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9702/41

May/June 2012

2 hours

No Additional Materials are required.

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

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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,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
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.

For
Examiner's
Use

- 1 (a) Define *gravitational potential* at a point.

.....
 [1]

- (b) The gravitational potential ϕ at distance r from point mass M is given by the expression

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

where G is the gravitational constant.

Explain the significance of the negative sign in this expression.

.....

 [2]

- (c) A spherical planet may be assumed to be an isolated point mass with its mass concentrated at its centre. A small mass m is moving near to, and normal to, the surface of the planet. The mass moves away from the planet through a short distance h .

State and explain why the change in gravitational potential energy ΔE_p of the mass is given by the expression

$$\Delta E_p = mgh$$

where g is the acceleration of free fall.

.....

 [4]

- (d) The planet in (c) has mass M and diameter 6.8×10^3 km. The product GM for this planet is $4.3 \times 10^{13} \text{ N m}^2 \text{ kg}^{-1}$.

For
Examiner's
Use

A rock, initially at rest a long distance from the planet, accelerates towards the planet. Assuming that the planet has negligible atmosphere, calculate the speed of the rock as it hits the surface of the planet.

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

- 2 (a) The kinetic theory of gases is based on some simplifying assumptions.
The molecules of the gas are assumed to behave as hard elastic identical spheres.
State the assumption about ideal gas molecules based on

For
Examiner's
Use

- (i) the nature of their movement,

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

- (ii) their volume.

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

- (b) A cube of volume V contains N molecules of an ideal gas. Each molecule has a component c_x of velocity normal to one side S of the cube, as shown in Fig. 2.1.

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Use

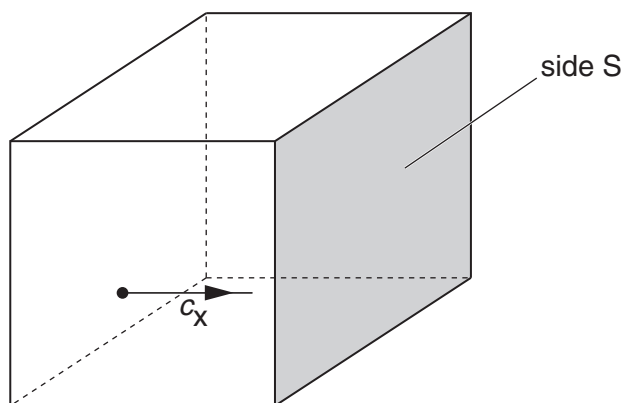


Fig. 2.1

The pressure p of the gas due to the component c_x of velocity is given by the expression

$$pV = Nmc_x^2$$

where m is the mass of a molecule.

Explain how the expression leads to the relation

$$pV = \frac{1}{3}Nm\langle c^2 \rangle$$

where $\langle c^2 \rangle$ is the mean square speed of the molecules.

[3]

- (c) The molecules of an ideal gas have a root-mean-square (r.m.s.) speed of 520 m s^{-1} at a temperature of 27°C .

Calculate the r.m.s. speed of the molecules at a temperature of 100°C .

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

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

.....

.....

..... [2]

- (b) The heater in an electric kettle has a power of 2.40 kW.
When the water in the kettle is boiling at a steady rate, the mass of water evaporated in 2.0 minutes is 106 g.
The specific latent heat of vaporisation of water is 2260 J g^{-1} .

Calculate the rate of loss of thermal energy to the surroundings of the kettle during the boiling process.

rate of loss = ... W [3]

- 4 A small metal ball is suspended from a fixed point by means of a string, as shown in Fig. 4.1.

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Examiner's
Use

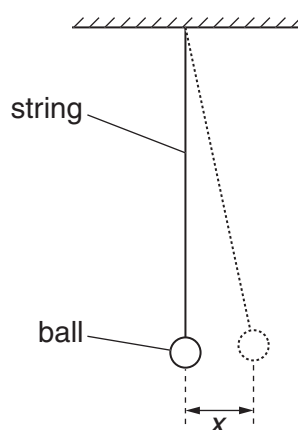


Fig. 4.1

The ball is pulled a small distance to one side and then released. The variation with time t of the horizontal displacement x of the ball is shown in Fig. 4.2.

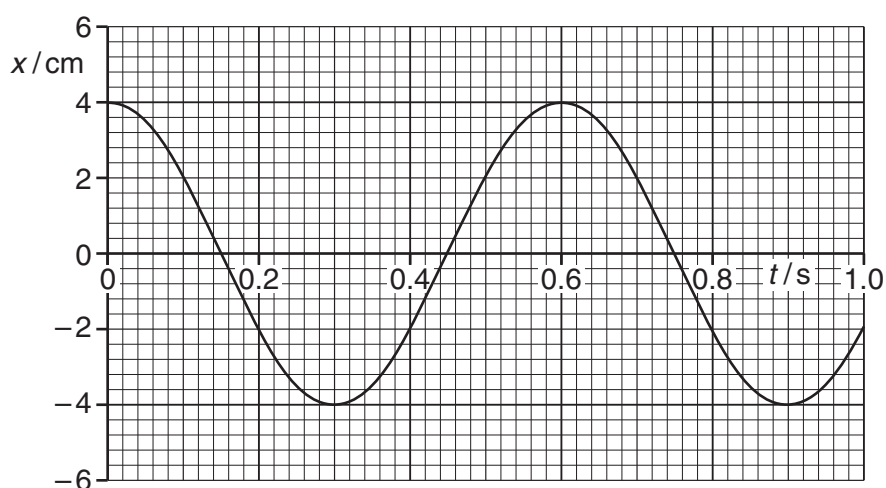


Fig. 4.2

The motion of the ball is simple harmonic.

- (a) Use data from Fig. 4.2 to determine the horizontal acceleration of the ball for a displacement x of 2.0 cm.

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

- (b) The maximum kinetic energy of the ball is E_K .
On the axes of Fig. 4.3, sketch a graph to show the variation with time t of the kinetic energy of the ball for the first 1.0 s of its motion.

For
Examiner's
Use

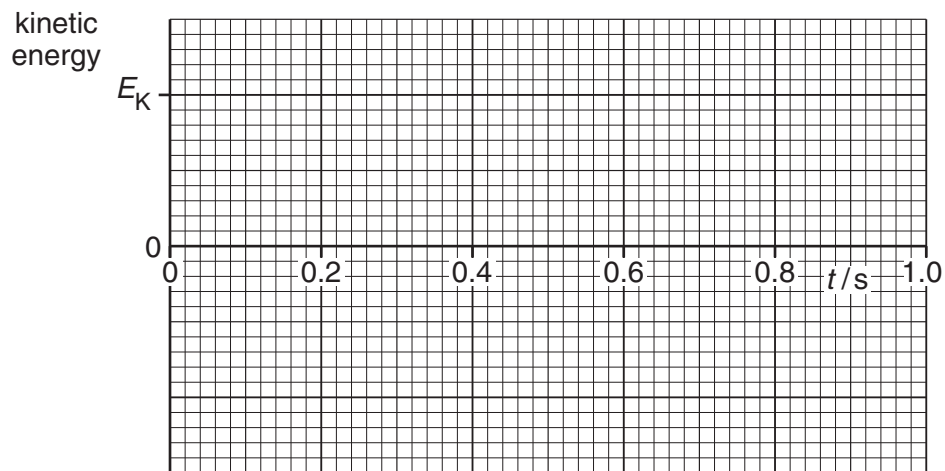


Fig. 4.3

[3]

- 5 (a) Define *electric field strength*.

.....
 [1]

- (b) An isolated metal sphere is to be used to store charge at high potential. The charge stored may be assumed to be a point charge at the centre of the sphere. The sphere has a radius of 25 cm. Electrical breakdown (a spark) occurs in the air surrounding the sphere when the electric field strength at the surface of the sphere exceeds $1.8 \times 10^4 \text{ V cm}^{-1}$.

- (i) Show that the maximum charge that can be stored on the sphere is $12.5 \mu\text{C}$.

[2]

- (ii) Calculate the potential of the sphere for this maximum charge.

potential = ... V [2]

- 6 A sinusoidal alternating voltage supply is connected to a bridge rectifier consisting of four ideal diodes. The output of the rectifier is connected to a resistor R and a capacitor C as shown in Fig. 6.1.

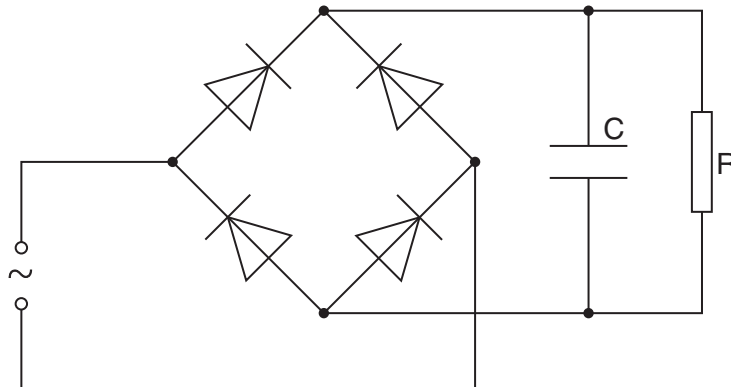


Fig. 6.1

The function of C is to provide some smoothing to the potential difference across R . The variation with time t of the potential difference V across the resistor R is shown in Fig. 6.2.

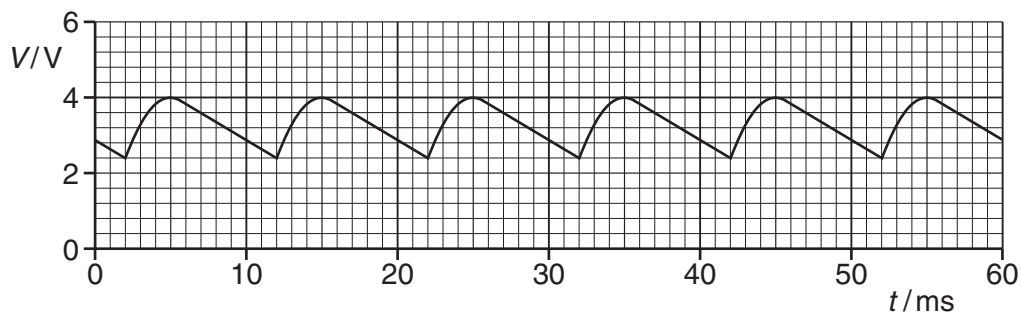


Fig. 6.2

- (a) Use Fig. 6.2 to determine, for the alternating supply,

- (i) the peak voltage,

peak voltage = ... V [1]

- (ii) the root-mean-square (r.m.s.) voltage,

r.m.s. voltage = ... V [1]

- (iii) the frequency. Show your working.

For
Examiner's
Use

frequency = ... Hz [2]

- (b) The capacitor C has capacitance $5.0\ \mu\text{F}$.
For a single discharge of the capacitor through the resistor R, use Fig. 6.2 to

- (i) determine the change in potential difference,

change = ... V [1]

- (ii) determine the change in charge on each plate of the capacitor,

change = ... C [2]

- (iii) show that the average current in the resistor is $1.1 \times 10^{-3}\text{ A}$.

[2]

- (c) Use Fig. 6.2 and the value of the current given in (b)(iii) to estimate the resistance of resistor R.

For
Examiner's
Use

resistance = ... Ω [2]

- 7 Two long straight parallel copper wires A and B are clamped vertically. The wires pass through holes in a horizontal sheet of card PQRS, as shown in Fig. 7.1.

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Examiner's
Use

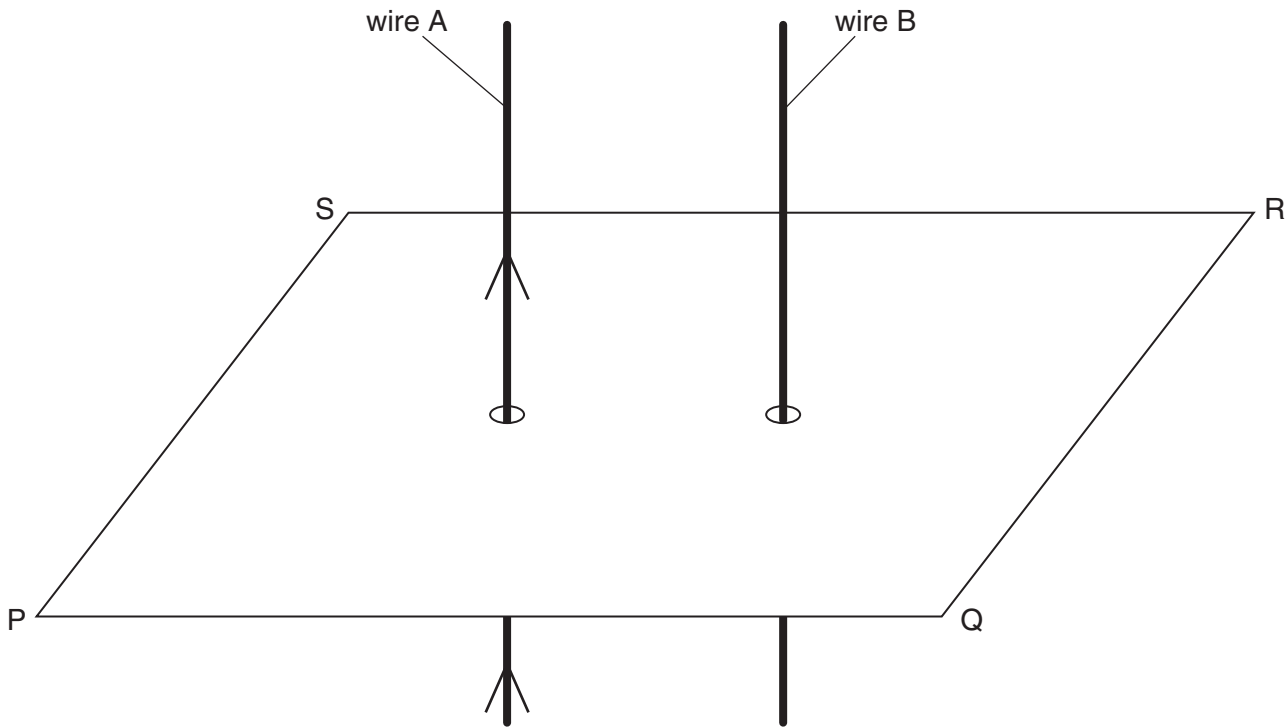


Fig. 7.1

- (a) There is a current in wire A in the direction shown on Fig. 7.1.
On Fig. 7.1, draw four field lines in the plane PQRS to represent the magnetic field due to the current in wire A. [3]
- (b) A direct current is now passed through wire B in the same direction as that in wire A.
The current in wire B is larger than the current in wire A.
- (i) On Fig. 7.1, draw an arrow in the plane PQRS to show the direction of the force on wire B due to the magnetic field produced by the current in wire A. [1]
- (ii) Wire A also experiences a force. State and explain which wire, if any, will experience the larger force.
-
-
- [2]
- (c) The direct currents in wires A and B are now replaced by sinusoidal alternating currents of equal peak values. The currents are in phase.
Describe the variation, if any, of the force experienced by wire B.
-
-
-
- [3]

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

For
Examiner's
Use

.....

.....

.....

..... [3]

- (b) An emission spectrum is seen as a series of differently coloured lines on a black background.

Suggest how this observation provides evidence for discrete electron energy levels in atoms.

.....

.....

.....

..... [2]

- 9 (a) (i) State what is meant by the *decay constant* of a radioactive isotope.

For
Examiner's
Use

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

- (ii) Show that the decay constant λ and the half-life $t_{\frac{1}{2}}$ of an isotope are related by the expression

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

[3]

- (b) In order to determine the half-life of a sample of a radioactive isotope, a student measures the count rate near to the sample, as illustrated in Fig. 9.1.

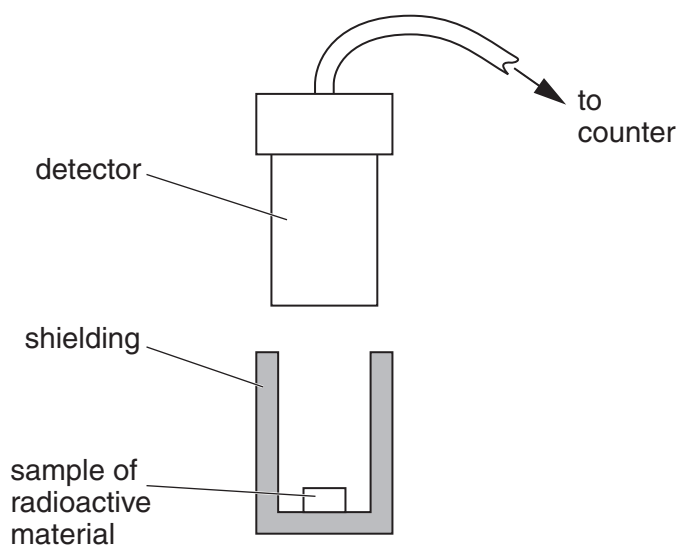


Fig. 9.1

Initially, the measured count rate is 538 per minute. After a time of 8.0 hours, the measured count rate is 228 per minute.

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Use these data to estimate the half-life of the isotope.

half-life = ... hours [3]

- (c) The accepted value of the half-life of the isotope in (b) is 5.8 hours.
The difference between this value for the half-life and that calculated in (b) cannot be explained by reference to faulty equipment.

Suggest two possible reasons for this difference.

1.
.....
2.
.....

[2]

Section B

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

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- 10** A student designs an electronic sensor that is to be used to switch on a lamp when the light intensity is low. Part of the circuit is shown in Fig. 10.1.

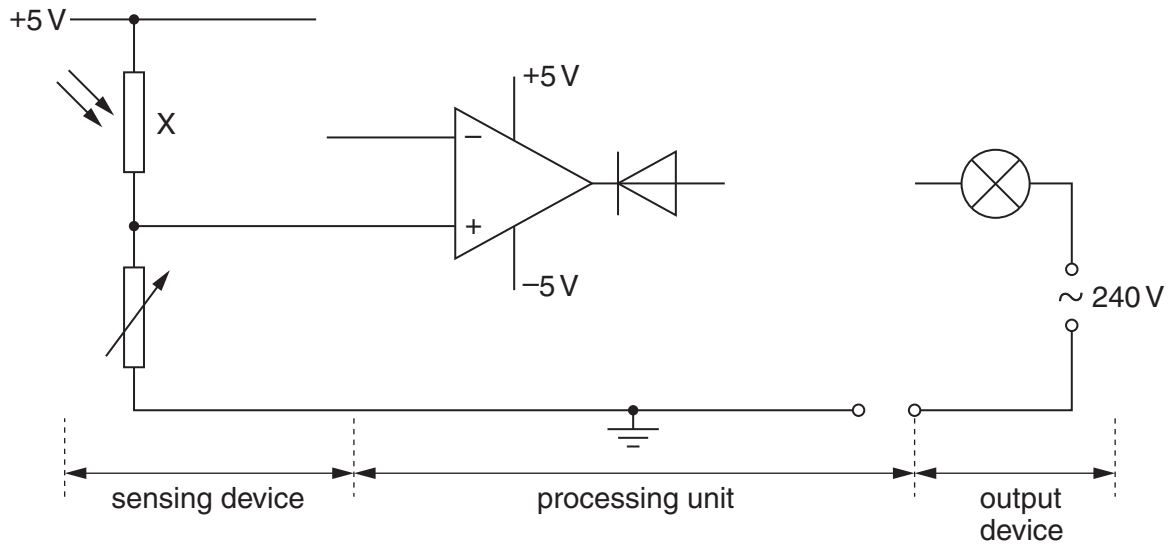


Fig. 10.1

- (a)** State the name of the component labelled X on Fig. 10.1.

..... [1]

- (b)** On Fig. 10.1, draw the symbols for

(i) two resistors to complete the circuit for the sensing device, [2]

(ii) a relay to complete the circuit for the processing unit. [2]

- (c)** (i) State the purpose of the relay.

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

- (ii) Suggest why the diode is connected to the output of the operational amplifier (op-amp) in the direction shown.

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

- 11 High-speed electrons are incident on a metal target. The spectrum of the emitted X-ray radiation is shown in Fig. 11.1.

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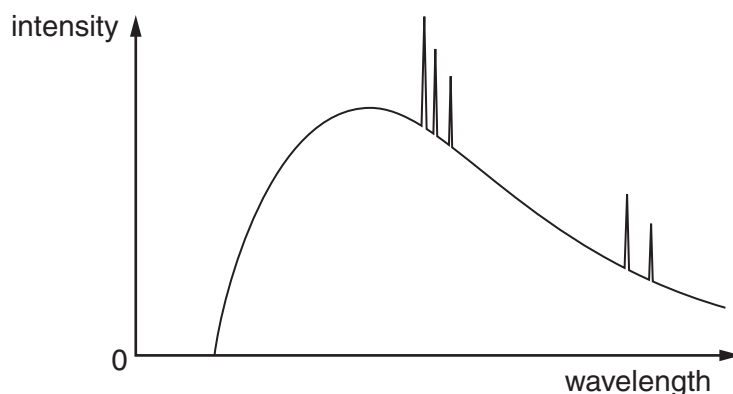


Fig. 11.1

(a) Explain why

- (i) there is a continuous distribution of wavelengths,

.....

 [2]

- (ii) there is a sharp cut-off at short wavelength.

.....

 [2]

(b) State

- (i) what is meant by the *hardness* of an X-ray beam,

.....

 [2]

- (ii) how hardness is controlled.

.....

 [2]

- (c) (i) Suggest why, when producing an X-ray image, long-wavelength X-ray radiation poses a greater hazard to health than short-wavelength radiation.

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Use*

.....

..... [1]

- (ii) Suggest how this hazard is minimised.

.....

..... [1]

12 A person is to be investigated using a magnetic resonance (MR) scanner.

- (a)** This technique involves the use of two superimposed magnetic fields. Describe the functions of these two magnetic fields.

.....

.....

.....

.....

.....

..... [4]

- (b)** The frequency f of the electromagnetic waves emitted by protons on relaxation in an MR scanner is given by the equation

$$f = 2\pi B$$

where B is the total magnetic flux density and c is a constant equal to $1.34 \times 10^8 \text{ s}^{-1} \text{ T}^{-1}$. The magnetic flux density changes by $2.0 \times 10^{-4} \text{ T}$ for each 1.0 cm thickness of tissue in a section.

The scanner is adjusted so that the thickness of each section is 3.0 mm.

Calculate, for corresponding points in neighbouring sections,

- (i)** the difference in magnetic flux density,

difference in flux density = ... T [1]

- (ii)** the change in emitted frequency.

frequency change = ... Hz [2]

- 13 (a)** In a mobile phone system, the area covered by the system is divided into a number of cells.

For this system, explain why

- (i)** neighbouring cells use different carrier frequencies,

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

- (ii)** each cell has a limited area, even in sparsely populated regions.

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

- (b)** A mobile phone handset is left switched on.

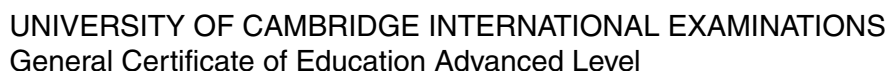
Explain why, although a call is not being made, the computer at the cellular exchange is still operating for this phone.

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

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Section A

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

For
Examiner's
Use

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

.....

.....

..... [2]

- (b) The Earth and the Moon may be considered to be isolated in space with their masses concentrated at their centres.
The orbit of the Moon around the Earth is circular with a radius of 3.84×10^5 km. The period of the orbit is 27.3 days.

Show that

- (i) the angular speed of the Moon in its orbit around the Earth is $2.66 \times 10^{-6} \text{ rad s}^{-1}$,

[1]

- (ii) the mass of the Earth is 6.0×10^{24} kg.

[2]

(c) The mass of the Moon is 7.4×10^{22} kg.

- (i) Using data from (b), determine the gravitational force between the Earth and the Moon.

For
Examiner's
Use

force = ... N [2]

- (ii) Tidal action on the Earth's surface causes the radius of the orbit of the Moon to increase by 4.0 cm each year.

Use your answer in (i) to determine the change, in one year, of the gravitational potential energy of the Moon. Explain your working.

energy change = ... J [3]

- 2 A ball of mass 37 g is held between two fixed points A and B by two stretched helical springs, as shown in Fig. 2.1.

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Examiner's
Use

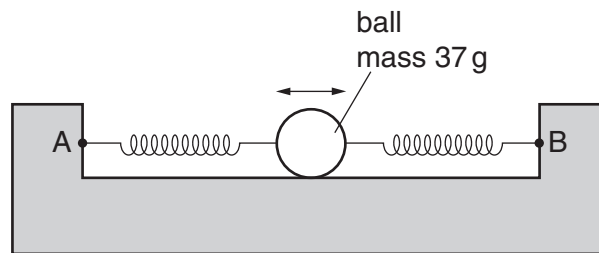


Fig. 2.1

The ball oscillates along the line AB with simple harmonic motion of frequency 3.5 Hz and amplitude 2.8 cm.

- (a) Show that the total energy of the oscillations is 7.0 mJ.

[2]

- (b) At two points in the oscillation of the ball, its kinetic energy is equal to the potential energy stored in the springs.
Calculate the magnitude of the displacement at which this occurs.

displacement = ... cm [3]

(c) On the axes of Fig. 2.2 and using your answers in (a) and (b), sketch a graph to show the variation with displacement x of

- (i) the total energy of the system (label this line T), [1]
- (ii) the kinetic energy of the ball (label this line K), [2]
- (iii) the potential energy stored in the springs (label this line P). [2]

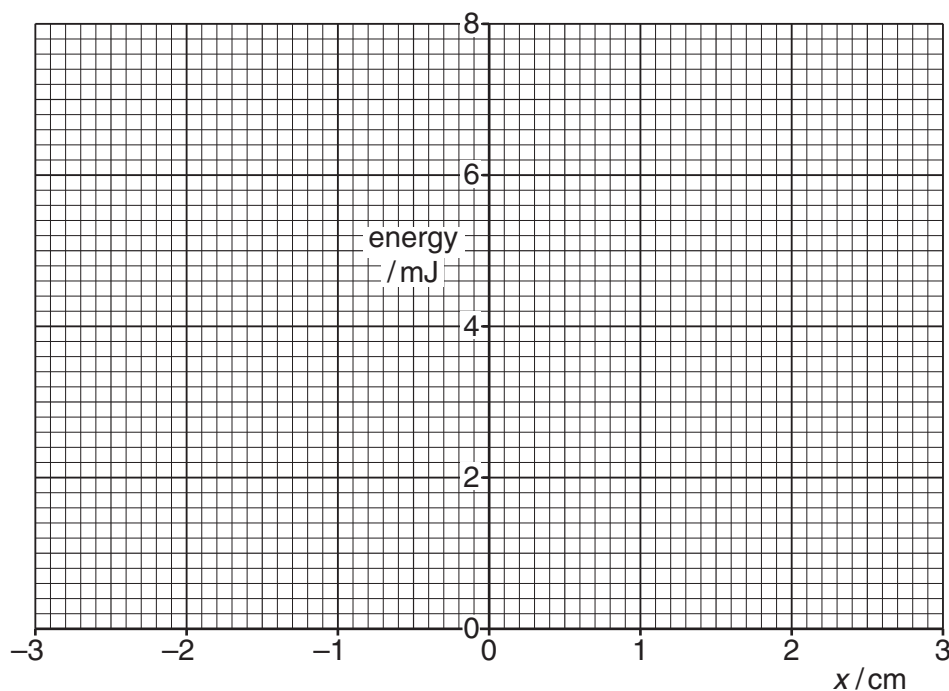


Fig. 2.2

(d) The arrangement in Fig. 2.1 is now rotated through 90° so that the line AB is vertical and the ball oscillates in a vertical plane.

Suggest one form of energy, other than those in (c), that must be taken into consideration when plotting new graphs to show energy changes with displacement.

..... [1]

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- 3 (a) State what is meant by the *internal energy* of a system.

For
Examiner's
Use

.....

.....

.....[2]

- (b) State and explain qualitatively the change, if any, in the internal energy of the following systems:

- (i) a lump of ice at 0°C melts to form liquid water at 0°C ,

.....

.....

.....

.....[3]

- (ii) a cylinder containing gas at constant volume is in sunlight so that its temperature rises from 25°C to 35°C .

.....

.....

.....

.....[3]

- 4 A charged point mass is situated in a vacuum. A proton travels directly towards the mass, as illustrated in Fig. 4.1.

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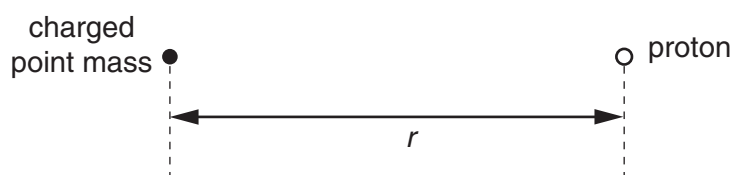


Fig. 4.1

When the separation of the mass and the proton is r , the electric potential energy of the system is U_p .

The variation with r of the potential energy U_p is shown in Fig. 4.2.

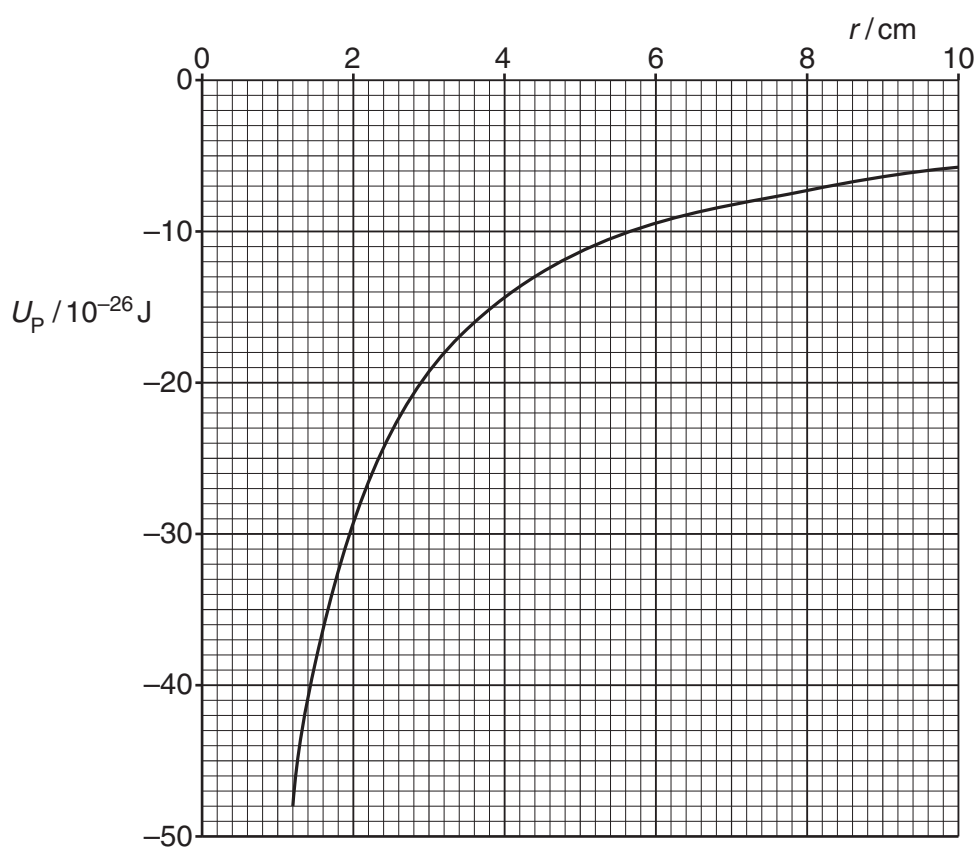


Fig. 4.2

- (a) (i) Use Fig. 4.2 to state and explain whether the mass is charged positively or negatively.

.....

 [2]

- (ii) The gradient at a point on the graph of Fig. 4.2 is G .
 Show that the electric field strength E at this point due to the charged point mass is given by the expression

$$Eq = G$$

where q is the charge at this point.

.....

 [2]

- (b) Use the expression in (a)(ii) and Fig. 4.2 to determine the electric field strength at a distance of 4.0 cm from the charged point mass.

field strength = ... V m^{-1} [4]

- 5 (a) Define the *tesla*.

.....

.....

.....

.....[3]

- (b) A horseshoe magnet is placed on a balance. A stiff metal wire is clamped horizontally between the poles, as illustrated in Fig. 5.1.

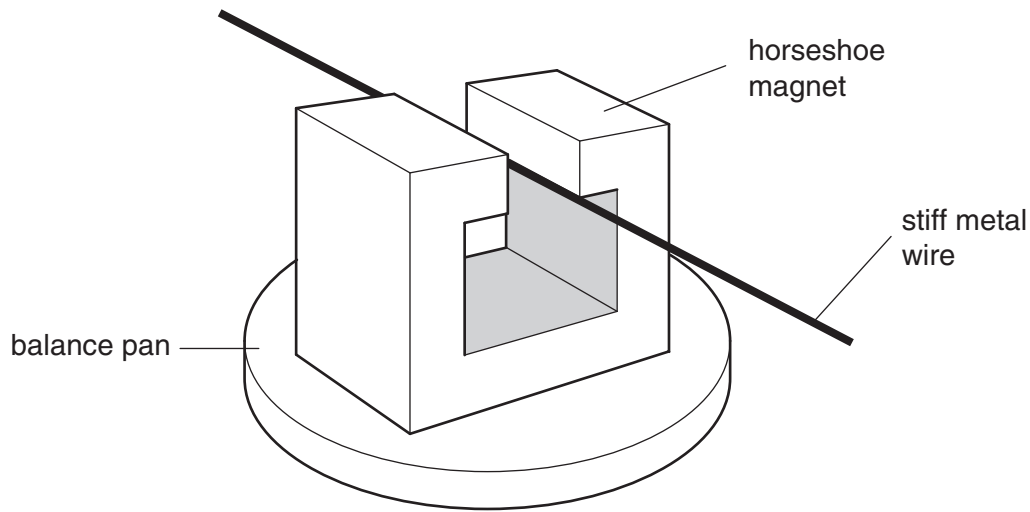


Fig. 5.1

The magnetic flux density in the space between the poles of the magnet is uniform and is zero outside this region.

The length of the metal wire normal to the magnetic field is 6.4 cm.

When a current in the wire is switched on, the reading on the balance increases by 2.4 g. The current in the wire is 5.6 A.

- (i) State and explain the direction of the force on the wire due to the current.

.....

.....

.....

.....[3]

- (ii) Calculate the magnitude of the magnetic flux density between the poles of the magnet.

For
Examiner's
Use

flux density = ... T [2]

- (c) A low frequency alternating current is now passed through the wire in (b).
The root-mean-square (r.m.s.) value of the current is 5.6 A.

Describe quantitatively the variation of the reading seen on the balance.

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

- [7]

- $3.2 \times 10^{-19} \text{ C};$ $6.4 \times 10^{-19} \text{ C};$ $16 \times 10^{-19} \text{ C};$ $9.7 \times 10^{-19} \text{ C};$
 $12.8 \times 10^{-19} \text{ C};$ $3.1 \times 10^{-19} \text{ C};$ $6.3 \times 10^{-19} \text{ C}.$

fundamental charge = ... C [1]

- 7 The photoelectric effect may be represented by the equation

photon energy = work function energy + maximum kinetic energy of electron.

For
Examiner's
Use

- (a) State what is meant by *work function energy*.

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

- (b) The variation with frequency f of the maximum kinetic energy E_K of photoelectrons emitted from the surface of sodium metal is shown in Fig. 7.1.

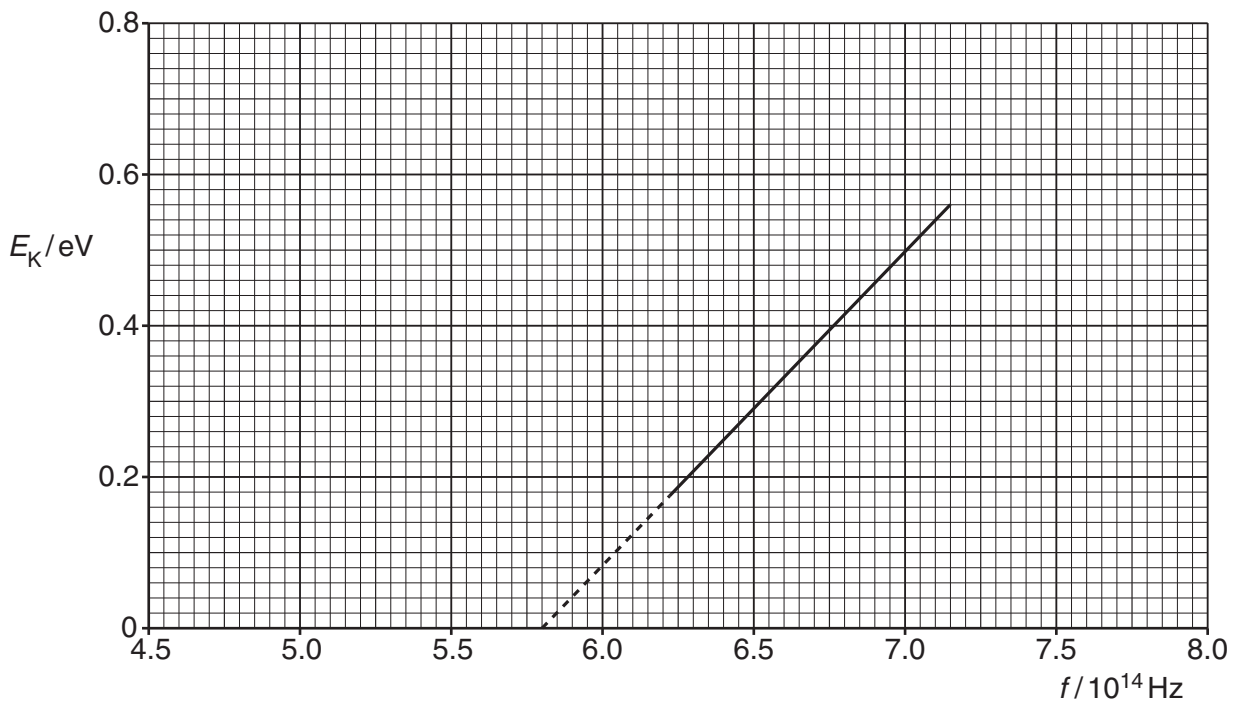


Fig. 7.1

Use the gradient of the graph of Fig. 7.1 to determine a value for the Planck constant h .
Show your working.

$h = \dots\dots\dots \text{Js}$ [2]

- (c) The sodium metal in (b) has a work function energy of 2.4 eV. The sodium is replaced by calcium which has a work function energy of 2.9 eV.

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Examiner's
Use

On Fig. 7.1, draw a line to show the variation with frequency f of the maximum kinetic energy E_k of photoelectrons emitted from the surface of calcium. [3]

- 8 The element strontium has at least 16 isotopes. One of these isotopes is strontium-89. This isotope has a half-life of 52 days.

(a) State what is meant by *isotopes*.

.....

 [2]

(b) Calculate the probability per second of decay of a nucleus of strontium-89.

probability = ... s⁻¹ [3]

(c) A laboratory prepares a strontium-89 source.

The activity of this source is measured 21 days after preparation of the source and is found to be 7.4×10^6 Bq.

Determine, for the strontium-89 source at the time that it was prepared,

(i) the activity,

activity = ... Bq [2]

(ii) the mass of strontium-89.

mass = ... g [2]

Section B

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

For
Examiner's
Use

- 9 An operational amplifier (op-amp) may be used as part of the processing unit in an electronic sensor.

(a) State four properties of an ideal operational amplifier.

1.
2.
3.
4.

[4]

(b) A comparator circuit incorporating an ideal op-amp is shown in Fig. 9.1.

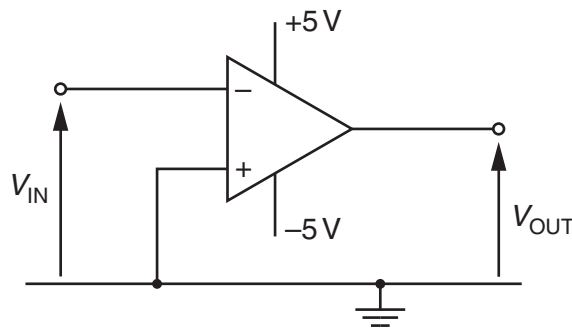


Fig. 9.1

The variation with time t of the input potential V_{IN} is shown in Fig. 9.2.

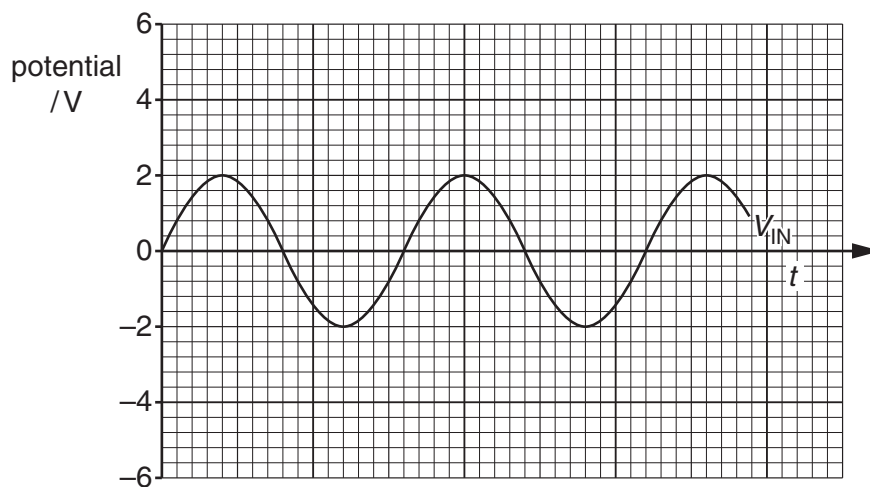


Fig. 9.2

On the axes of Fig. 9.2, draw a graph to show the variation with time t of the output potential V_{OUT} .

[3]

- (c) The output potential V_{OUT} is to be displayed using two light-emitting diodes (LEDs). A diode emitting red light is to indicate when V_{OUT} is positive and a diode emitting green light is to be used to indicate when V_{OUT} is negative.

*For
Examiner's
Use*

Complete Fig. 9.3 to show the connections of the two LEDs to the output of the op-amp. Label each LED with the colour of light that it emits.

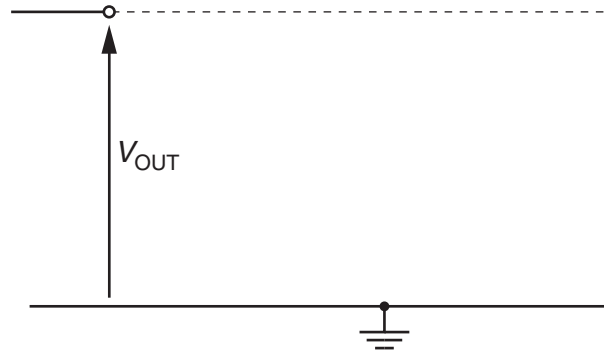


Fig. 9.3

[3]

- 10 (a) An aluminium block is placed near to a small source of X-ray radiation, as shown in Fig. 10.1.

For
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Use

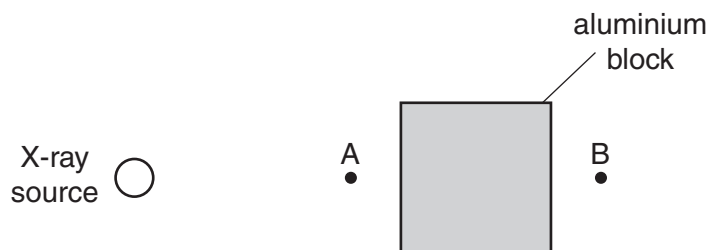


Fig. 10.1

X-rays from the source are detected at point A and at point B.

State two reasons why the intensity of the X-ray beam at point B is not as great as the intensity at point A.

1.
-
2.
-

[2]

- (b) A cross-section through a model of a finger is shown in Fig. 10.2.

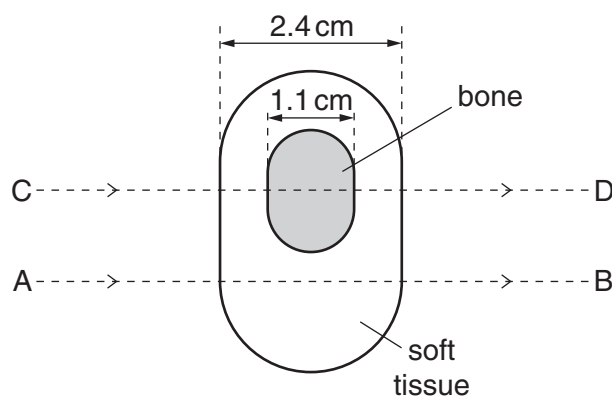


Fig. 10.2

The thickness of the model is 2.4 cm and that of the bone in the model is 1.1 cm. Parallel beams of X-rays are incident on the model in the directions AB and CD, as shown in Fig. 10.2.

Data for the linear attenuation (absorption) coefficient μ for the bone and the soft tissue in the model are given in Fig. 10.3.

For
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Use

	μ / cm^{-1}
bone	3.0
soft tissue	0.27

Fig. 10.3

Calculate the ratio

$$\frac{\text{intensity of X-ray beam incident on the model}}{\text{intensity of X-ray beam emergent from the model}}$$

for

(i) the beam AB,

ratio = ...[2]

(ii) the beam CD.

ratio = ...[2]

(c) Use your answers in (b) to suggest why, for this model, an X-ray image with good contrast may be obtained.

.....
[1]

11 A signal that is transmitted over a long distance will be attenuated and it will pick up noise.

(a) State what is meant by

(i) *attenuation*,

.....
 [1]

(ii) *noise*.

.....

 [2]

(b) Explain why regenerator amplifiers do not amplify the noise that has been picked up on digital signals.

.....

 [2]

(c) A transmitter on Earth produces a signal of power 2.4 kW. This signal, when received by a satellite, is attenuated by 195 dB.

Calculate the signal power received by the satellite.

power = ... W [3]

- 12** An incomplete simplified block diagram of the circuitry for a mobile-phone handset is shown in Fig. 12.1.

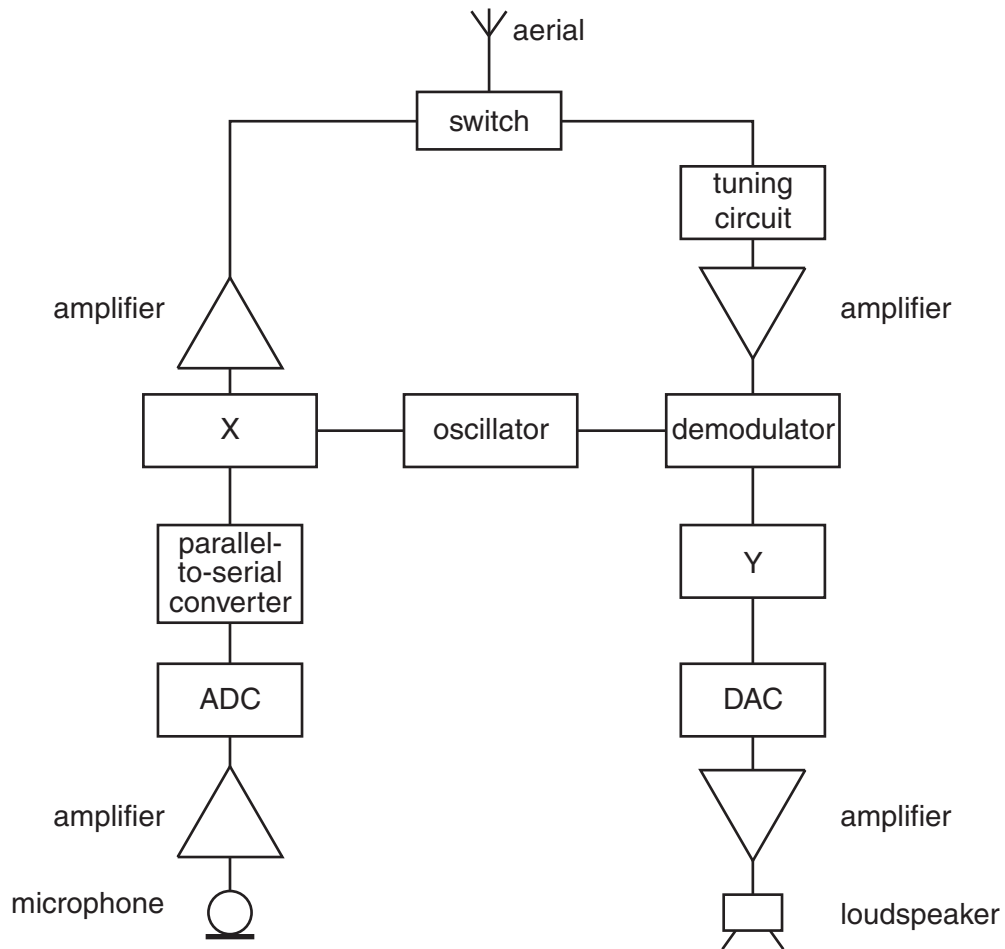


Fig. 12.1

- (a)** State the name of the block labelled

(i) X,

..... [1]

(ii) Y.

..... [1]

Question 12 continues on page 24.

(b) Explain the purpose of

(i) the switch,

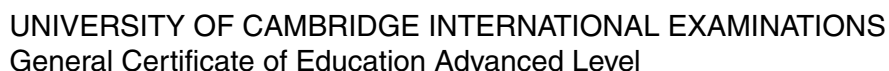
.....
.....[1]

(ii) the parallel-to-serial converter.

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

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9702/43

May/June 2012

2 hours

No Additional Materials are required.

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 a soft pencil for any diagrams, graphs or rough working.
Do not use staples, paper clips, highlighters, glue or correction fluid.
DO NOT WRITE IN ANY BARCODES.

Answer **all** questions.

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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1	
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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,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
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.

For
Examiner's
Use

- 1 (a) Define *gravitational potential* at a point.

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

- (b) The gravitational potential ϕ at distance r from point mass M is given by the expression

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

where G is the gravitational constant.

Explain the significance of the negative sign in this expression.

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

- (c) A spherical planet may be assumed to be an isolated point mass with its mass concentrated at its centre. A small mass m is moving near to, and normal to, the surface of the planet. The mass moves away from the planet through a short distance h .

State and explain why the change in gravitational potential energy ΔE_p of the mass is given by the expression

$$\Delta E_p = mgh$$

where g is the acceleration of free fall.

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

- (d) The planet in (c) has mass M and diameter 6.8×10^3 km. The product GM for this planet is $4.3 \times 10^{13} \text{ N m}^2 \text{ kg}^{-1}$.

For
Examiner's
Use

A rock, initially at rest a long distance from the planet, accelerates towards the planet. Assuming that the planet has negligible atmosphere, calculate the speed of the rock as it hits the surface of the planet.

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

- 2 (a)** The kinetic theory of gases is based on some simplifying assumptions. The molecules of the gas are assumed to behave as hard elastic identical spheres. State the assumption about ideal gas molecules based on

*For
Examiner's
Use*

- (i)** the nature of their movement,

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

- (ii)** their volume.

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

- (b) A cube of volume V contains N molecules of an ideal gas. Each molecule has a component c_x of velocity normal to one side S of the cube, as shown in Fig. 2.1.

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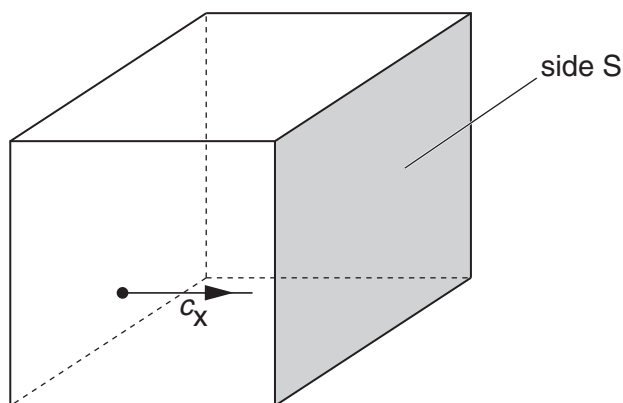


Fig. 2.1

The pressure p of the gas due to the component c_x of velocity is given by the expression

$$pV = Nmc_x^2$$

where m is the mass of a molecule.

Explain how the expression leads to the relation

$$pV = \frac{1}{3}Nm\langle c^2 \rangle$$

where $\langle c^2 \rangle$ is the mean square speed of the molecules.

[3]

- (c) The molecules of an ideal gas have a root-mean-square (r.m.s.) speed of 520 m s^{-1} at a temperature of 27°C .

Calculate the r.m.s. speed of the molecules at a temperature of 100°C .

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

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

.....

.....

..... [2]

- (b) The heater in an electric kettle has a power of 2.40 kW.
When the water in the kettle is boiling at a steady rate, the mass of water evaporated in 2.0 minutes is 106 g.
The specific latent heat of vaporisation of water is 2260 J g^{-1} .

Calculate the rate of loss of thermal energy to the surroundings of the kettle during the boiling process.

rate of loss = ... W [3]

- 4 A small metal ball is suspended from a fixed point by means of a string, as shown in Fig. 4.1.

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Examiner's
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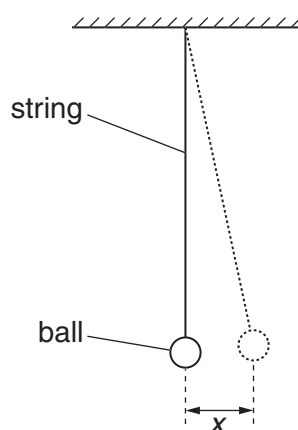


Fig. 4.1

The ball is pulled a small distance to one side and then released. The variation with time t of the horizontal displacement x of the ball is shown in Fig. 4.2.

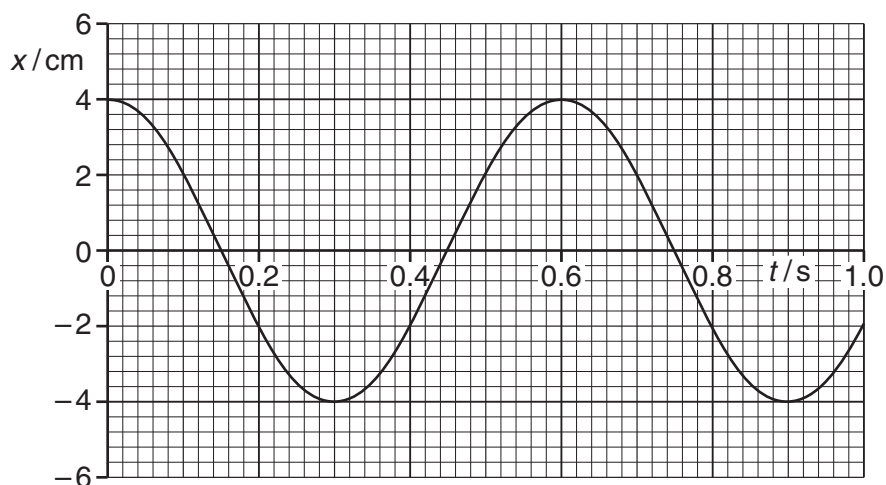


Fig. 4.2

The motion of the ball is simple harmonic.

- (a) Use data from Fig. 4.2 to determine the horizontal acceleration of the ball for a displacement x of 2.0 cm.

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

- (b) The maximum kinetic energy of the ball is E_K .
On the axes of Fig. 4.3, sketch a graph to show the variation with time t of the kinetic energy of the ball for the first 1.0 s of its motion.

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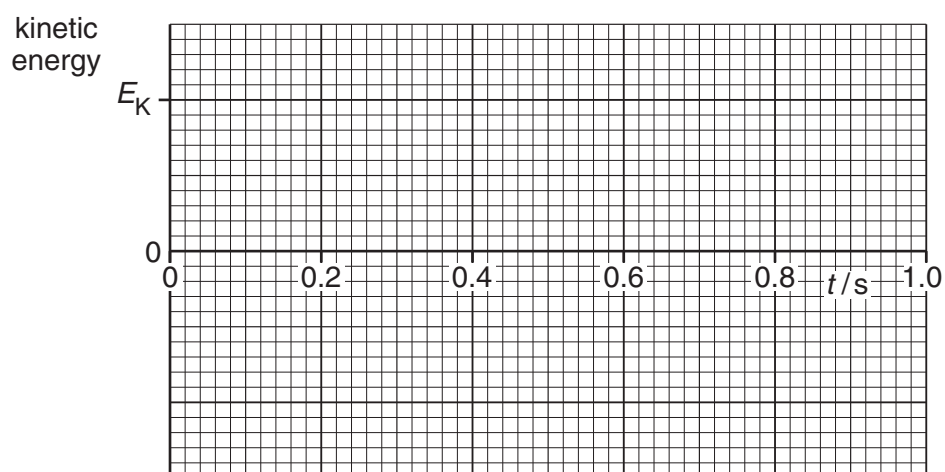


Fig. 4.3

[3]

- 5 (a) Define *electric field strength*.

.....
 [1]

- (b) An isolated metal sphere is to be used to store charge at high potential. The charge stored may be assumed to be a point charge at the centre of the sphere. The sphere has a radius of 25 cm. Electrical breakdown (a spark) occurs in the air surrounding the sphere when the electric field strength at the surface of the sphere exceeds $1.8 \times 10^4 \text{ V cm}^{-1}$.

- (i) Show that the maximum charge that can be stored on the sphere is $12.5 \mu\text{C}$.

[2]

- (ii) Calculate the potential of the sphere for this maximum charge.

potential = ... V [2]

- 6 A sinusoidal alternating voltage supply is connected to a bridge rectifier consisting of four ideal diodes. The output of the rectifier is connected to a resistor R and a capacitor C as shown in Fig. 6.1.

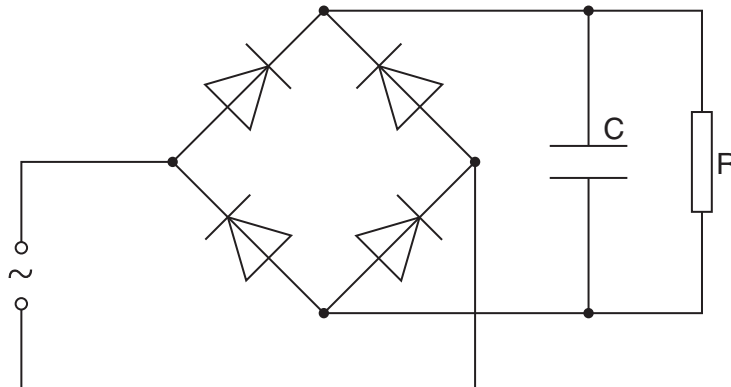


Fig. 6.1

The function of C is to provide some smoothing to the potential difference across R . The variation with time t of the potential difference V across the resistor R is shown in Fig. 6.2.

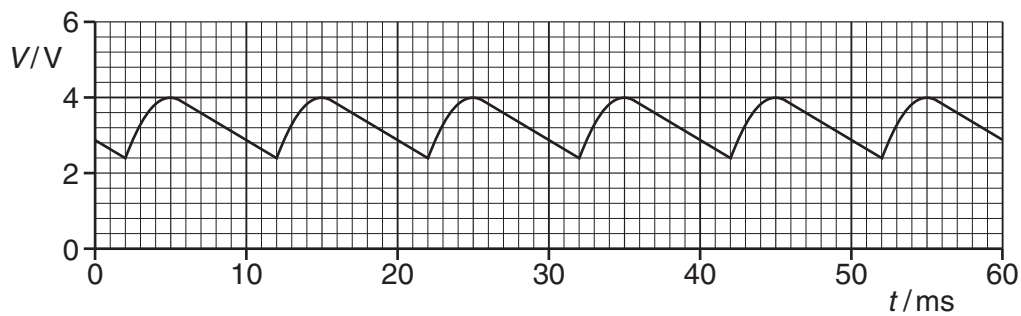


Fig. 6.2

- (a) Use Fig. 6.2 to determine, for the alternating supply,

- (i) the peak voltage,

peak voltage = ... V [1]

- (ii) the root-mean-square (r.m.s.) voltage,

r.m.s. voltage = ... V [1]

- (iii) the frequency. Show your working.

For
Examiner's
Use

frequency = ... Hz [2]

- (b) The capacitor C has capacitance $5.0\ \mu\text{F}$.
For a single discharge of the capacitor through the resistor R, use Fig. 6.2 to

- (i) determine the change in potential difference,

change = ... V [1]

- (ii) determine the change in charge on each plate of the capacitor,

change = ... C [2]

- (iii) show that the average current in the resistor is $1.1 \times 10^{-3}\text{ A}$.

[2]

- (c) Use Fig. 6.2 and the value of the current given in (b)(iii) to estimate the resistance of resistor R.

For
Examiner's
Use

resistance = ... Ω [2]

- 7 Two long straight parallel copper wires A and B are clamped vertically. The wires pass through holes in a horizontal sheet of card PQRS, as shown in Fig. 7.1.

For
Examiner's
Use

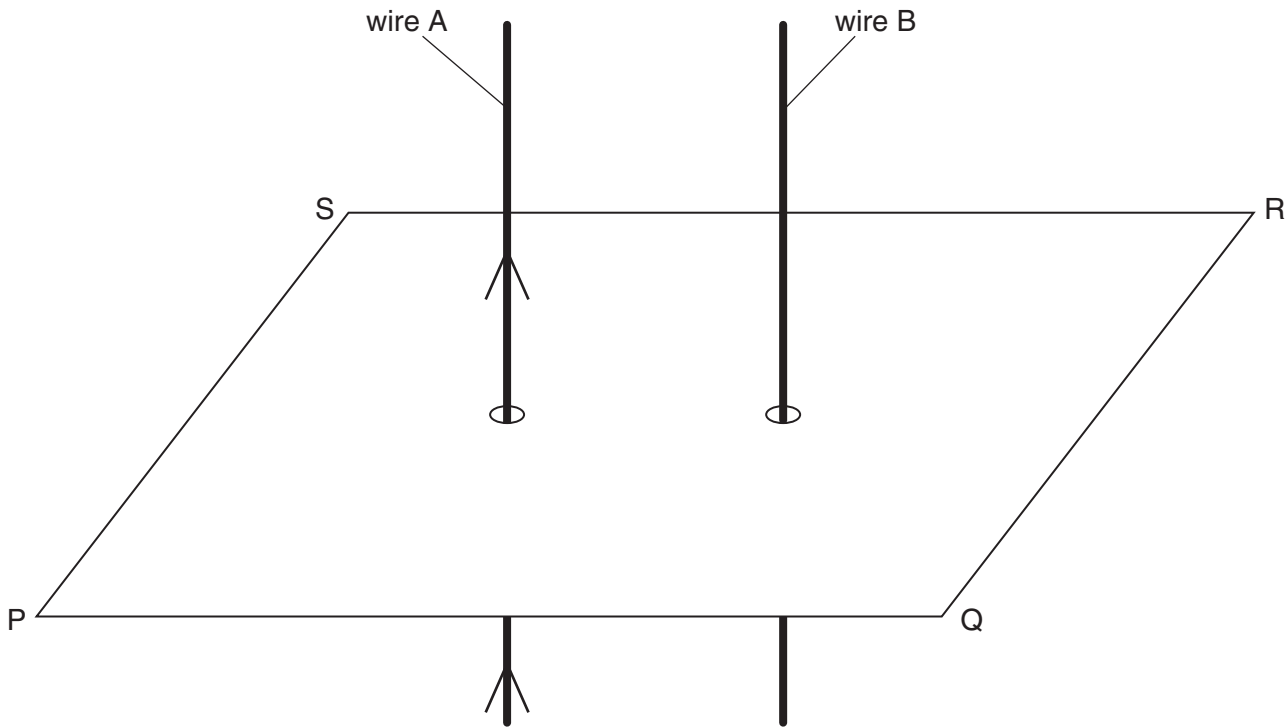


Fig. 7.1

- (a) There is a current in wire A in the direction shown on Fig. 7.1.
On Fig. 7.1, draw four field lines in the plane PQRS to represent the magnetic field due to the current in wire A. [3]
- (b) A direct current is now passed through wire B in the same direction as that in wire A.
The current in wire B is larger than the current in wire A.
- (i) On Fig. 7.1, draw an arrow in the plane PQRS to show the direction of the force on wire B due to the magnetic field produced by the current in wire A. [1]
- (ii) Wire A also experiences a force. State and explain which wire, if any, will experience the larger force.
-
-
- [2]
- (c) The direct currents in wires A and B are now replaced by sinusoidal alternating currents of equal peak values. The currents are in phase.
Describe the variation, if any, of the force experienced by wire B.
-
-
-
- [3]

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

For
Examiner's
Use

.....

.....

.....

..... [3]

- (b) An emission spectrum is seen as a series of differently coloured lines on a black background.

Suggest how this observation provides evidence for discrete electron energy levels in atoms.

.....

.....

.....

..... [2]

- 9 (a) (i) State what is meant by the *decay constant* of a radioactive isotope.

For
Examiner's
Use

.....

.....

..... [2]

- (ii) Show that the decay constant λ and the half-life $t_{\frac{1}{2}}$ of an isotope are related by the expression

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

[3]

- (b) In order to determine the half-life of a sample of a radioactive isotope, a student measures the count rate near to the sample, as illustrated in Fig. 9.1.

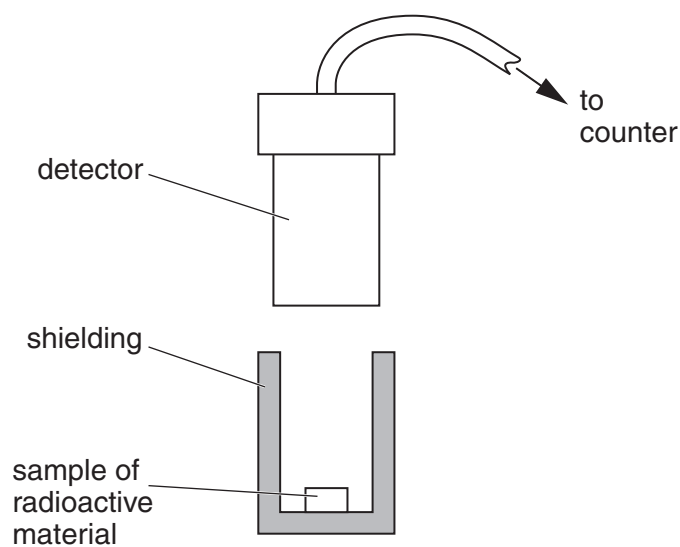


Fig. 9.1

Initially, the measured count rate is 538 per minute. After a time of 8.0 hours, the measured count rate is 228 per minute.

For
Examiner's
Use

Use these data to estimate the half-life of the isotope.

half-life = ... hours [3]

- (c) The accepted value of the half-life of the isotope in (b) is 5.8 hours.
The difference between this value for the half-life and that calculated in (b) cannot be explained by reference to faulty equipment.

Suggest two possible reasons for this difference.

1.

.....

2.

.....

[2]

Section B

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

For
Examiner's
Use

- 10** A student designs an electronic sensor that is to be used to switch on a lamp when the light intensity is low. Part of the circuit is shown in Fig. 10.1.

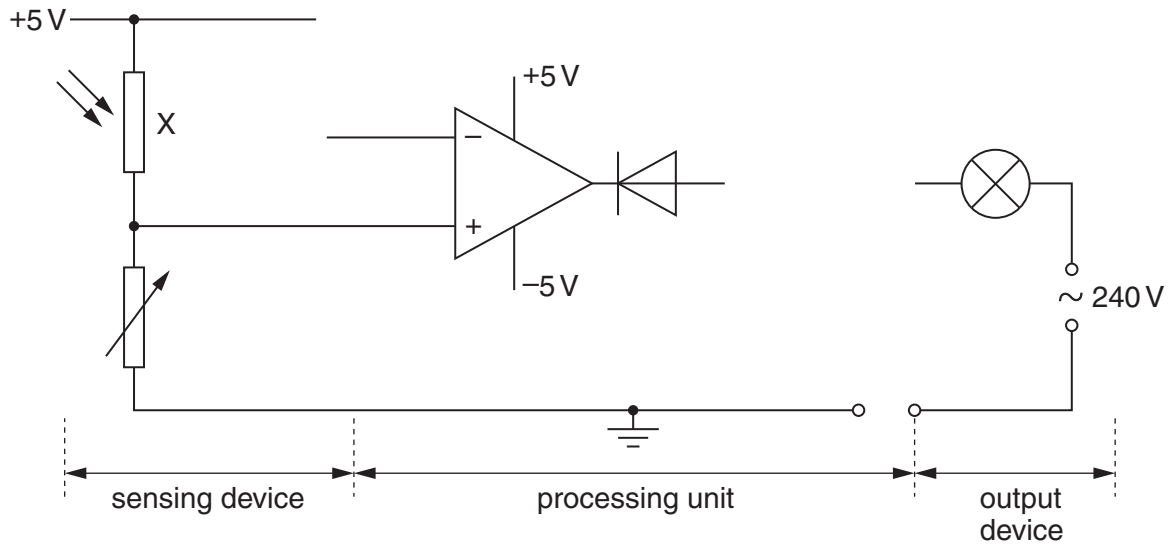


Fig. 10.1

- (a)** State the name of the component labelled X on Fig. 10.1.

..... [1]

- (b)** On Fig. 10.1, draw the symbols for

(i) two resistors to complete the circuit for the sensing device, [2]

(ii) a relay to complete the circuit for the processing unit. [2]

- (c)** (i) State the purpose of the relay.

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

- (ii) Suggest why the diode is connected to the output of the operational amplifier (op-amp) in the direction shown.

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

- 11 High-speed electrons are incident on a metal target. The spectrum of the emitted X-ray radiation is shown in Fig. 11.1.

For
Examiner's
Use

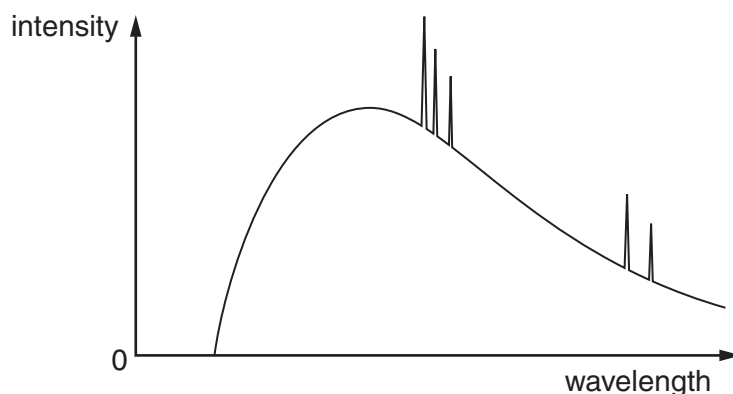


Fig. 11.1

(a) Explain why

- (i) there is a continuous distribution of wavelengths,

.....

 [2]

- (ii) there is a sharp cut-off at short wavelength.

.....

 [2]

(b) State

- (i) what is meant by the *hardness* of an X-ray beam,

.....

 [2]

- (ii) how hardness is controlled.

.....

 [2]

- (c) (i) Suggest why, when producing an X-ray image, long-wavelength X-ray radiation poses a greater hazard to health than short-wavelength radiation.

*For
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Use*

.....

..... [1]

- (ii) Suggest how this hazard is minimised.

.....

..... [1]

12 A person is to be investigated using a magnetic resonance (MR) scanner.

- (a)** This technique involves the use of two superimposed magnetic fields. Describe the functions of these two magnetic fields.

.....

.....

.....

.....

.....

..... [4]

- (b)** The frequency f of the electromagnetic waves emitted by protons on relaxation in an MR scanner is given by the equation

$$f = 2\pi B$$

where B is the total magnetic flux density and c is a constant equal to $1.34 \times 10^8 \text{ s}^{-1} \text{ T}^{-1}$. The magnetic flux density changes by $2.0 \times 10^{-4} \text{ T}$ for each 1.0 cm thickness of tissue in a section.

The scanner is adjusted so that the thickness of each section is 3.0 mm.

Calculate, for corresponding points in neighbouring sections,

- (i)** the difference in magnetic flux density,

difference in flux density = ... T [1]

- (ii)** the change in emitted frequency.

frequency change = ... Hz [2]

- 13 (a)** In a mobile phone system, the area covered by the system is divided into a number of cells.

For this system, explain why

- (i)** neighbouring cells use different carrier frequencies,

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

- (ii)** each cell has a limited area, even in sparsely populated regions.

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

- (b)** A mobile phone handset is left switched on.

Explain why, although a call is not being made, the computer at the cellular exchange is still operating for this phone.

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

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