78

Cambridge International AS & A Level

Cambridge International Examinations
Cambridge International Advanced Subsidiary and Advanced Level

CANDIDATE NAME	

CENTRE NUMBER						CANDIDATE NUMBER					

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PHYSICS **9702/41**

Paper 4 A Level Structured Questions **May/June 2016**

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 **26** printed pages and **2** blank pages.

DC (NF/SG) 108406/3

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Data

speed of light in free space	$c = 3.00 \times 10^{8}\,\mathrm{m\,s^{-1}}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{H\,m^{-1}}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12}\,\mathrm{F\,m^{-1}}$
	$(\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}\,\mathrm{m\,F^{-1}})$
elementary charge	$e = 1.60 \times 10^{-19}\,\mathrm{C}$
the Planck constant	$h = 6.63 \times 10^{-34}\,\mathrm{J\,s}$
unified atomic mass unit	$1\,\mathrm{u} = 1.66 \times 10^{-27}\,\mathrm{kg}$
rest mass of electron	$m_e = 9.11 \times 10^{-31}\,\mathrm{kg}$
rest mass of proton	$m_p = 1.67 \times 10^{-27}\,\mathrm{kg}$
molar gas constant	$R = 8.31\,\mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant	$N_A = 6.02 \times 10^{23}\,\mathrm{mol^{-1}}$
the Boltzmann constant	$k = 1.38 \times 10^{-23}\,\mathrm{J\,K^{-1}}$
gravitational constant	$G = 6.67 \times 10^{-11}\,\mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall	$g = 9.81\,\mathrm{m\,s^{-2}}$

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	$\phi = -\dfrac{Gm}{r}$
hydrostatic pressure	$p = \rho gh$
pressure of an ideal gas	$p = \frac{1}{3}\dfrac{Nm}{V}\langle c^2\rangle$
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	$f_o = \dfrac{f_s v}{v \pm v_s}$
electric potential	$V = \dfrac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy of charged capacitor	$W = \frac{1}{2}QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
Hall voltage	$V_H = \dfrac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \dfrac{0.693}{t_{\frac{1}{2}}}$

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

1 **(a)** By reference to the definition of gravitational potential, explain why gravitational potential is a negative quantity.

It is the work done in moving a small mass from infinity to a point in the gravitational field and since the gravitational force is attractive, the work done is negative [2] 1

(b) Two stars A and B have their surfaces separated by a distance of 1.4×10^{12} m, as illustrated in Fig. 1.1.

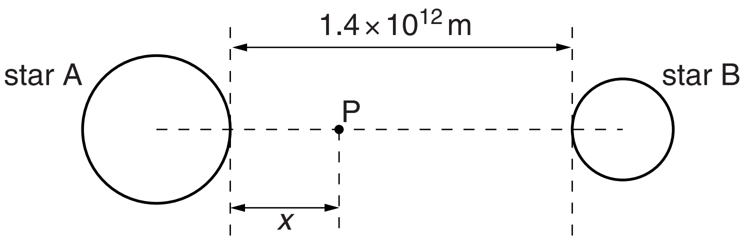


Fig. 1.1

Point P lies on the line joining the centres of the two stars. The distance x of point P from the surface of star A may be varied.

The variation with distance x of the gravitational potential ϕ at point P is shown in Fig. 1.2.

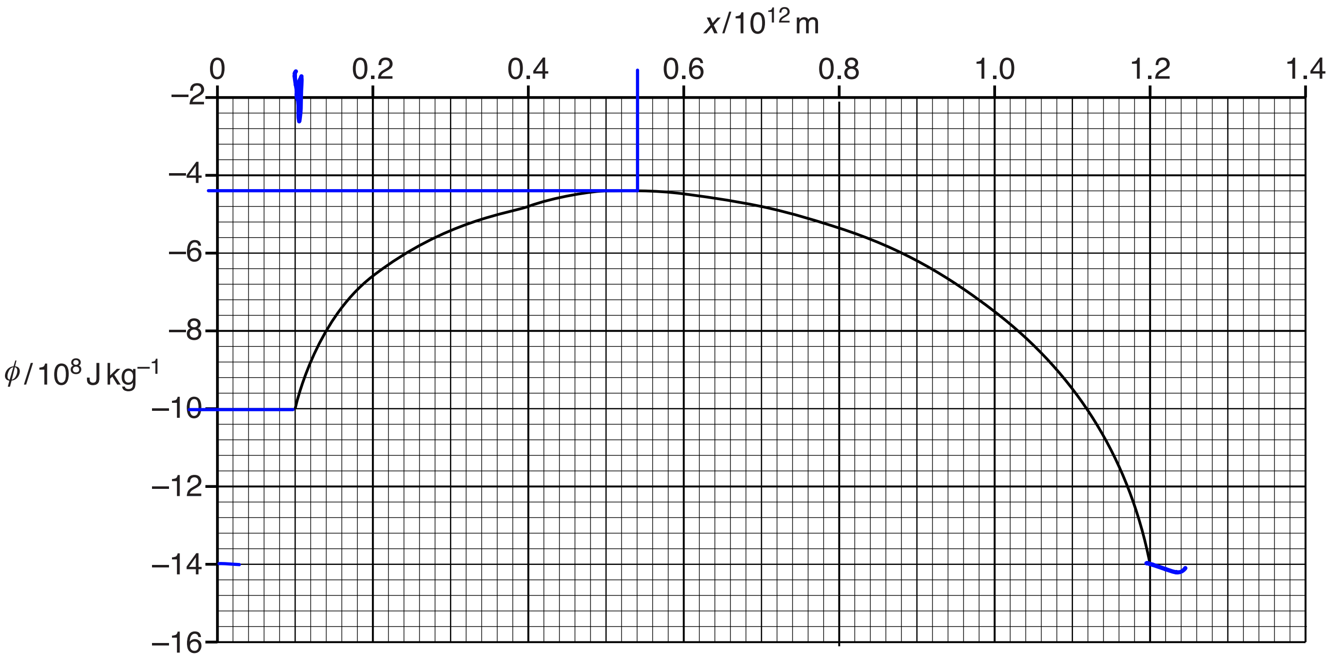


Fig. 1.2

A rock of mass 180 kg moves along the line joining the centres of the two stars, from star A towards star B.

#

(i) Use data from Fig. 1.2 to calculate the change in kinetic energy of the rock when it moves from the point where $x = 0.1 \times 10^{12}$ m to the point where $x = 1.2 \times 10^{12}$ m.
State whether this change is an increase or a decrease.

$\Delta\phi \times m$

$4 \times 10^{8} \times 180$

0.

#

change = 7.2×10^{10} J

increases

when decreases?

[3]

(ii) At a point where $x = 0.1 \times 10^{12}$ m, the speed of the rock is *v*.

Determine the minimum speed *v* such that the rock reaches the point where $x = 1.2 \times 10^{12}$ m.

#

$\Delta\phi = \frac{1}{2} m v^2$

$v = \sqrt{2\Delta\phi}$

$= \sqrt{2 \times (10 - 4.4) \times 10^{8}}$

$= 3.3466 \times 10^{4}$

minimum speed = 3.3×10^{4} m s^{-1} [3]

[Total: 8]

1

2 **(a)** An ideal gas is assumed to consist of atoms or molecules that behave as hard, identical spheres that are in continuous motion and undergo elastic collisions.

State two further assumptions of the kinetic theory of gases.

Hanke

1. molecules have negligible volume compared to vol of container

2. All molecules have same speed.

[2]

(b) Helium-4 ($^4_2$He) may be assumed to be an ideal gas.

(i) Show that the mass of one atom of helium-4 is 6.6×10^{-24} g.

1 mol = 6.02×10^{23} atoms = 4 g

1 atom = 6.6 ~~4~~ 4 5 $\times 10^{-24}$

$\approx 6.6 \times 10^{-24}$

[1]

(ii) The mean kinetic energy E_K of an atom of an ideal gas is given by the expression

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

Calculate the root-mean-square (r.m.s.) speed of a helium-4 atom at a temperature of 27 °C.

$\frac{3}{\cancel{2}} KT = \frac{1}{\cancel{2}} m \langle c^2 \rangle$

$\langle c^2 \rangle = \frac{3KT}{m}$

$c_{rms} = \sqrt{\frac{3KT}{m}} = \sqrt{\frac{3 \times 1.38 \times 10^{-23} \times (27+273)}{6.64 \times 10^{-24}}}$

$= 43.249$

r.m.s. speed = 43 m s^{-1} [3]

[Total: 6]

3 **(a)** State, by reference to displacement, what is meant by *simple harmonic motion*.

To and fro motion of a body about a fixed point. The body's acceleration is proportional to its displacement.
" " always directed towards the fixed point.

[2] 1

(b) A mass is undergoing oscillations in a vertical plane.

The variation with displacement *x* of the acceleration *a* of the mass is shown in Fig. 3.1.

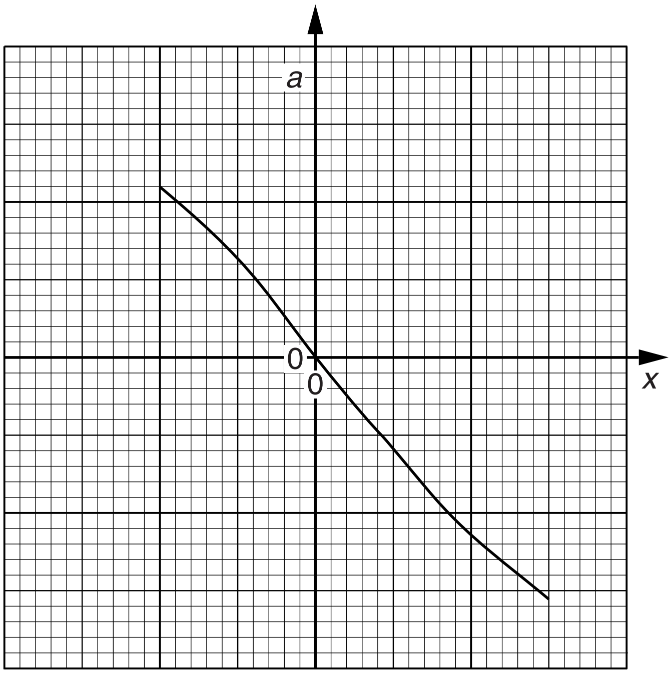


Fig. 3.1

State two reasons why the motion of the mass is not simple harmonic.

1. line isn't straight which shows acc isn't proportional to displacement

2. +ve displacement is not equal to -ve desplacement as graph isnt centered

[2] 1

(c) A block of wood is floating in a liquid, as shown in Fig. 3.2.

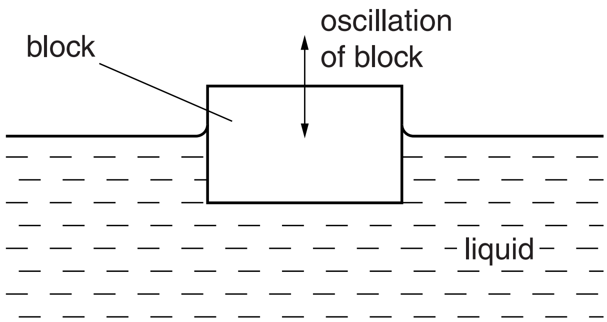


Fig. 3.2

The block is displaced vertically and then released.

The variation with time t of the displacement y of the block from its equilibrium position is shown in Fig. 3.3.

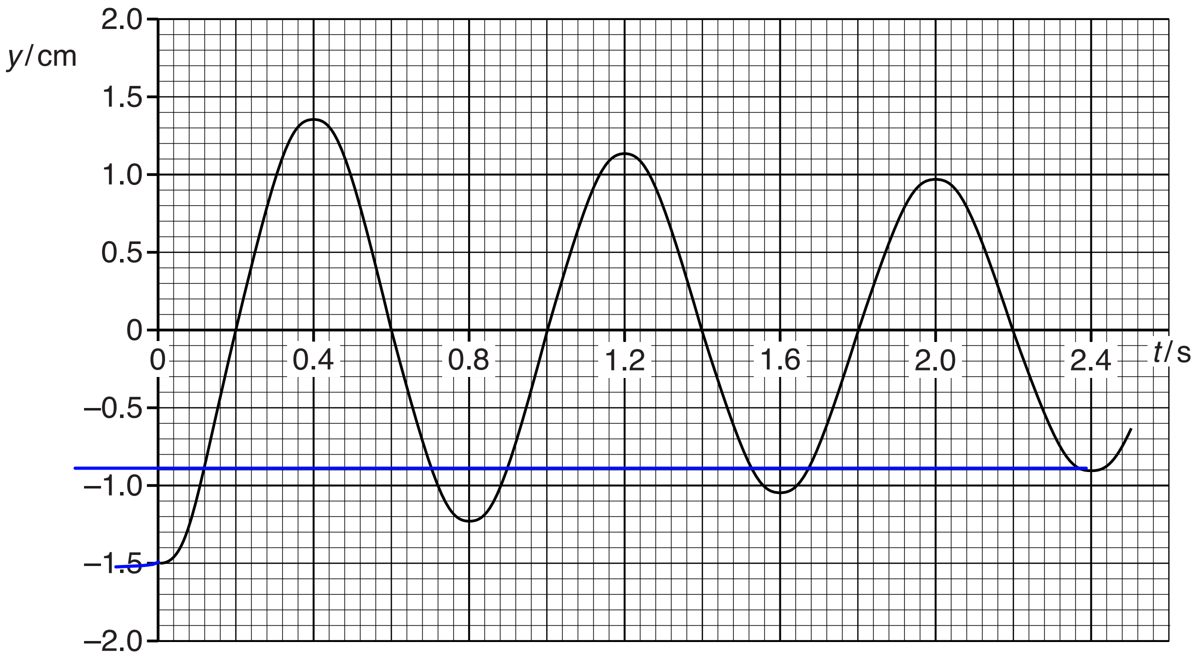


Fig. 3.3

Use data from Fig. 3.3 to determine

(i) the angular frequency ω of the oscillations,

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.8} = 7.85398$$

ω = ...7.9.......... rad s^{-1} [2]

(ii) the maximum vertical acceleration of the block.

$a = -\omega^2 x_0$

$= -(2.85398)^2 \left(-\frac{1.5}{100}\right) = 0.12217$

not showing - in second step, ok??

maximum acceleration = ...0.12........ m s^{-2} [2]

1

(iii) The block has mass 120 g.

The oscillations of the block are damped. Calculate the loss in energy of the oscillations of the block during the first three complete periods of its oscillations.

$\frac{1}{2} m \omega^2 x_0^2$

$\frac{1}{2} \times 0.12 \times (2.85398)^2 (0.015^2 - 0.009^2)$

$= 7.037 \times 10^{-5}$

energy loss = ...7.0×10^{-5}........ J [3]

1

[Total: 11]

7

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

It is the product of density and speed of sound in that medium.

[2]

(ii) The intensity reflection coefficient α is given by the expression

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

Explain the meanings of the symbols in this expression.

#omki α: ~~Reflection coefficient~~, tells us how much of a beam reflects back from a boundary b/w two materials

Z_2 and Z_1:

#

[2]

(b) A parallel beam of ultrasound has intensity I_0 as it enters a muscle.
The beam passes through a thickness of 3.4 cm of muscle before being incident on the boundary with a bone, as shown in Fig. 4.1.

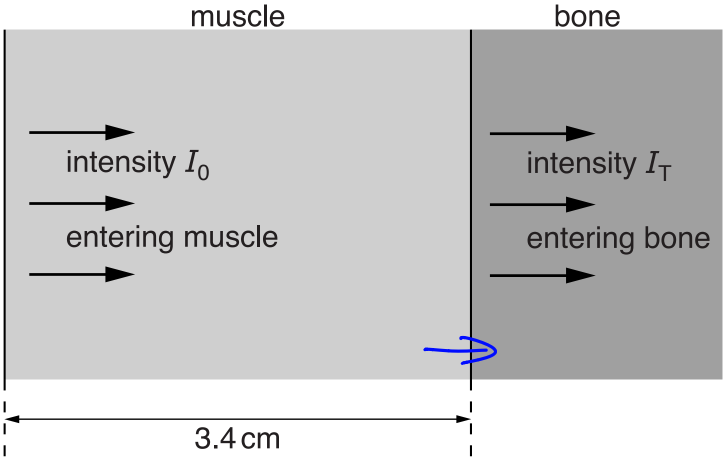


Fig. 4.1

The intensity of the ultrasound beam as it passes into the bone is I_T.

Some data for muscle and bone are given in Fig. 4.2.

	linear absorption coefficient / m^{-1}	specific acoustic impedance / $kg\,m^{-2}\,s^{-1}$
muscle bone	23 130	1.7×10^6 6.3×10^6

Fig. 4.2

Calculate the ratio $\frac{I_T}{I_0}$.

$$\alpha = \frac{(6.3\times10^6 - 1.7\times10^6)^2}{(6.3\times10^6 + 1.7\times10^6)^2}$$

$\alpha = 0.330625$

$1-\alpha = 0.669375$

$$\frac{I_T}{I_0} = e^{-\mu x} \times (1-\alpha)$$

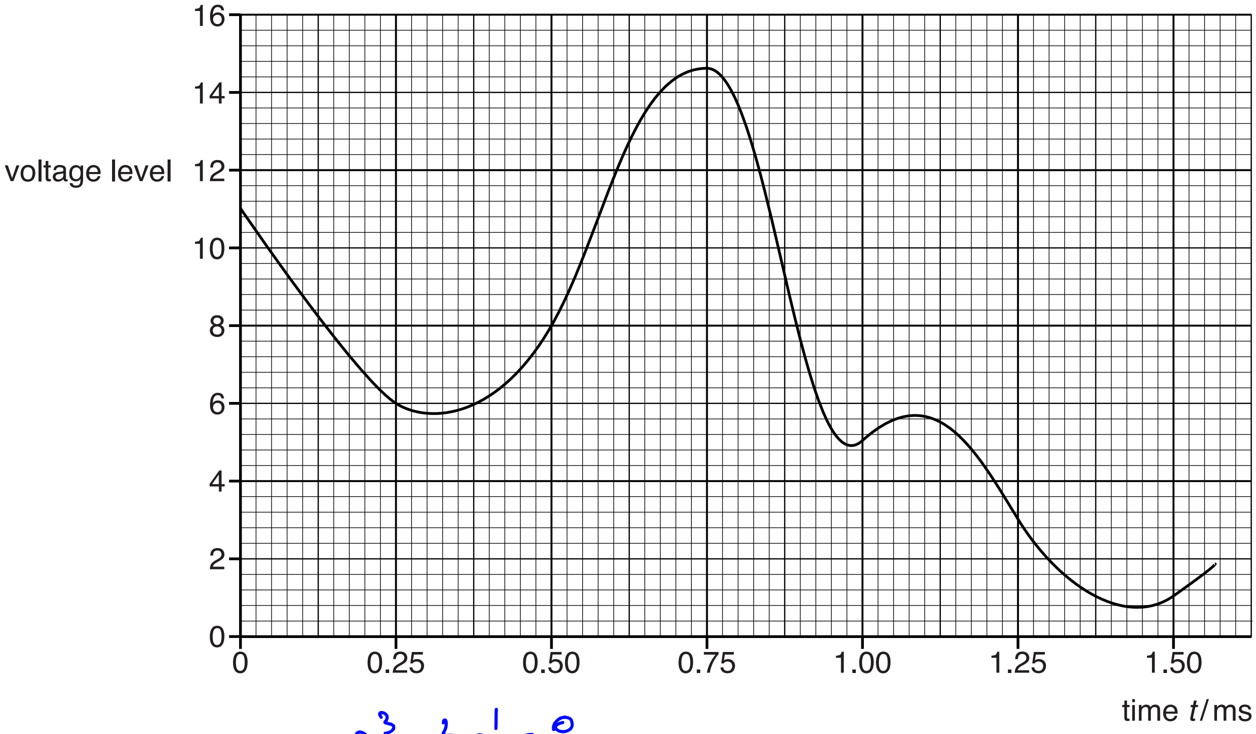
$$= e^{-23\times0.034} \times 0.669375$$

$$= 0.30623$$

ratio = 0.31 [5]

[Total: 9]

5 The variation with time *t* of the voltage level of part of an analogue signal is shown in Fig. 5.1.



2^3 2^2 2^1 2^0
8 4 2 1

Fig. 5.1

The signal is sampled at 0.25 ms intervals. Each sample is converted into a four-bit digital number.

Fig. 5.2 lists various times *t* at which the voltage level is sampled.
The digital number for time *t* = 0 is shown.

time *t* / ms	0	0.25	0.50	0.75	1.00	1.25	1.50
digital number	1011	0110	1000	1110	0101	0011	0001

Fig. 5.2

(a) **(i)** On Fig. 5.2, underline the most significant bit (MSB) for the digital number at time *t* = 0. [1]

(ii) Complete Fig. 5.2 for the times shown. [2]

(b) After transmission of the digital numbers, the signal is passed through a digital-to-analogue converter (DAC).

On Fig. 5.3, plot the transmitted analogue signal from the DAC.

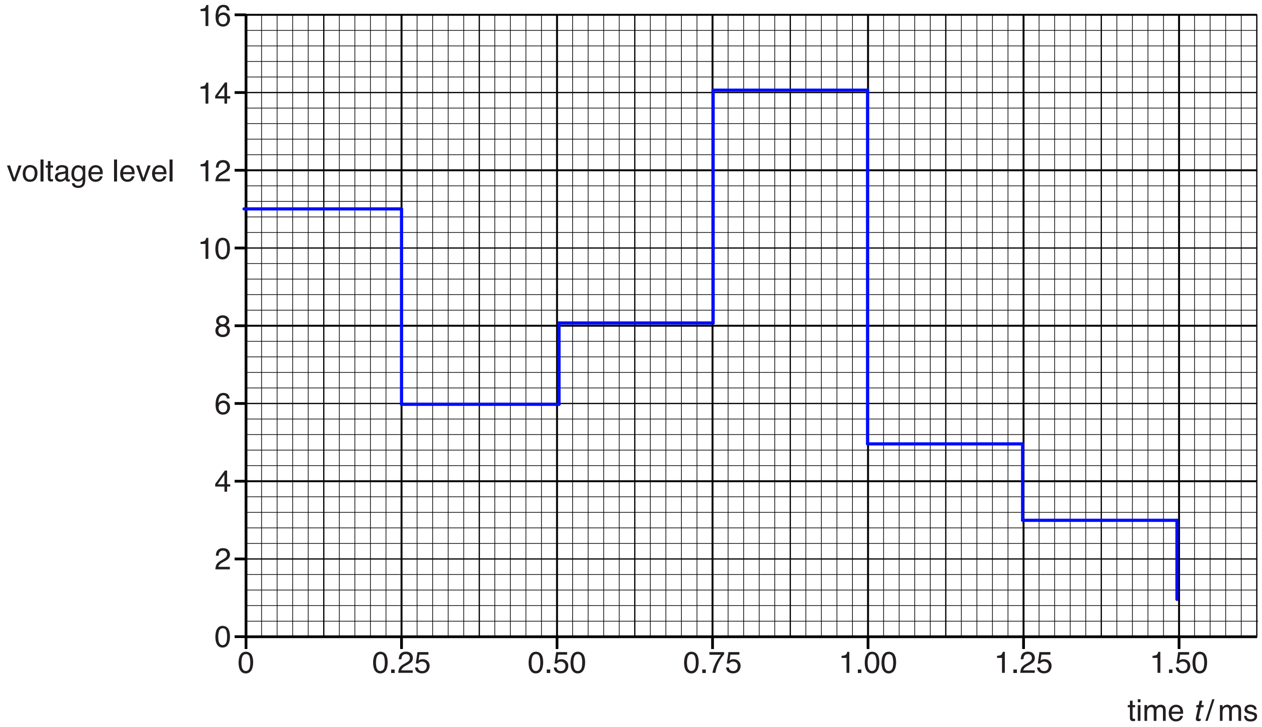


Fig. 5.3

[3]

(c) The transmitted signal in **(b)** has less detail than the original signal in Fig. 5.1.

Suggest and explain two means by which the level of detail in the transmitted signal could be increased.

1. increasing sampling rate, decreases step width

2. Adding additional bits, " " height

[4]

[Total: 10]

10

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6 A solid metal sphere of radius R is isolated in space. The sphere is positively charged so that the electric potential at its surface is V_S. The electric field strength at the surface is E_S.

(a) On the axes of Fig. 6.1, show the variation of the electric potential with distance x from the centre of the sphere for values of x from $x = 0$ to $x = 3R$.

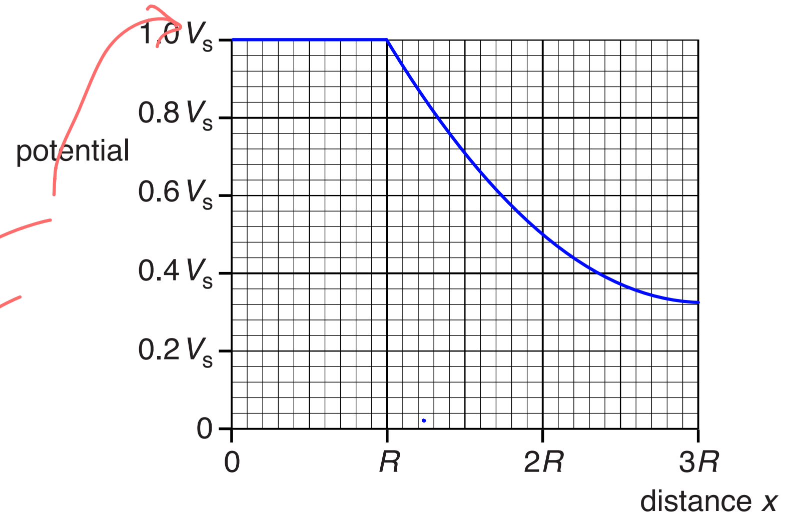


Fig. 6.1

[3]

(b) On the axes of Fig. 6.2, show the variation of the electric field strength with distance x from the centre of the sphere for values of x from $x = 0$ to $x = 3R$.

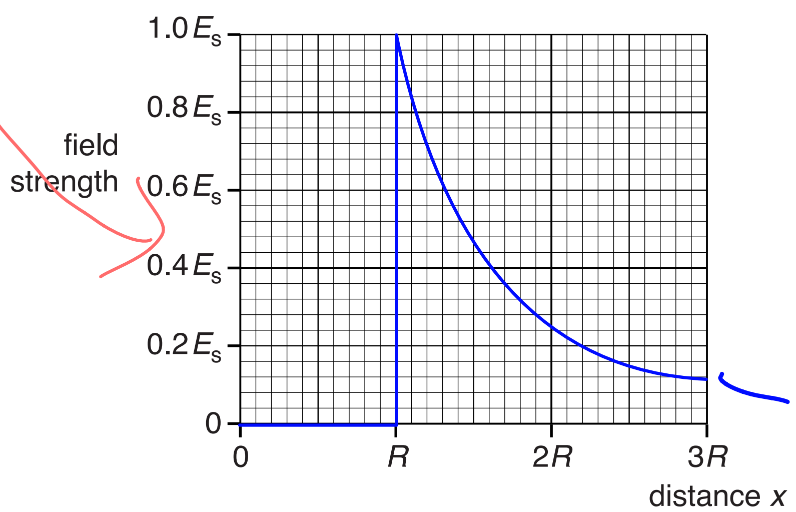


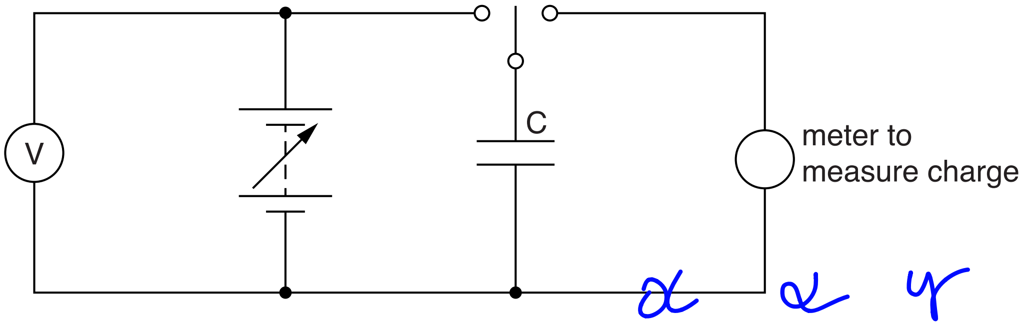
Fig. 6.2

[3]

[Total: 6]

6

7 A student sets up the circuit shown in Fig. 7.1 to measure the charge on a capacitor C for different values of potential difference across the capacitor.



x x y

Fig. 7.1 10 20

The variation with potential difference V of the charge Q stored on the capacitor is shown in Fig. 7.2.

20 30

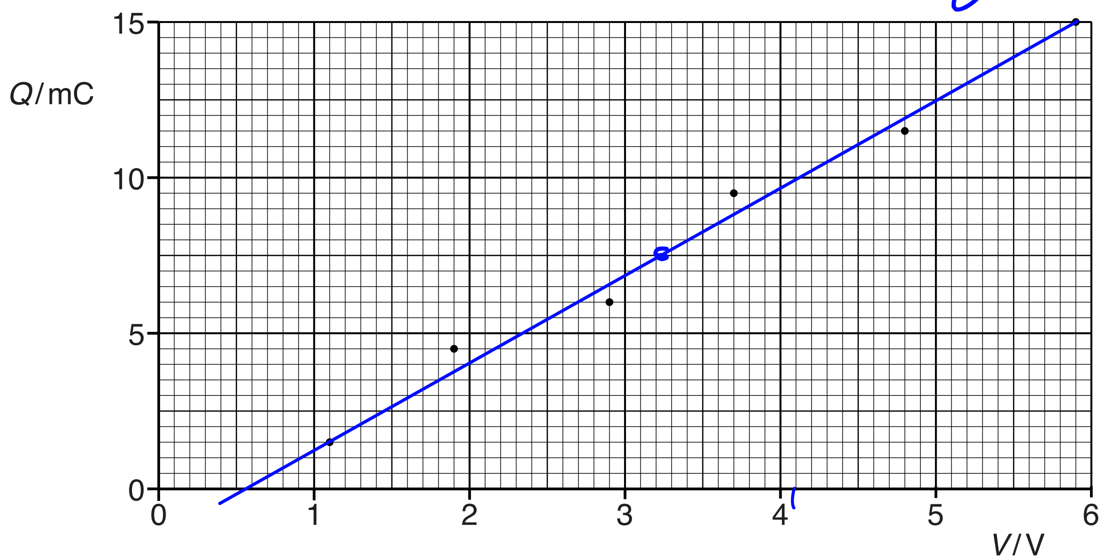


Fig. 7.2 ?? ?? what other type? random?

(a) State and explain how Fig. 7.2 indicates that there is a systematic error in the readings of one of the meters.

Ankit Tabhi

....

....

.... [2]

(b) Use Fig. 7.2 to determine the capacitance, in μF, of capacitor C.

$C = \frac{Q}{V} = \frac{10 \times 10^{-3}}{4.1}$

$= 2.439 \times 10^{-3} = f$

$= 2439 \mu f$

2

capacitance = ~~2400~~ 2800 μF [3]

(c) Use your answer in **(b)** to determine the additional energy stored in the capacitor C when the potential difference across it is increased from 6.0 V to 9.0 V.

$Q = C \Delta V$

$= 2.439 \times 10^{-3} (3)$

energy = 7.3×10^{-3} J [3]

[Total: 8]

2

8 The circuit of an inverting amplifier incorporating an ideal operational amplifier (op-amp) is shown in Fig. 8.1.

$V = \frac{I}{R}$

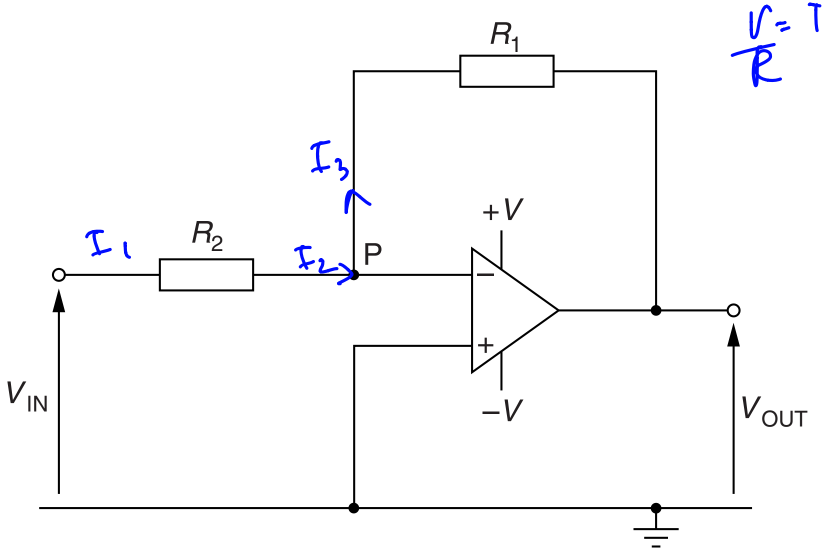


Fig. 8.1

(a) Explain why point P is known as a *virtual earth*.

As the amplifier is ideal, gain is infinite so, for the op-amp to not saturate $V^- \approx V^+$, V^+ is 0 $\therefore$ V^- is ≈ 0.

[3]

(b) Derive an expression, in terms of the resistances R_1 and R_2, for the gain of the amplifier circuit.
Explain your working.

\# Anki

$$I_1 = I_2 + I_3$$

$$\frac{V}{R_2} = \frac{V}{R_2} + \frac{V}{R_1}$$

[3]

(c) A relay and the output terminals of the amplifier circuit are shown in Fig. 8.2.

#anki

#check

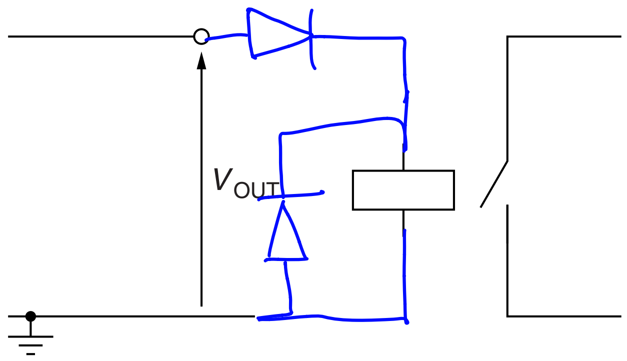


Fig. 8.2

On Fig. 8.2, show how the relay may be connected to the amplifier output so that the relay operates only when V_{OUT} is positive. [3]

[Total: 9]

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9 A thin rectangular slice of aluminium has sides of length 65 mm, 50 mm and 0.10 mm, as shown in Fig. 9.1.

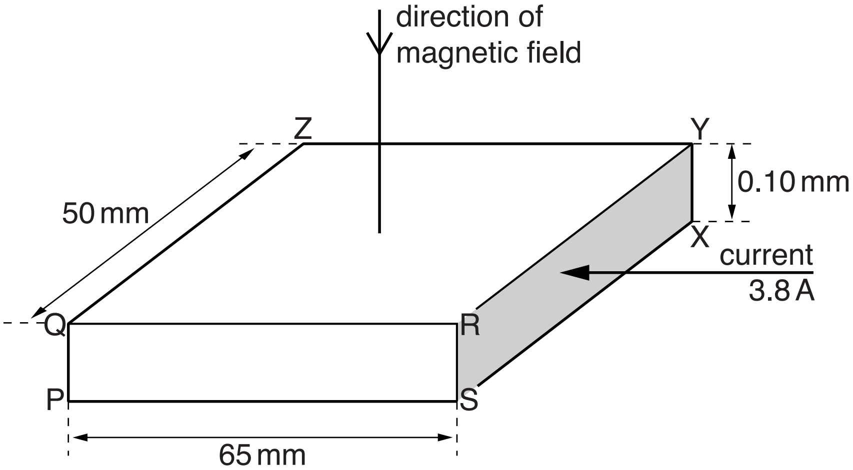

Fig. 9.1 (not to scale)

Some of the corners of the slice are labelled.

A current I of 3.8 A is normal to face RSXY of the slice.

In aluminium, the number of free electrons per unit volume is $6.0 \times 10^{28}\,m^{-3}$.

A uniform magnetic field of magnetic flux density B equal to 0.13 T is normal to face QRYZ of the aluminium slice in the direction from Q to P.

A Hall voltage V_H is developed across the slice and is given by the expression

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

22

$\frac{0.1}{1000}$

(a) Use Fig. 9.1 to state the magnitude of the distance t.

t = ...0.1.................................... mm [1]

(b) Calculate the magnitude of the Hall voltage V_H.

$$V_H = \frac{0.13 \times 3.8}{6 \times 10^{28} \times \frac{0.01}{100} \times 1.6 \times 10^{-19}}$$

$$= 5.1458 \times 10^{-7}$$

V_H = ...5.1×10^{-7}........................ V [2]

[Total: 3]

10 (a) A coil of insulated wire is wound on a copper core, as illustrated in Fig. 10.1.

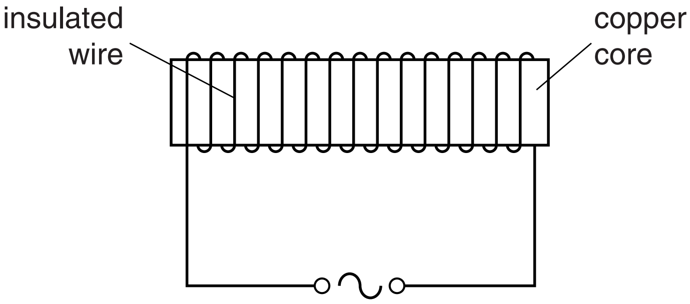

Fig. 10.1

An alternating current is passed through the coil.

The heating effect of the current in the coil is negligible.

Explain why the temperature of the core rises.

The current in the coil causes a changing magnetic flux which cuts with the copper core. This induces an emf in the copper core. Eddy currents are formed in the core which heats it up which also oppose the AC

3

[4]

(b) Two hollow tubes of equal length hang vertically as shown in Fig. 10.2.

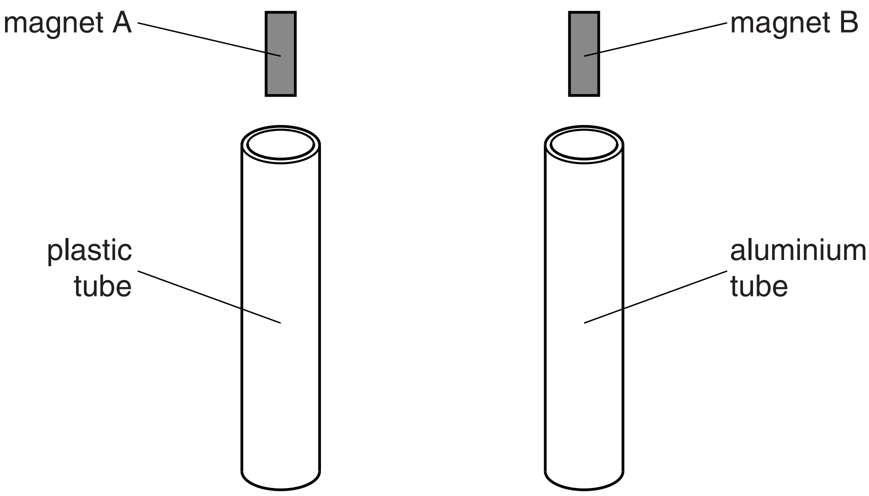

Fig. 10.2

One tube is made of plastic and the other of aluminium.

Two small similar bar magnets A and B are held above the tubes and then released simultaneously.

The magnets do not touch the sides of the tubes.

Explain why magnet B takes much longer than magnet A to fall through the tube.

As the magnet B enters the aluminium tube, its field lines cut the field lines of the aluminium tube this induces emf and eddy currents in the tube. According to Lenz's law this emf tries to oppose the change causing it which in this case is the movement of the magnet. So there is a upward force on the magnet, slowing it down. with magnet A, the tube is plastic so there is no induction and magnet A falls at 9.81 ms^{-2}

#

[5] 4

[Total: 9]

7

11 The variation with time t of the sinusoidal current I in a resistor of resistance 450 Ω is shown in Fig. 11.1.

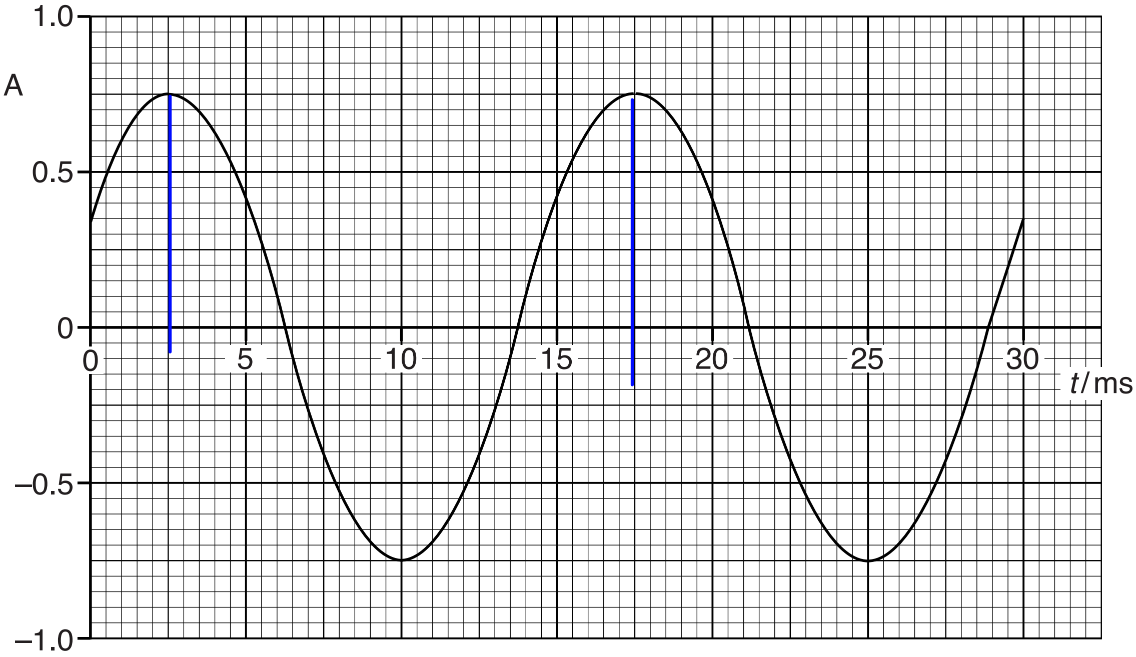

Fig. 11.1

Use data from Fig. 11.1 to determine, for the time $t = 0$ to $t = 30$ ms,

(a) the frequency of the current,

$$f = \frac{1}{T} = \frac{1}{(17.5 - 2.5)\times10^{-3}} = 66.666$$

frequency = ...67.......... Hz [2]

(b) the mean current,

mean current = ...0.......... A [1]

(c) the root-mean-square (r.m.s.) current,

$$\frac{I_0}{\sqrt{2}} = 0.53033$$

r.m.s. current = ...0.53.......... A [2]

(d) the energy dissipated by the resistor.

$P \times T = I^2 R T$

$= 0.53^2 \times 450 \times 30 \times 10^{-3}$

$= 3.792$

energy = ...3.8...... J [2]

[Total: 7]

7

12 Some of the electron energy bands in a solid are illustrated in Fig. 12.1.

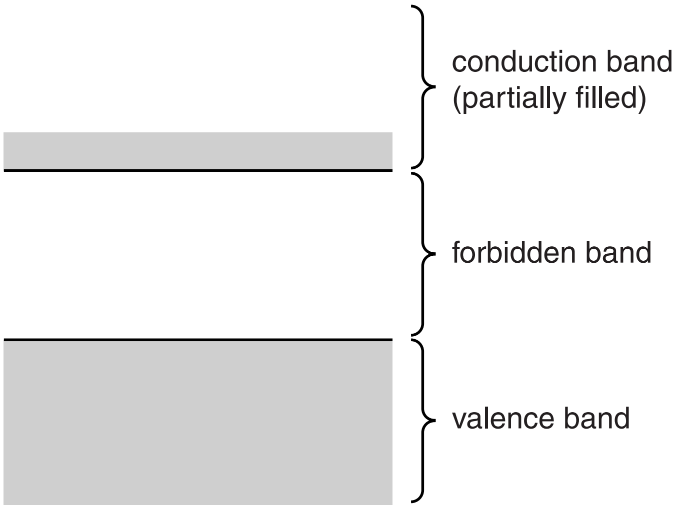

Fig. 12.1

(a) In isolated atoms, electron energy levels have discrete values.
Suggest why, in a solid, there are energy bands, rather than discrete energy levels.

As there are many atoms and therefore all the electrons from different atoms have interaction and so they form cloud of energy levels.

[3] 1

(b) A light-dependent resistor (LDR) consists of an intrinsic semiconductor.

Use band theory to explain the dependence on light intensity of the resistance of the LDR when it is at constant temperature.

In darkness, the conduction band is mostly empty ∴ high resistance. In daylight however, electrons absorb energy from photons and jump to the conduction band, leaving holes behind in the valence band. Together an electron and a hole make up one charge carrier. More charge charge carriers in daylight ∴ resistance decreases.

[5]

[Total: 8]

6

13 Copper-66 is a radioactive isotope.

When a nucleus of copper-66 decays, the emissions include a β^- particle and a γ-ray photon.

The count rate produced from a sample of the isotope copper-66 is measured using a detector and counter, as illustrated in Fig. 13.1.

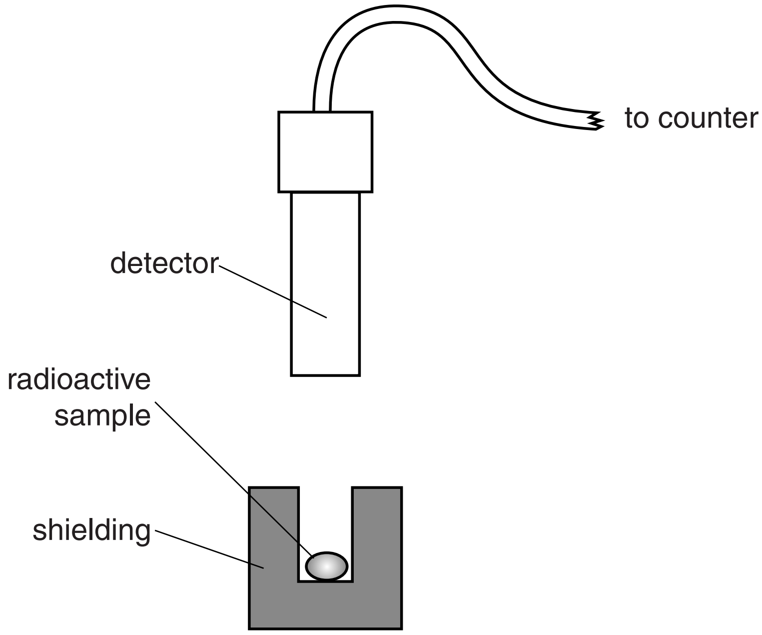

Fig. 13.1

(a) State three reasons why the activity of the sample of copper-66 is not equal to the measured count rate.

1. Background radiation

2. deadtime of detector

3. Some radiation may be absorbe in air before reaching the detector.

[3]

(b) In a time of 42.0 minutes, the count rate from the sample of copper-66 is found to decrease from 3.62×10^4 Bq to 1.21×10^2 Bq.

Calculate the half-life of copper-66.

$$\frac{\ln\left(\frac{1.21\times10^2}{3.62\times10^4}\right)}{-42} = \lambda$$

$\lambda = 0.1357$

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{0.1357}$$

5.10648 mins

half-life = ...5.1........ minutes [2]

(c) The γ-ray photons emitted from radioactive nuclei have specific energies, dependent on the nucleus emitting the photons.

By comparison with emission line spectra, suggest what can be deduced about energy levels in nuclei.

2 ... 2

That there are discrete energy levels.

.... [1]

[Total: 6]

6