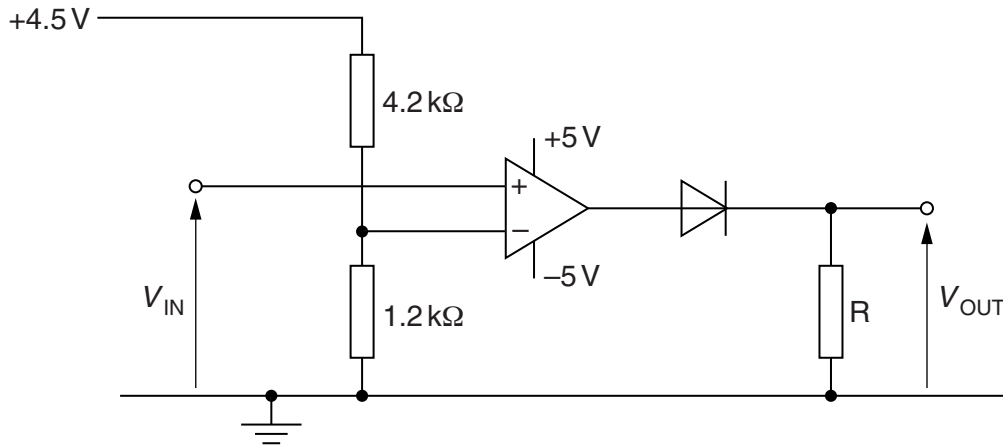


Fig. 10.1

- (a) (i) Show that the potential at the inverting input of the op-amp is +1.0V.

[1]

- (ii) Explain why the potential difference across resistor R is + 5V when V_{IN} is greater than 1.0V and is zero when V_{IN} is less than 1.0V.

$V_{IN} > 1.0V$:

.....

.....

$V_{IN} < 1.0V$:

.....

.....

[4]

(b) The variation with time t of the input voltage V_{IN} is shown in Fig. 10.2.

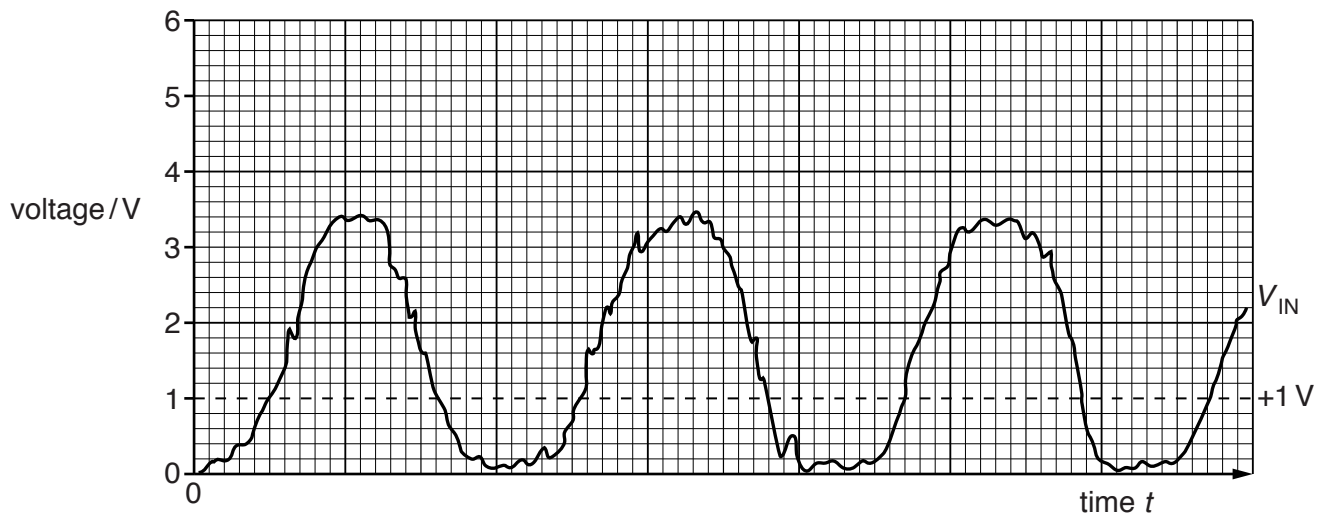


Fig. 10.2

- (i) On the axes of Fig. 10.2, draw the variation with time t of the output potential V_{OUT} . [2]
- (ii) Suggest a use for this type of circuit.

.....

..... [1]

- 11 (a) State and explain how, in an X-ray tube, the hardness of the X-ray beam is controlled.

.....

 [3]

- (b) A parallel beam of X-rays has intensity I_0 and is incident on a medium having a linear absorption (attenuation) coefficient μ .

- (i) State an equation for the variation of the intensity I with the thickness x of the medium.

..... [1]

- (ii) Data for the linear absorption (attenuation) coefficient μ for an X-ray beam in blood and in muscle is shown in Fig. 11.1.

	μ/cm^{-1}
blood	0.23
muscle	0.22

Fig. 11.1

Suggest why, if this X-ray beam is used to image blood vessels in muscle, contrast on the image would be poor.

.....

 [2]

- 12 (a)** Information may be carried by means of various channels of communication.

Name examples, one in each case, of devices where information is carried to the device using

- (i)** a wire pair,

..... [1]

- (ii)** a coaxial cable,

..... [1]

- (iii)** microwaves.

..... [1]

- (b)** State two advantages of optic fibres as compared with coaxial cables for long-range communication.

1.

2.

[2]

- (c)** An optic fibre has length 62 km and an attenuation per unit length of 0.21 dB km^{-1} .
The input power to the fibre is P . At the receiver, the noise power is $9.2 \mu\text{W}$.
The signal-to-noise ratio at the receiver is 25 dB.

- (i)** Calculate the ratio, in dB, of the input power P to the noise power at the receiver.

ratio = ... dB [2]

- (ii)** Use your answer in **(i)** to determine the input power P .

$P = \dots\dots\dots \text{ W}$ [2]

- 13** During magnetic resonance imaging to obtain information about internal body structures, a large constant magnetic field is used with a calibrated non-uniform magnetic field superimposed on it.

(a) State and explain the purpose of

(i) the large constant magnetic field,

.....

.....

..... [2]

(ii) the non-uniform magnetic field.

.....

.....

.....

..... [3]

- (b)** The de-excitation energy E (measured in joule) of a proton in magnetic resonance imaging is given by the expression

$$E = 2.82 \times 10^{-26} B$$

where B is the magnetic flux density measured in tesla.

The energy E is emitted as a photon of electromagnetic radiation in the radio-frequency range.

Calculate the magnetic flux density required for the radio frequency to be 42 MHz.

magnetic flux density = ... T [2]

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radioactive decay,	$x = x_0 \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

Section A

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

- 1 (a) The Earth may be considered to be a uniform sphere of radius $6.37 \times 10^3 \text{ km}$ with its mass of $5.98 \times 10^{24} \text{ kg}$ concentrated at its centre. The Earth spins on its axis with a period of 24.0 hours.

- (i) A stone of mass 2.50 kg rests on the Earth's surface at the Equator.

1. Calculate, using Newton's law of gravitation, the gravitational force on the stone.

gravitational force = ... N [2]

2. Determine the force required to maintain the stone in its circular path.

force = ... N [2]

- (ii) The stone is now hung from a newton-meter.

Use your answers in (i) to determine the reading on the meter. Give your answer to three significant figures.

reading = ... N [2]

- (b) A satellite is orbiting the Earth. For an astronaut in the satellite, his sensation of weight is caused by the contact force from his surroundings.

The astronaut reports that he is 'weightless', despite being in the Earth's gravitational field.

Suggest what is meant by the astronaut reporting that he is 'weightless'.

.....

.....

.....

.....[3]

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- 2 In a sample of gas at room temperature, five atoms have the following speeds:

$$1.32 \times 10^3 \text{ m s}^{-1}$$

$$1.50 \times 10^3 \text{ m s}^{-1}$$

$$1.46 \times 10^3 \text{ m s}^{-1}$$

$$1.28 \times 10^3 \text{ m s}^{-1}$$

$$1.64 \times 10^3 \text{ m s}^{-1}.$$

For these five atoms, calculate, to three significant figures,

- (a) the mean speed,

$$\text{mean speed} = \dots\dots\dots \text{ m s}^{-1} \text{ [1]}$$

- (b) the mean-square speed,

$$\text{mean-square speed} = \dots\dots\dots \text{ m}^2 \text{ s}^{-2} \text{ [2]}$$

- (c) the root-mean-square speed.

$$\text{root-mean-square speed} = \dots\dots\dots \text{ m s}^{-1} \text{ [1]}$$

3 (a) Define *specific latent heat*.

.....

.....

.....[2]

(b) A beaker containing a liquid is placed on a balance, as shown in Fig. 3.1.

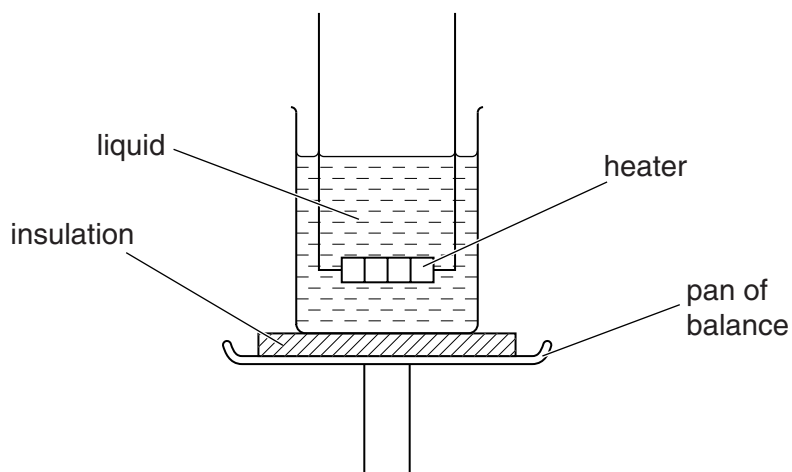


Fig. 3.1

A heater of power 110W is immersed in the liquid. The heater is switched on and, when the liquid is boiling, balance readings m are taken at corresponding times t .

A graph of the variation with time t of the balance reading m is shown in Fig. 3.2.

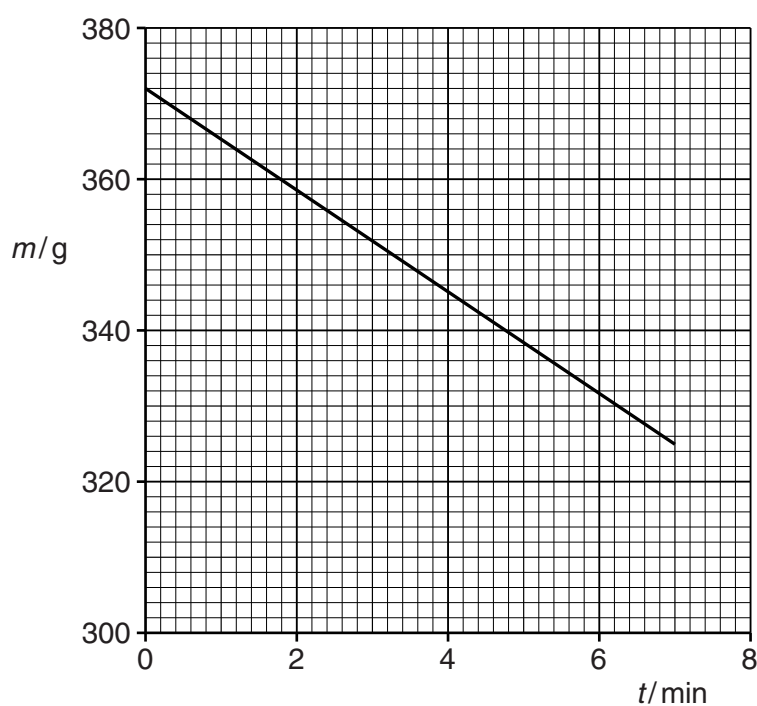


Fig. 3.2

- (i) State the feature of Fig. 3.2 which suggests that the liquid is boiling at a steady rate.

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

- (ii) Use data from Fig. 3.2 to determine a value for the specific latent heat L of vaporisation of the liquid.

$$L = \text{..... J kg}^{-1} \text{ [3]}$$

- (iii) State, with a reason, whether the value determined in (ii) is likely to be an overestimate or an underestimate of the normally accepted value for the specific latent heat of vaporisation of the liquid.

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

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

.....

[2]

- (b) The variation with time t of the displacement x of two oscillators P and Q is shown in Fig. 4.1.

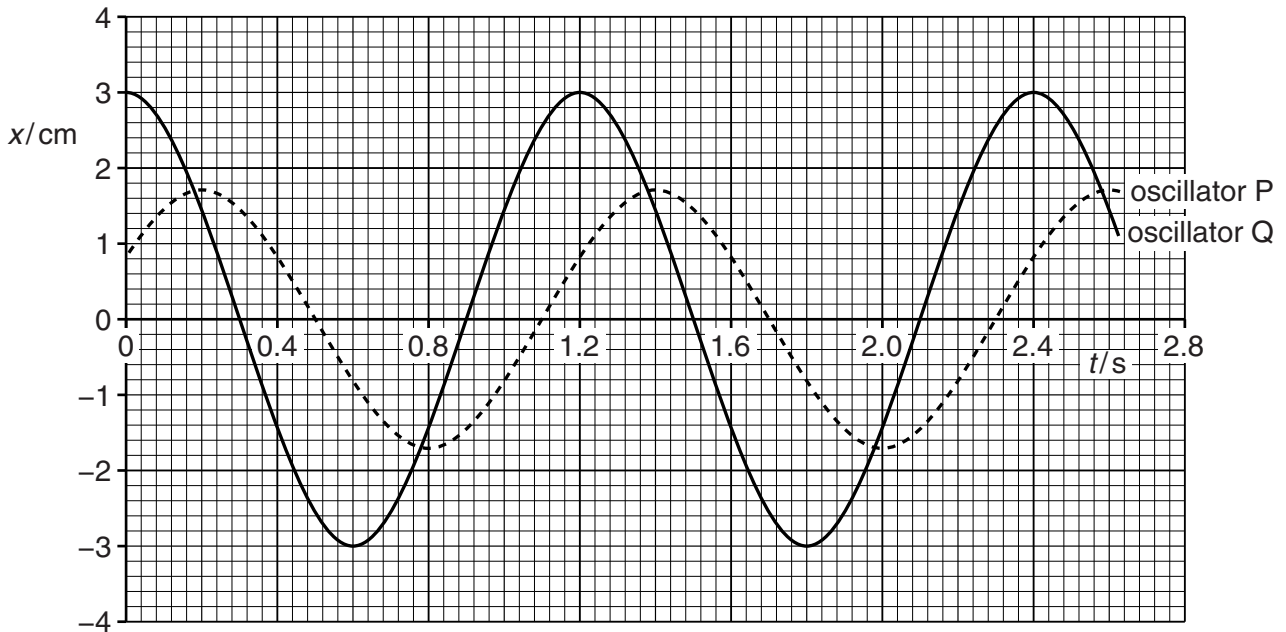


Fig. 4.1

The two oscillators each have the same mass.

Use Fig. 4.1 to determine

- (i) the phase difference between the two oscillators,

phase difference = ... rad [1]

- (ii) the maximum acceleration of oscillator Q,

maximum acceleration = ... ms^{-2} [2]

(iii) the ratio

$$\frac{\text{maximum kinetic energy of oscillations of Q}}{\text{maximum kinetic energy of oscillations of P}}$$

ratio = ... [2]

(c) Use data from (b) to sketch, on the axes of Fig. 4.2, the variation with displacement x of the acceleration a of oscillator Q.

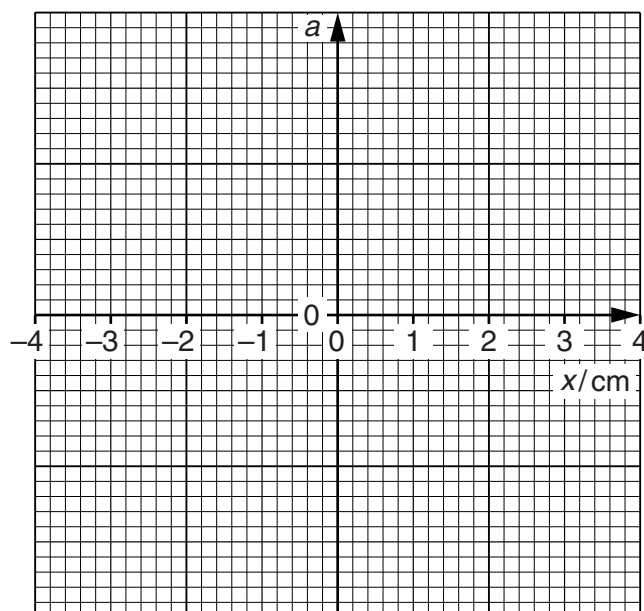


Fig. 4.2

[2]

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

.....

.....

.....[2]

- (b) Two positively charged metal spheres A and B are situated in a vacuum, as shown in Fig. 5.1.

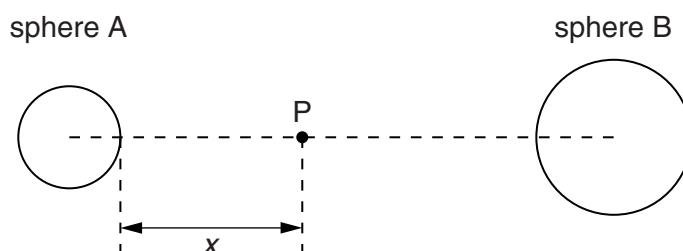


Fig. 5.1

A point P lies on the line joining the centres of the two spheres and is a distance x from the surface of sphere A.

The variation with x of the electric potential V due to the two charged spheres is shown in Fig. 5.2.

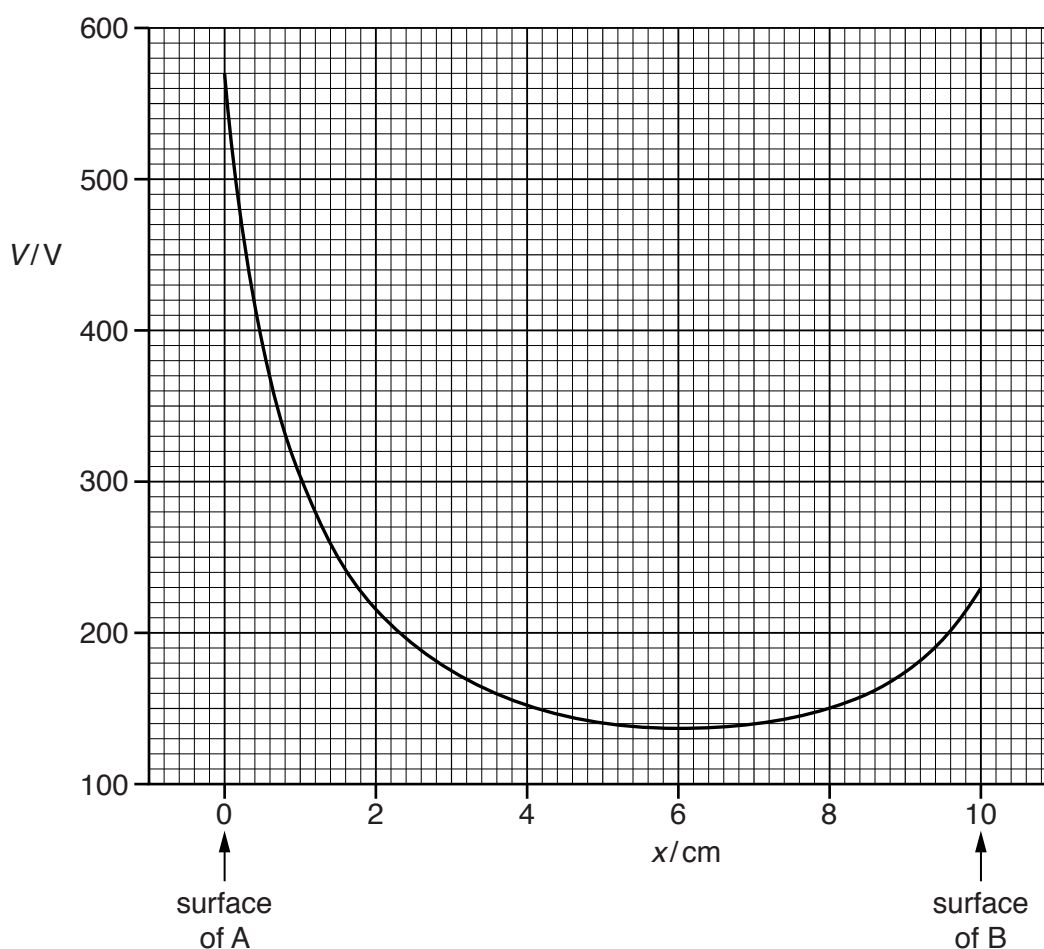


Fig. 5.2

- (i) State how the magnitude of the electric field strength at any point P may be determined from the graph of Fig. 5.2.

.....
[1]

- (ii) Without any calculation, describe the force acting on a positively charged particle placed at point P for values of x from $x = 0$ to $x = 10$ cm.

.....

[3]

- (c) The positively charged particle in (b)(ii) has charge q and mass m given by the expression

$$\frac{q}{m} = 4.8 \times 10^7 \text{ C kg}^{-1}.$$

Initially, the particle is at rest on the surface of sphere A where $x = 0$. It then moves freely along the line joining the centres of the spheres until it reaches the surface of sphere B.

- (i) On Fig. 5.2, mark with the letter M the point where the charged particle has its maximum speed. [1]
- (ii) 1. Use Fig. 5.2 to determine the potential difference between the spheres.

potential difference = ... V [1]

2. Use your answer in (ii) part 1 to calculate the speed of the particle as it reaches the surface of sphere B.
 Explain your working.

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

- 6 (a) Explain what is meant by a *photon*.

.....

.....

.....[2]

- (b) An X-ray photon of energy $3.06 \times 10^{-14} \text{ J}$ is incident on an isolated stationary electron, as illustrated in Fig. 6.1.

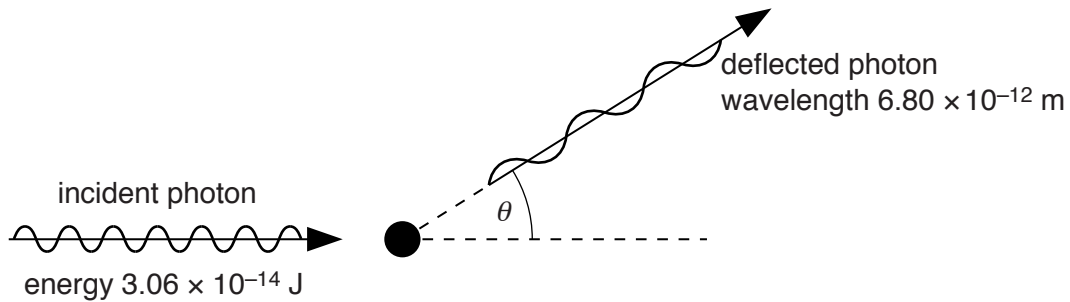


Fig. 6.1

The photon is deflected elastically by the electron through angle θ . The deflected photon has a wavelength of $6.80 \times 10^{-12} \text{ m}$.

- (i) On Fig. 6.1, draw an arrow to indicate a possible initial direction of motion of the electron after the photon has been deflected. [1]
- (ii) Calculate
1. the energy of the deflected photon,

photon energy = ... J [2]

2. the speed of the electron after the photon has been deflected.

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

- (c) Explain why the magnitude of the final momentum of the electron is not equal to the change in magnitude of the momentum of the photon.

.....

 [2]

- 7 (a) A solenoid is connected in series with a resistor, as shown in Fig. 7.1.

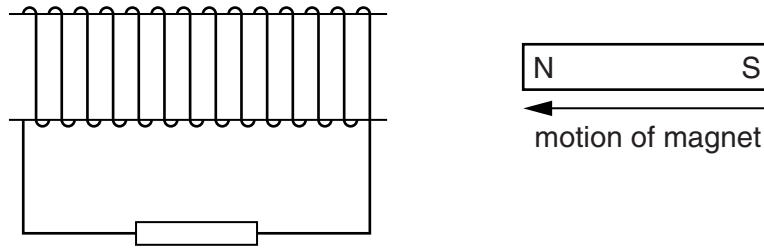


Fig. 7.1

As the magnet is being moved into the solenoid, thermal energy is transferred in the resistor. Use laws of electromagnetic induction to explain the origin of this thermal energy.

.....

 [4]

- (b) Explain why the alternating current in the primary coil of a transformer is not in phase with the alternating e.m.f. induced in the secondary coil.

.....

 [4]

- 8** The power for a space probe is to be supplied by the energy released when plutonium-236 decays by the emission of α -particles.

The α -particles, each of energy 5.75 MeV, are captured and their energy is converted into electrical energy with an efficiency of 24%.

(a) Calculate

- (i)** the energy, in joules, equal to 5.75 MeV,

energy = ... J [1]

- (ii)** the number of α -particles per second required to generate 1.9 kW of electrical power.

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

- (b)** Each plutonium-236 nucleus, on disintegration, produces one α -particle.
Plutonium-236 has a half-life of 2.8 years.

- (i)** Calculate the decay constant, in s^{-1} , of plutonium-236.

decay constant = ... s^{-1} [2]

- (ii) Use your answers in (a)(ii) and (b)(i) to determine the mass of plutonium-236 required for the generation of 1.9 kW of electrical power.

mass = ... g [4]

- (c) The minimum electrical power required for the space probe is 0.84 kW.

Calculate the time, in years, for which the sample of plutonium-236 in (b)(ii) will provide sufficient power.

time = ... years [2]

Section B

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

- 9 (a) The strain in a beam is to be monitored using a strain gauge.
The strain gauge is included in the potential divider circuit shown in Fig. 9.1.

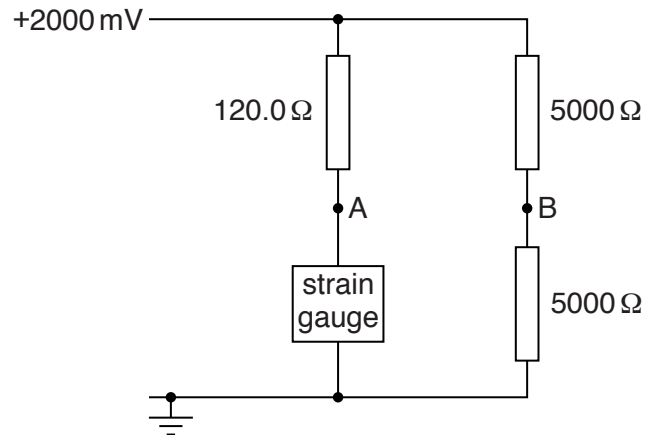


Fig. 9.1

The strain gauge has a resistance of $120.0\ \Omega$ when it is not strained. The resistance increases to $121.5\ \Omega$ when the strain is ε .

Calculate the potential difference between points A and B on Fig. 9.1 when the strain in the gauge is ε .

potential difference = ... mV [3]

- (b) An inverting amplifier, incorporating an operational amplifier (op-amp), uses a high-resistance voltmeter to display the output. A partially completed circuit for the amplifier is shown in Fig. 9.2.

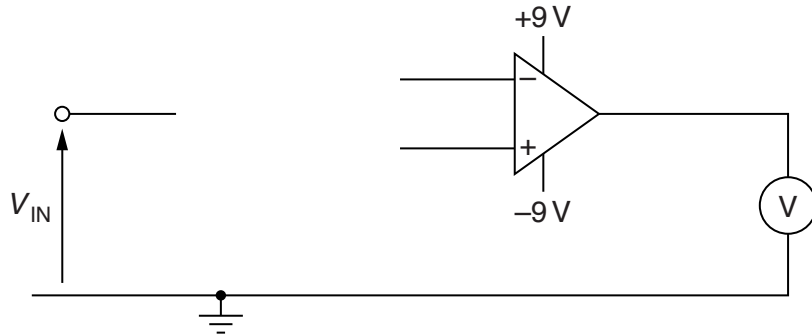


Fig. 9.2

The voltmeter is to indicate a full-scale deflection of +6.0V for an input potential V_{IN} of 0.15V.

- (i) On Fig. 9.2,
1. complete the circuit for the inverting amplifier, [2]
 2. mark, with the letter P, the positive terminal of the voltmeter. [1]
- (ii) Suggest appropriate values for the resistors you have shown in Fig. 9.2. Label the resistors in Fig. 9.2 with these values. [2]

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

.....

.....

.....[2]

- (b) The specific acoustic impedances Z of some media are given in Fig. 10.1.

	$Z/\text{kg m}^{-2} \text{s}^{-1}$
air	4.3×10^2
gel	1.5×10^6
soft tissue	1.6×10^6
bone	7.0×10^6

Fig. 10.1

- (i) The density of a sample of bone is $1.7 \times 10^3 \text{ kg m}^{-3}$.

Determine the wavelength, in mm, of ultrasound of frequency $9.0 \times 10^5 \text{ Hz}$ in the bone.

wavelength = ... mm [3]

- (ii) Ultrasound of intensity I is incident normally on the boundary between two media of specific acoustic impedances Z_1 and Z_2 , as shown in Fig. 10.2.

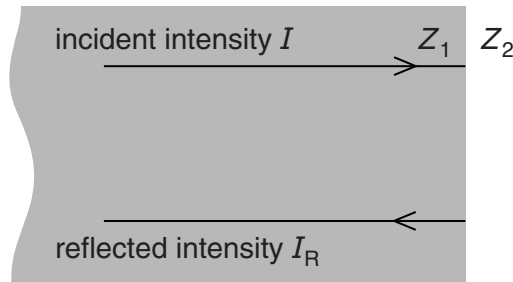


Fig. 10.2

The intensity of the ultrasound reflected from the boundary is I_R .

The ratio $\frac{I_R}{I}$ is given by the expression

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

By making reference to the data for air, gel and soft tissue, explain quantitatively why, during medical diagnosis using ultrasound, a gel is usually put on the skin.

.....

[4]

- 11 One channel of communication is by the use of a coaxial cable. Such a cable is illustrated in Fig. 11.1.

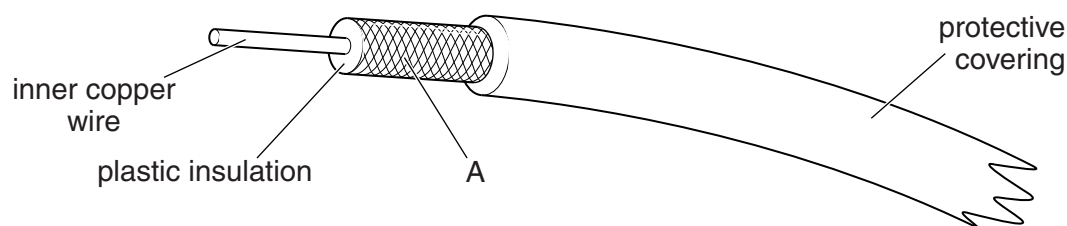


Fig. 11.1

- (a) (i) Suggest the material from which the component labelled A on Fig.11.1 is made.

.....[1]

- (ii) Suggest two functions of the component labelled A.

1.

.....

2.

.....

[2]

- (b) When a signal travels along the coaxial cable, it is attenuated.

- (i) State the meaning of *attenuation*.

.....

.....[1]

- (ii) State and explain why attenuation is frequently measured in decibels (dB).

.....

.....

.....[2]

- (c) A television aerial is connected to a receiver using a coaxial cable of length 11 m. The attenuation per unit length of the cable is 190 dB km^{-1} .

Calculate the ratio

$$\frac{\text{output signal from coaxial cable}}{\text{input signal to coaxial cable}}.$$

ratio = ...[3]

Please turn over for Question 12.

12 A mobile phone handset is, at its simplest, a radio transmitter and receiver.

Outline the role of base stations and the cellular exchange when a mobile phone is switched on and before a call is made.

.....

.....

.....

.....

.....

.....

.....[4]

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PHYSICS

Paper 4 A2 Structured Questions

9702/43

May/June 2015

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.

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11	
12	
13	
Total	

This document consists of **23** printed pages and **1** blank page.

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 constant,	$u = 1.66 \times 10^{-27} \text{ kg}$
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.,	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
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,	$W = \frac{1}{2} QV$
resistors in series,	$R = R_1 + R_2 + \dots$
resistors in parallel,	$1/R = 1/R_1 + 1/R_2 + \dots$
alternating current/voltage,	$x = x_0 \sin \omega t$
radioactive decay,	$x = x_0 \exp(-\lambda t)$
decay constant,	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

Section A

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

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

.....

.....

..... [2]

- (b) The planet Neptune has eight moons (satellites). Each moon orbits Neptune in a circular path of radius r with a period T .

Assuming that Neptune and each moon behave as point masses, show that r and T are related by the expression

$$GM_N = \frac{4\pi^2 r^3}{T^2}$$

where G is the gravitational constant and M_N is the mass of Neptune.

[3]

- (c) Data for the moon Triton that orbits Neptune and for the moon Oberon that orbits the planet Uranus are given in Fig. 1.1.

planet	moon	radius of orbit $r/10^5 \text{ km}$	period of orbit T/days
Neptune	Triton	3.55	5.9
Uranus	Oberon	5.83	13.5

Fig. 1.1

Use the expression in **(b)** to determine the ratio

$$\frac{\text{mass of Neptune}}{\text{mass of Uranus}}.$$

ratio = ... [3]

- 2 (a) State what is meant by *internal energy*.

.....

.....

..... [2]

- (b) The variation with volume V of the pressure p of an ideal gas as it undergoes a cycle ABCA of changes is shown in Fig. 2.1.

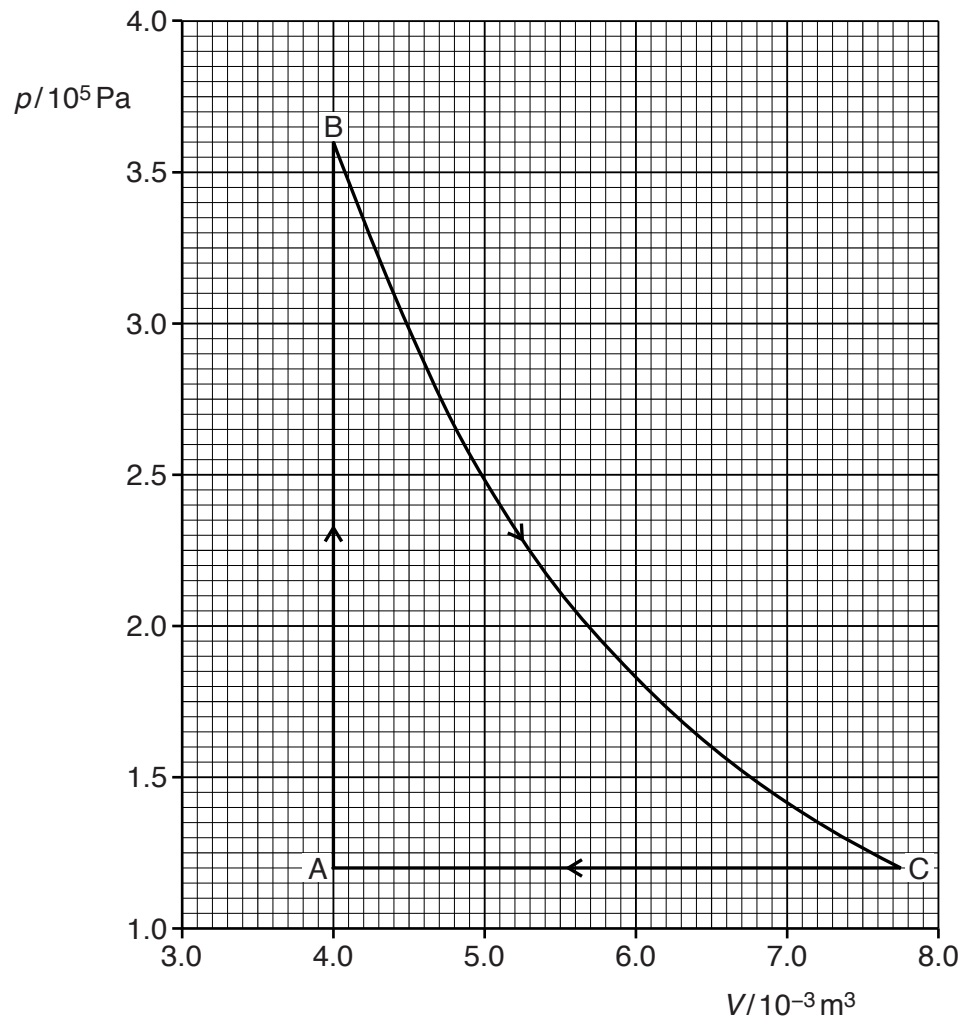


Fig. 2.1

The temperature of the gas at A is 290 K. The temperature at B is 870 K.

Determine

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

amount = ... mol [2]

(ii) the temperature of the gas at C.

temperature = ... K [2]

(c) Explain why the change from C to A involves external work and a change in internal energy.

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

- 3 (a) Define *specific latent heat*.

.....

.....

.....

..... [2]

- (b) An electrical heater is immersed in some melting ice that is contained in a funnel, as shown in Fig. 3.1.

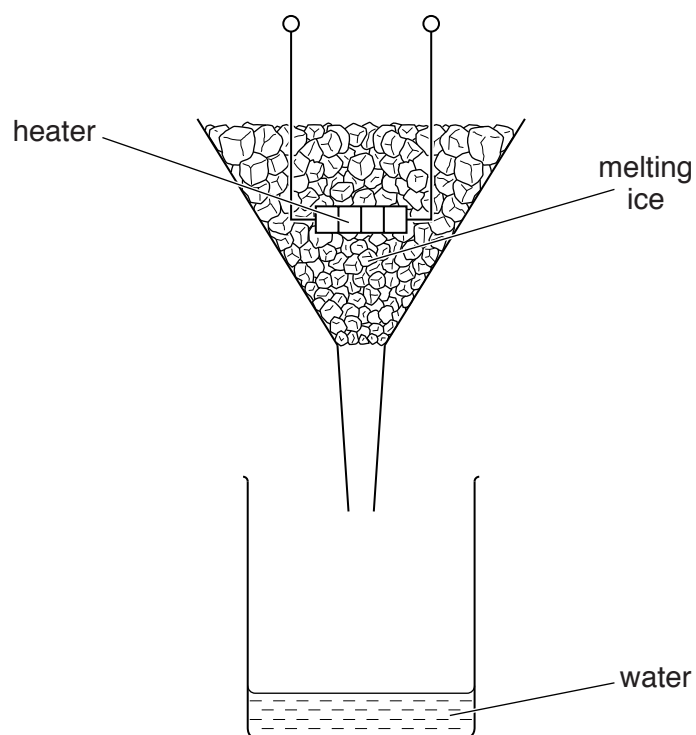


Fig. 3.1

The heater is switched on and, when the ice is melting at a constant rate, the mass m of ice melted in 5.0 minutes is noted, together with the power P of the heater. The power P of the heater is then increased. A new reading for the mass m of ice melted in 5.0 minutes is recorded when the ice is melting at a constant rate.

Data for the power P and the mass m are shown in Fig. 3.2.

power of heater P/W	mass m melted in 5.0 minutes/g	mass m melted per second/ gs^{-1}
70	78	
110	114	

Fig. 3.2

- (i) Complete Fig. 3.2 to determine the mass melted per second for each power of the heater. [2]
- (ii) Use the data in the completed Fig. 3.2 to determine
1. a value for the specific latent heat of fusion L of ice,

$$L = \dots\dots\dots \text{J g}^{-1} \quad [3]$$

2. the rate h of thermal energy gained by the ice from the surroundings.

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

4 (a) For an oscillating body, state what is meant by

(i) forced frequency,

.....
 [1]

(ii) natural frequency of vibration,

.....
 [1]

(iii) resonance.

.....

 [2]

(b) State and explain one situation where resonance is useful.

.....

 [2]

(c) In some situations, resonance should be avoided.

State one such situation and suggest how the effects of resonance are reduced.

.....

 [2]

- 5 A charged metal sphere is isolated in space. Measurements of the electric potential V are made for different distances x from the centre of the sphere.

The variation with distance x of the potential V is shown in Fig. 5.1.

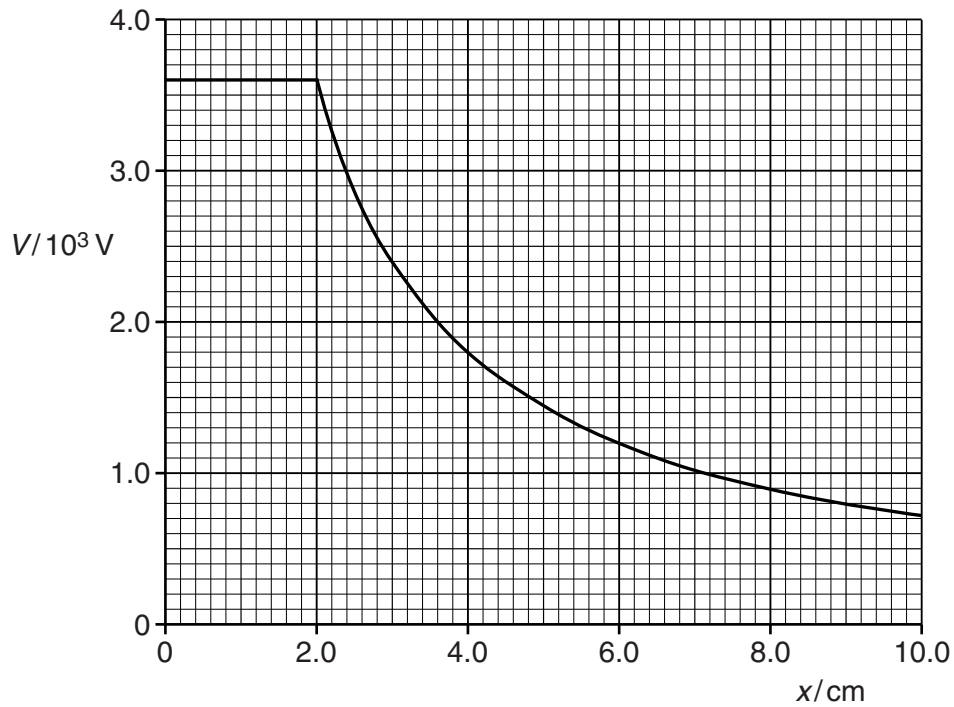


Fig. 5.1

- (a) Use Fig. 5.1 to determine the electric field strength, in NC^{-1} , at a point where $x = 4.0 \text{ cm}$. Explain your working.

electric field strength = ... NC^{-1} [3]

- (b) The charge on the sphere is $8.0 \times 10^{-9} \text{ C}$.

- (i) Use Fig. 5.1 to state the electric potential at the surface of the sphere.

potential = ... V [1]

- (ii) The sphere acts as a capacitor. Determine the capacitance of the sphere.

capacitance = ... F [2]

6 (a) State the type of field, or fields, that may cause a force to be exerted on a particle that is

(i) uncharged and moving,

..... [1]

(ii) charged and stationary,

..... [1]

(iii) charged and moving at right-angles to the field.

..... [2]

(b) A particle X has mass $3.32 \times 10^{-26} \text{ kg}$ and charge $+1.60 \times 10^{-19} \text{ C}$.

The particle is travelling in a vacuum with speed $7.60 \times 10^4 \text{ m s}^{-1}$. It enters a region of uniform magnetic field that is normal to the direction of travel of the particle. The particle travels in a semicircle of diameter 12.2 cm, as shown in Fig. 6.1.

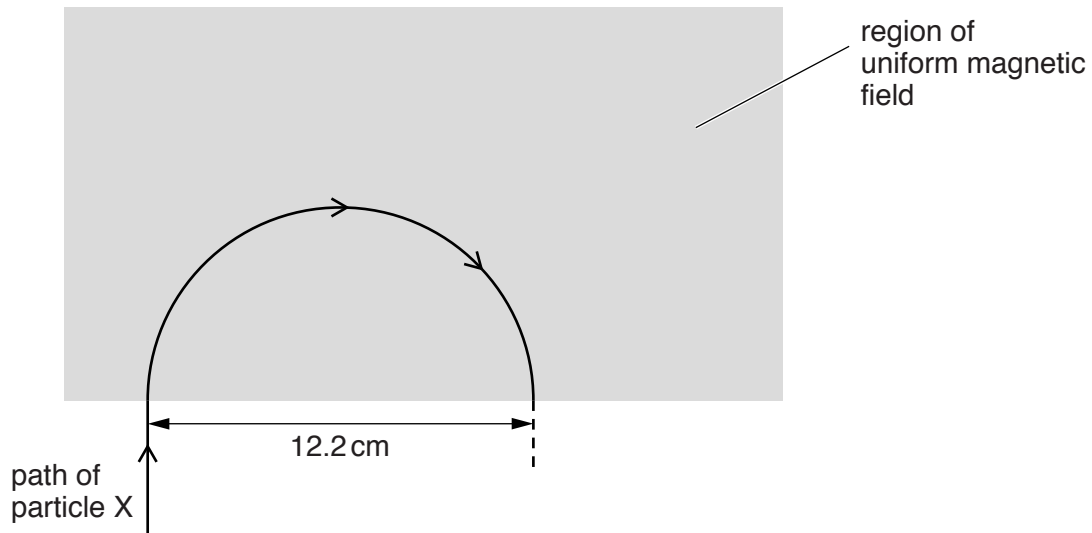


Fig. 6.1

For the uniform magnetic field,

(i) state its direction,

.....
 [1]

(ii) calculate the magnetic flux density.

magnetic flux density = ... T [3]

(c) A second particle Y has mass less than that of particle X in (b) and the same charge.

It enters the region of uniform magnetic field in (b) with the same speed and along the same initial path as particle X.

On Fig. 6.1, draw the path of particle Y in the region of the magnetic field. [1]

7 In many distribution systems for electrical energy, the energy is transmitted using alternating current at high voltages.

Suggest and explain an advantage, one in each case, for the use of

(a) alternating voltages,

.....

 [2]

(b) high voltages.

.....

 [2]

- 8 A photon of wavelength $6.50 \times 10^{-12} \text{ m}$ is incident on an isolated stationary electron, as illustrated in Fig. 8.1.

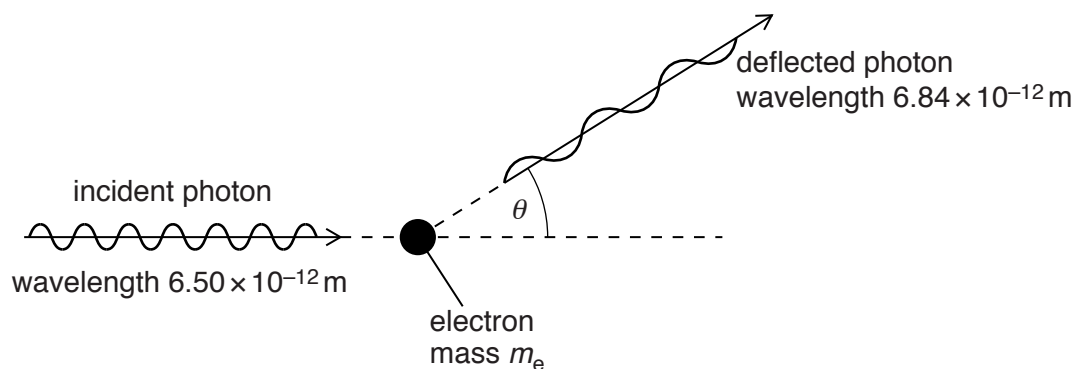


Fig. 8.1

The photon is deflected elastically by the electron of mass m_e . The wavelength of the deflected photon is $6.84 \times 10^{-12} \text{ m}$.

- (a) Calculate, for the incident photon,

- (i) its momentum,

momentum = ... Ns [2]

- (ii) its energy.

energy = ... J [2]

- (b) The angle θ through which the photon is deflected is given by the expression

$$\Delta\lambda = \frac{h}{m_e c} (1 - \cos \theta)$$

where $\Delta\lambda$ is the change in wavelength of the photon, h is the Planck constant and c is the speed of light in free space.

- (i) Calculate the angle θ .

$$\theta = \dots\dots\dots^\circ \quad [2]$$

- (ii) Use energy considerations to suggest why $\Delta\lambda$ must always be positive.

.....

 [3]

- 9 (a) An isotope of an element is radioactive. Explain what is meant by *radioactive decay*.

.....

.....

.....

..... [3]

- (b) At time t , a sample of a radioactive isotope contains N nuclei. In a short time Δt , the number of nuclei that decay is ΔN .

State expressions, in terms of the symbols t , Δt , N and ΔN for

- (i) the number of undecayed nuclei at time $(t + \Delta t)$,

number = ... [1]

- (ii) the mean activity of the sample during the time interval Δt ,

mean activity = ... [1]

- (iii) the probability of decay of a nucleus during the time interval Δt ,

probability = ... [1]

- (iv) the decay constant.

decay constant = ... [1]

- (c) The variation with time t of the activity A of a sample of a radioactive isotope is shown in Fig. 9.1.

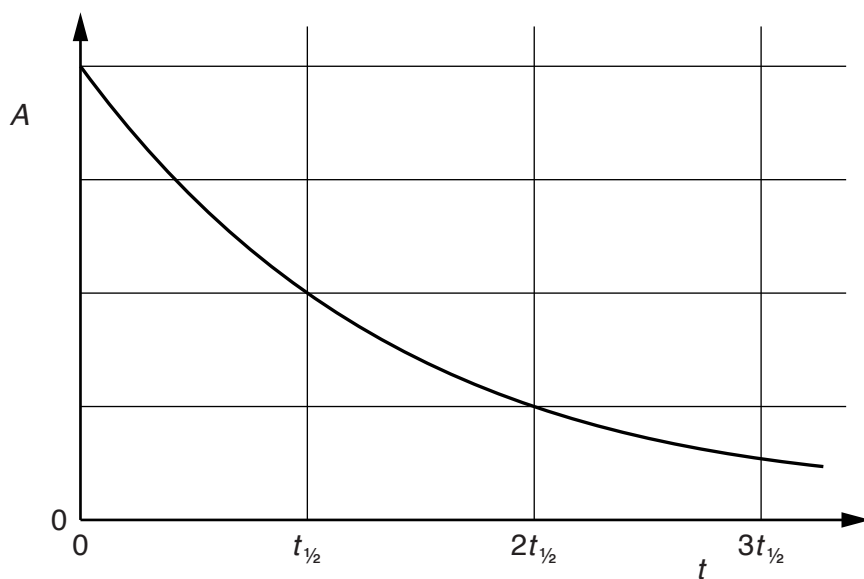


Fig. 9.1

The radioactive isotope decays to form a stable isotope S. At time $t = 0$, there are no nuclei of S in the sample.

On the axes of Fig. 9.2, sketch a graph to show the variation with time t of the number n of nuclei of S in the sample.

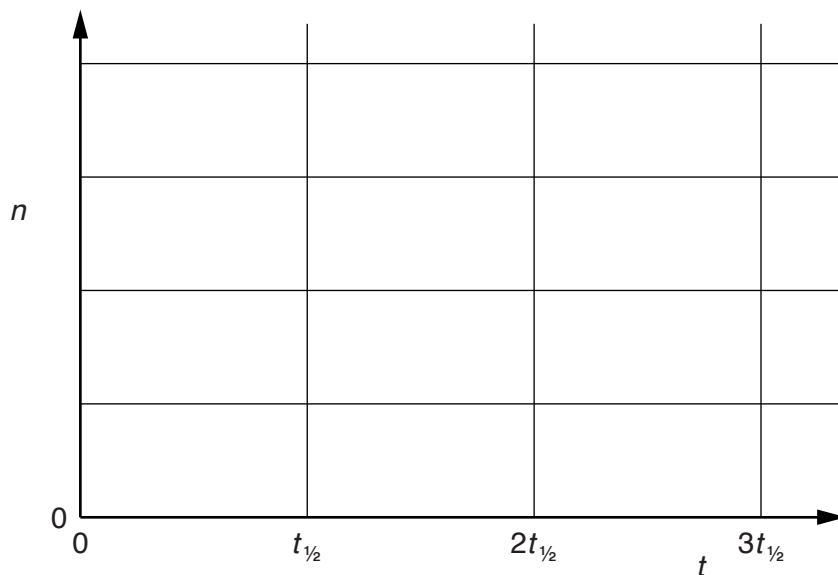


Fig. 9.2

[2]

Section B

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

- 10 An operational amplifier (op-amp) is used in the comparator circuit of Fig. 10.1.

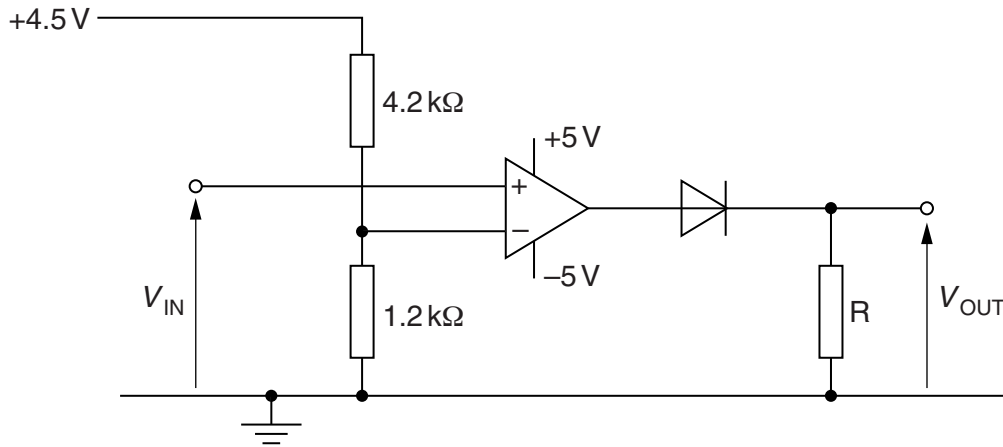


Fig. 10.1

- (a) (i) Show that the potential at the inverting input of the op-amp is +1.0V.

[1]

- (ii) Explain why the potential difference across resistor R is + 5V when V_{IN} is greater than 1.0V and is zero when V_{IN} is less than 1.0V.

$V_{IN} > 1.0V$:

.....

.....

$V_{IN} < 1.0V$:

.....

.....

[4]

(b) The variation with time t of the input voltage V_{IN} is shown in Fig. 10.2.

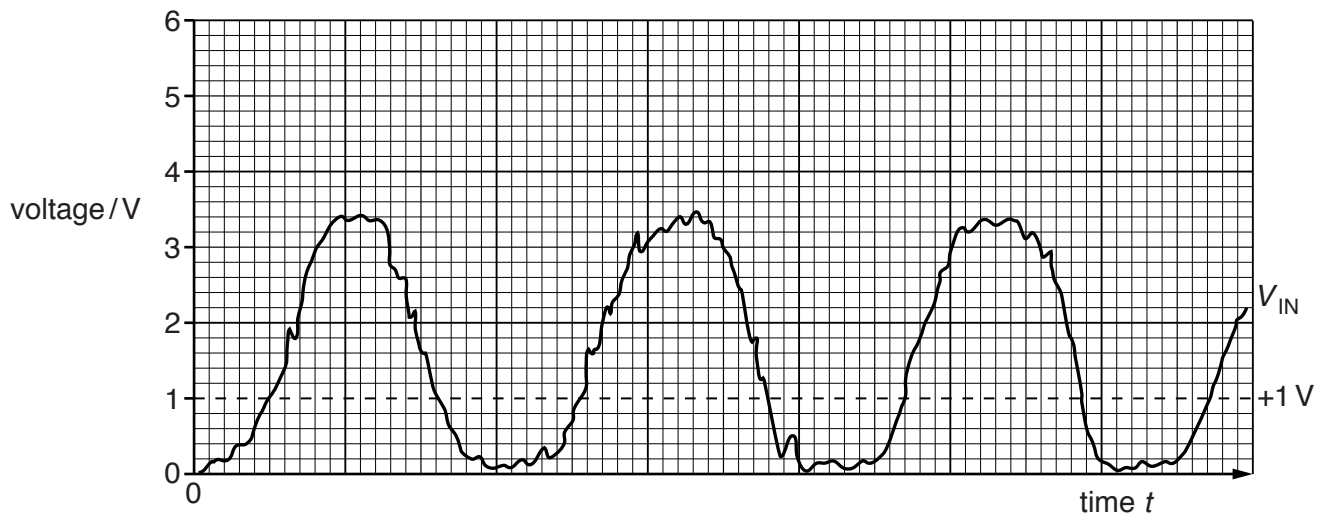


Fig. 10.2

- (i) On the axes of Fig. 10.2, draw the variation with time t of the output potential V_{OUT} . [2]
- (ii) Suggest a use for this type of circuit.

.....

..... [1]

- 11 (a) State and explain how, in an X-ray tube, the hardness of the X-ray beam is controlled.

.....

 [3]

- (b) A parallel beam of X-rays has intensity I_0 and is incident on a medium having a linear absorption (attenuation) coefficient μ .

- (i) State an equation for the variation of the intensity I with the thickness x of the medium.

..... [1]

- (ii) Data for the linear absorption (attenuation) coefficient μ for an X-ray beam in blood and in muscle is shown in Fig. 11.1.

	μ/cm^{-1}
blood	0.23
muscle	0.22

Fig. 11.1

Suggest why, if this X-ray beam is used to image blood vessels in muscle, contrast on the image would be poor.

.....

 [2]

- 12 (a)** Information may be carried by means of various channels of communication.

Name examples, one in each case, of devices where information is carried to the device using

- (i)** a wire pair,

..... [1]

- (ii)** a coaxial cable,

..... [1]

- (iii)** microwaves.

..... [1]

- (b)** State two advantages of optic fibres as compared with coaxial cables for long-range communication.

1.

2.

[2]

- (c)** An optic fibre has length 62 km and an attenuation per unit length of 0.21 dB km^{-1} .
The input power to the fibre is P . At the receiver, the noise power is $9.2 \mu\text{W}$.
The signal-to-noise ratio at the receiver is 25 dB.

- (i)** Calculate the ratio, in dB, of the input power P to the noise power at the receiver.

ratio = ... dB [2]

- (ii)** Use your answer in **(i)** to determine the input power P .

$P = \dots\dots\dots \text{ W}$ [2]

- 13** During magnetic resonance imaging to obtain information about internal body structures, a large constant magnetic field is used with a calibrated non-uniform magnetic field superimposed on it.

(a) State and explain the purpose of

(i) the large constant magnetic field,

.....

.....

..... [2]

(ii) the non-uniform magnetic field.

.....

.....

.....

..... [3]

- (b)** The de-excitation energy E (measured in joule) of a proton in magnetic resonance imaging is given by the expression

$$E = 2.82 \times 10^{-26} B$$

where B is the magnetic flux density measured in tesla.

The energy E is emitted as a photon of electromagnetic radiation in the radio-frequency range.

Calculate the magnetic flux density required for the radio frequency to be 42 MHz.

magnetic flux density = ... T [2]

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