



UNIVERSITY OF CAMBRIDGE INTERNATIONAL EXAMINATIONS
General Certificate of Education Advanced Level

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PHYSICS

9702/41

Paper 4 A2 Structured Questions

October/November 2009

1 hour 45 minutes

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 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.

For Examiner's Use

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Total	

This document consists of **21** printed pages and **3** blank pages.



Data

speed of light in free space,	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
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) State Newton's law of gravitation.

.....

 [2]

- (b) The Earth may be considered to be a uniform sphere of radius R equal to 6.4×10^6 m.

A satellite is in a geostationary orbit.

- (i) Describe what is meant by a *geostationary orbit*.

.....

 [3]

- (ii) Show that the radius x of the geostationary orbit is given by the expression

$$gR^2 = x^3\omega^2$$

where g is the acceleration of free fall at the Earth's surface and ω is the angular speed of the satellite about the centre of the Earth.

[3]

- (iii) Determine the radius x of the geostationary orbit.

radius = ... m [3]

- 2 An ideal gas occupies a container of volume $4.5 \times 10^3 \text{ cm}^3$ at a pressure of $2.5 \times 10^5 \text{ Pa}$ and a temperature of 290 K.

For
Examiner's
Use

- (a) Show that the number of atoms of gas in the container is 2.8×10^{23} .

[2]

- (b) Atoms of a real gas each have a diameter of $1.2 \times 10^{-10} \text{ m}$.

- (i) Estimate the volume occupied by 2.8×10^{23} atoms of this gas.

volume = ... m^3 [2]

- (ii) By reference to your answer in (i), suggest whether the real gas does approximate to an ideal gas.

.....

.....

..... [2]

- 3 (a) A student states, quite wrongly, that temperature measures the amount of thermal energy (heat) in a body.

For
Examiner's
Use

State and explain two observations that show why this statement is incorrect.

1.

.....

.....

2.

.....

.....

[4]

- (b) A thermometer and an electrical heater are inserted into holes in an aluminium block of mass 960 g, as shown in Fig. 3.1.

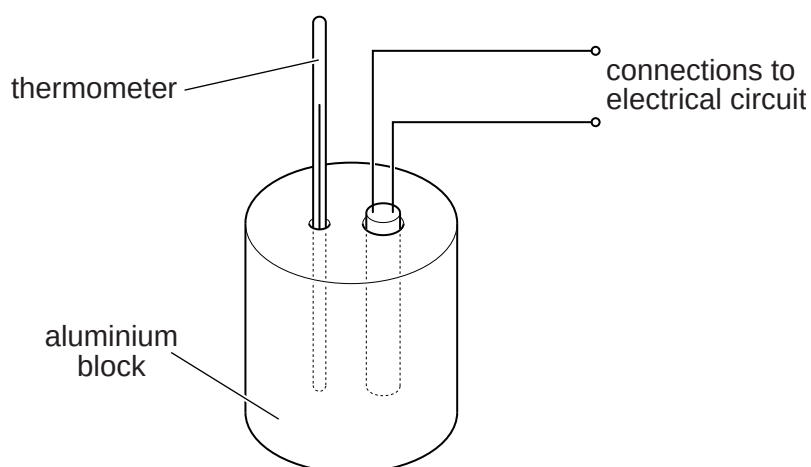


Fig. 3.1

The power rating of the heater is 54 W.

The heater is switched on and readings of the temperature of the block are taken at regular time intervals. When the block reaches a constant temperature, the heater is switched off and then further temperature readings are taken. The variation with time t of the temperature θ of the block is shown in Fig. 3.2.

For
Examiner's
Use

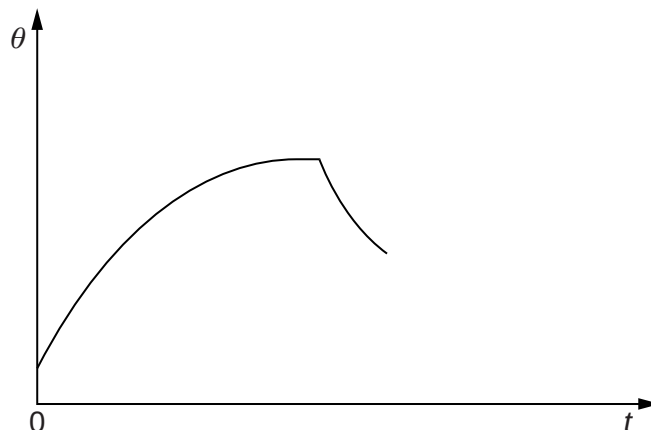


Fig. 3.2

- (i) Suggest why the rate of rise of temperature of the block decreases to zero.

.....

 [2]

- (ii) After the heater has been switched off, the maximum rate of fall of temperature is 3.7 K per minute.

Estimate the specific heat capacity of aluminium.

specific heat capacity = ... J kg⁻¹ K⁻¹ [3]

- 4 The variation with time t of the displacement x of the cone of a loudspeaker is shown in Fig. 4.1.

For
Examiner's
Use

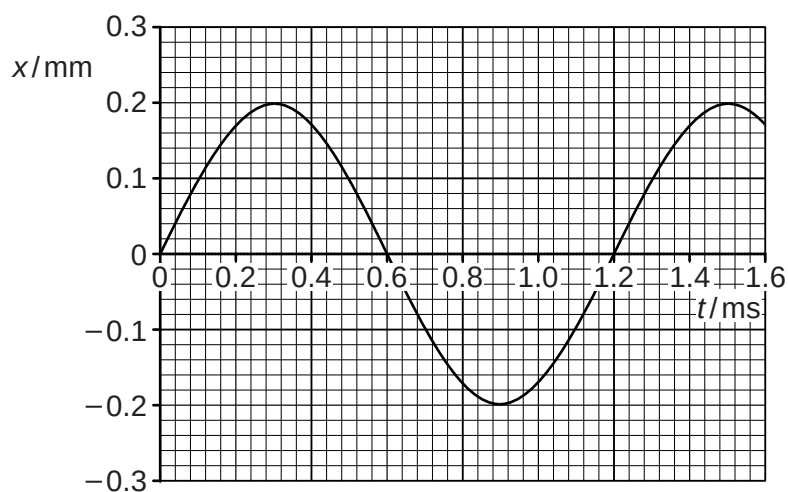


Fig. 4.1

- (a) Use Fig. 4.1 to determine, for these oscillations,

- (i) the amplitude,

amplitude = ... mm [1]

- (ii) the frequency.

frequency = ... Hz [2]

- (b) State two times at which

- (i) the speed of the cone is maximum,

time ms and time ms [1]

- (ii) the acceleration of the cone is maximum.

time ms and time ms [1]

- (c) The effective mass of the cone is 2.5 g.

Use your answers in (a) to determine the maximum kinetic energy of the cone.

For
Examiner's
Use

kinetic energy = ... J [3]

- (d) The loudspeaker must be designed so that resonance of the cone is avoided.

- (i) State what is meant by *resonance*.

.....

 [2]

- (ii) State and briefly explain one other situation in which resonance should be avoided.

.....

 [2]

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

For
Examiner's
Use

.....

 [2]

- (b) An α -particle is emitted from a radioactive source with kinetic energy of 4.8 MeV.

The α -particle travels in a vacuum directly towards a gold ($^{197}_{79}\text{Au}$) nucleus, as illustrated in Fig. 5.1.

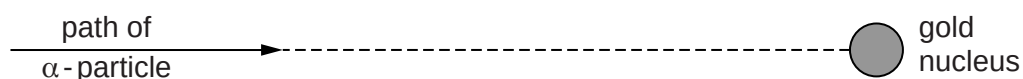


Fig. 5.1

The α -particle and the gold nucleus may be considered to be point charges in an isolated system.

- (i) Explain why, as the α -particle approaches the gold nucleus, it comes to rest.

.....

 [2]

- (ii) For the closest approach of the α -particle to the gold nucleus determine

1. their separation,

separation = ... m [3]

2. the magnitude of the force on the α -particle.

For
Examiner's
Use

force = ... N [2]

- 6 The current in a long, straight vertical wire is in the direction XY, as shown in Fig. 6.1.

For
Examiner's
Use

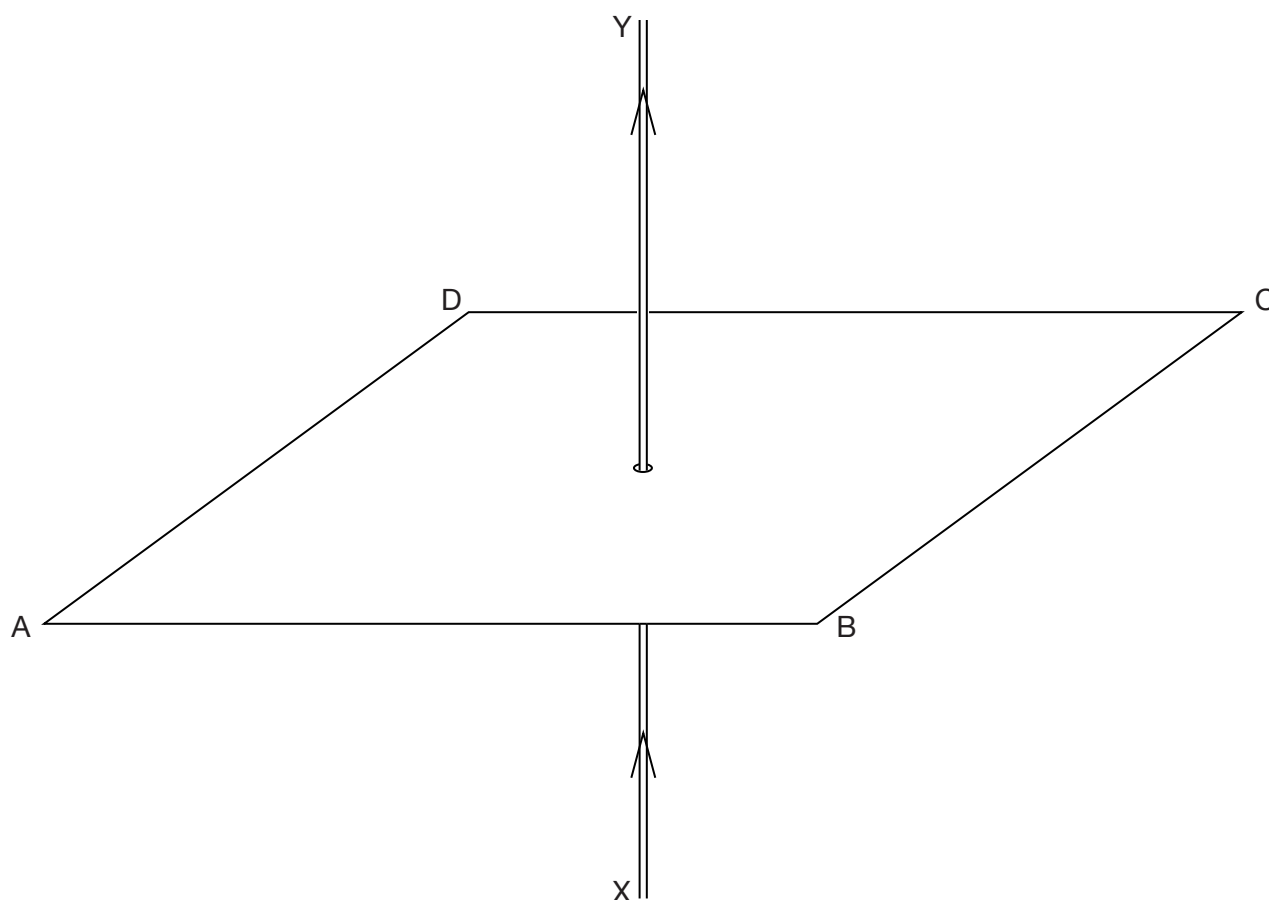


Fig. 6.1

- (a) On Fig. 6.1, sketch the pattern of the magnetic flux in the horizontal plane ABCD due to the current-carrying wire. Draw at least four flux lines. [3]
- (b) The current-carrying wire is within the Earth's magnetic field. As a result, the pattern drawn in Fig. 6.1 is superposed with the horizontal component of the Earth's magnetic field.

Fig. 6.2 shows a plan view of the plane ABCD with the current in the wire coming out of the plane.

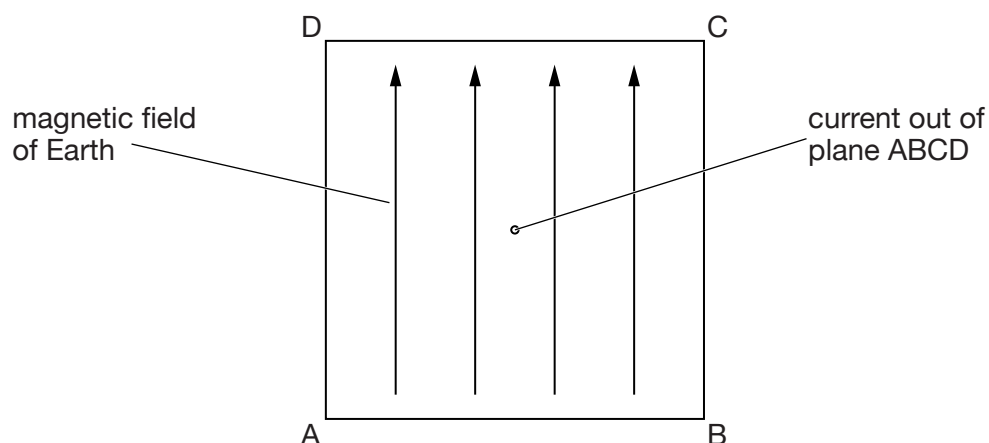


Fig. 6.2

The horizontal component of the Earth's magnetic field is also shown.

- (i) On Fig. 6.2, mark with the letter P a point where the magnetic field due to the current-carrying wire could be equal and opposite to that of the Earth. [1]
- (ii) For a long, straight wire carrying current I , the magnetic flux density B at distance r from the centre of the wire is given by the expression

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

where μ_0 is the permeability of free space.

The point P in (i) is found to be 1.9 cm from the centre of the wire for a current of 1.7 A.

Calculate a value for the horizontal component of the Earth's magnetic flux density.

flux density = ... T [2]

- (c) The current in the wire in (b)(ii) is increased. The point P is now found to be 2.8 cm from the wire.

Determine the new current in the wire.

current = ... A [2]

7 A sinusoidal alternating voltage is to be rectified.

- (a) Suggest one advantage of full-wave rectification as compared with half-wave rectification.

.....
 [1]

- (b) The rectification is produced using the circuit of Fig. 7.1.

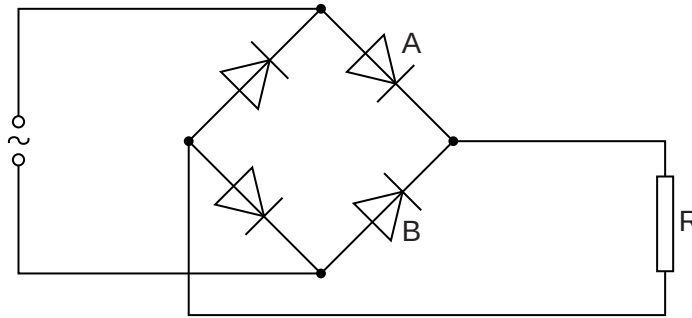


Fig. 7.1

All the diodes may be considered to be ideal.

The variation with time t of the alternating voltage applied to the circuit is shown in Fig. 7.2 and in Fig. 7.3.

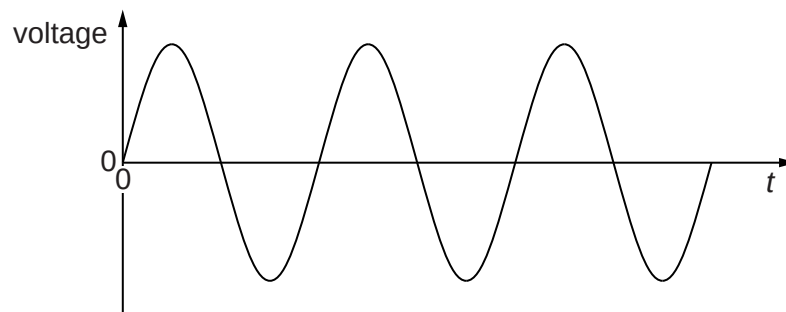


Fig. 7.2

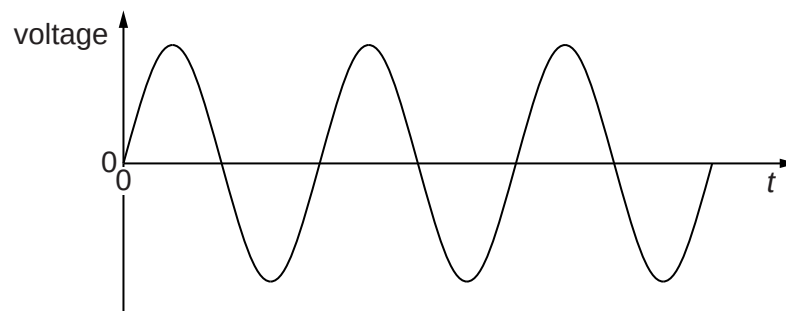


Fig. 7.3

- (i) On the axes of Fig. 7.2, draw a graph to show the variation with time t of the potential difference across diode A. [1]
- (ii) On the axes of Fig. 7.3, draw a graph to show the variation with time t of the potential difference across diode B. [1]
- (c) (i) On Fig. 7.1, draw the symbol for a capacitor, connected into the circuit so as to provide smoothing. [1]
- (ii) Fig. 7.4 shows the variation with time t of the smoothed potential difference across the resistor R in Fig. 7.1.

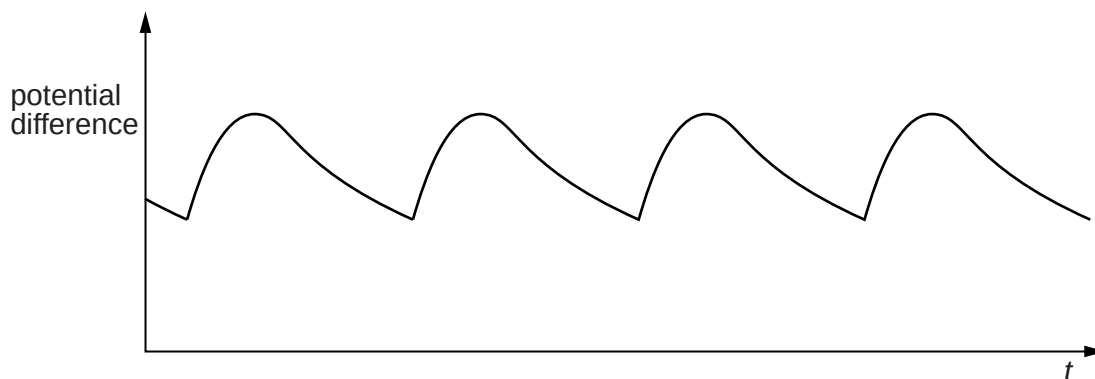


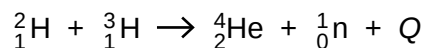
Fig. 7.4

1. State how the amount of smoothing may be increased.

.....
 [1]

2. On Fig. 7.4, draw the variation with time t of the potential difference across resistor R for increased smoothing. [2]

- 8 The controlled reaction between deuterium (${}^2_1\text{H}$) and tritium (${}^3_1\text{H}$) has involved ongoing research for many years. The reaction may be summarised as



where $Q = 17.7\text{ MeV}$.

Binding energies per nucleon are shown in Fig. 8.1.

	binding energy per nucleon /MeV
${}^2_1\text{H}$	1.12
${}^1_0\text{n}$	—
${}^4_2\text{He}$	7.07

Fig. 8.1

- (a) Suggest why binding energy per nucleon for the neutron is not quoted.

.....
 [1]

- (b) Calculate the mass defect, in kg, of a helium ${}^4_2\text{He}$ nucleus.

mass defect = ... kg [3]

- (c) (i) State the name of the type of reaction illustrated by this nuclear equation.

..... [1]

- (ii) Determine the binding energy per nucleon, in MeV, of tritium (${}^3_1\text{H}$).

binding energy per nucleon = ... MeV [3]

Section B

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

For
Examiner's
Use

- 9 A metal wire strain gauge is firmly fixed across a crack in a wall, as shown in Fig. 9.1, so that the growth of the crack may be monitored.

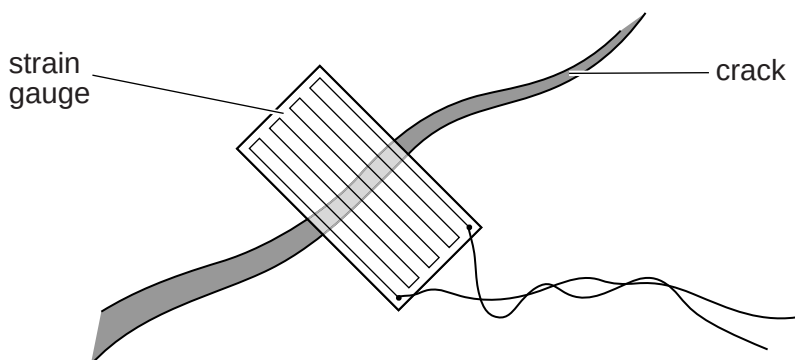


Fig. 9.1

- (a) Explain why, as the crack becomes wider, the resistance of the strain gauge increases.

.....

.....

.....

..... [3]

- (b) The strain gauge has an initial resistance of $143.0\ \Omega$ and, after being fixed in position across the crack for several weeks, the resistance is found to be $146.2\ \Omega$.

The change in the area of cross-section of the strain gauge wire is negligible.

Calculate the percentage increase in the width of the crack. Explain your working.

increase = ... % [3]

10 The circuit of Fig. 10.1 may be used to indicate temperature change.

For
Examiner's
Use

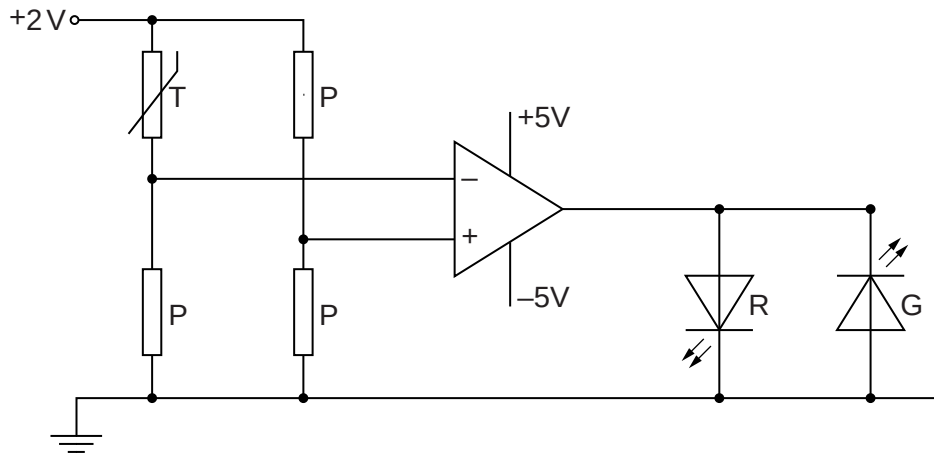


Fig. 10.1

The resistance of the thermistor T at 16°C is $2100\ \Omega$ and at 18°C , the resistance is $1900\ \Omega$. Each resistor P has a resistance of $2000\ \Omega$.

Determine the change in the states of the light-emitting diodes R and G as the temperature of the thermistor changes from 16°C to 18°C .

.....
 [4]

- [6]

- 12 (a)** State and explain two advantages of the transmission of information in digital, rather than analogue, form.

1.

 2.

[4]

- (b)** Convert

- (i)** the decimal number 13 to a four-bit digital number,

..... [1]

- (ii)** the digital number 0101 to a decimal number.

..... [1]

- (c)** An analogue signal is to be transmitted digitally. A block diagram for part of the transmission system is shown in Fig. 12.1.

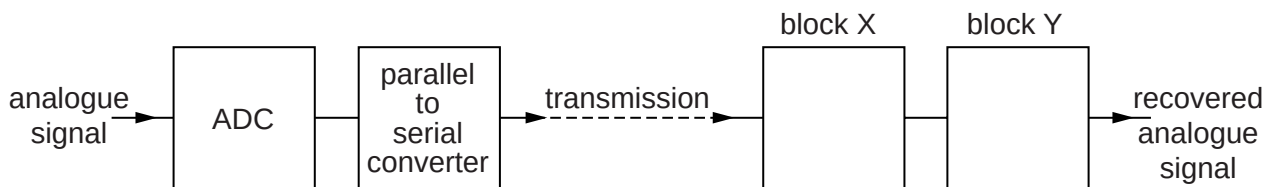


Fig. 12.1

- (i)** Complete Fig. 12.1 by labelling block X and block Y.

[2]

- (ii)** State the purpose of the parallel-to-serial converter.

.....

 [2]

- (d) The original analogue signal is shown in Fig. 12.2. The recovered signal after transmission is shown in Fig. 12.3.

For
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Use

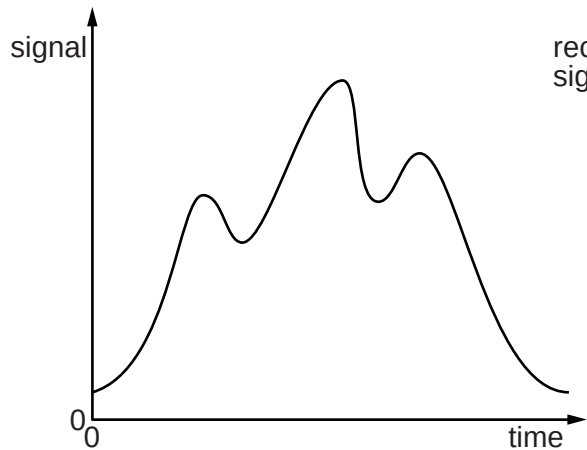


Fig. 12.2

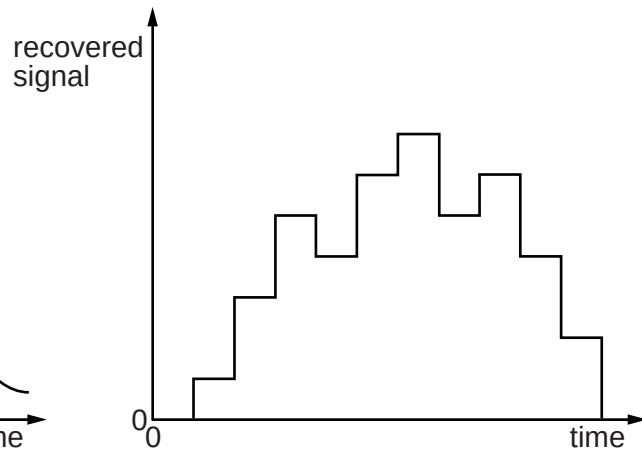


Fig. 12.3

Suggest and explain two ways in which the reproduction of the input signal may be improved.

1.

.....

.....

2.

.....

.....

[4]

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9702/42

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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.

For
Examiner's
Use

- 1 (a) The Earth may be considered to be a uniform sphere of radius $6.38 \times 10^3 \text{ km}$, with its mass concentrated at its centre.

- (i) Define *gravitational field strength*.

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

- (ii) By considering the gravitational field strength at the surface of the Earth, show that the mass of the Earth is $5.99 \times 10^{24} \text{ kg}$.

[2]

- (b) The Global Positioning System (GPS) is a navigation system that can be used anywhere on Earth. It uses a number of satellites that orbit the Earth in circular orbits at a distance of $2.22 \times 10^4 \text{ km}$ above its surface.

- (i) Use data from (a) to calculate the angular speed of a GPS satellite in its orbit.

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

- (ii) Use your answer in (i) to show that the satellites are not in geostationary orbits.

For
Examiner's
Use

[3]

- (c) The planes of the orbits of the GPS satellites in (b) are inclined at an angle of 55° to the Equator.

Suggest why the satellites are not in equatorial orbits.

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

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

For
Examiner's
Use

.....

.....

..... [2]

- (b) The first law of thermodynamics may be represented by the equation

$$\Delta U = q + w.$$

State what is meant by each of the following symbols.

$+\Delta U$

$+q$

$+w$ [3]

- (c) An amount of 0.18 mol of an ideal gas is held in an insulated cylinder fitted with a piston, as shown in Fig. 2.1.

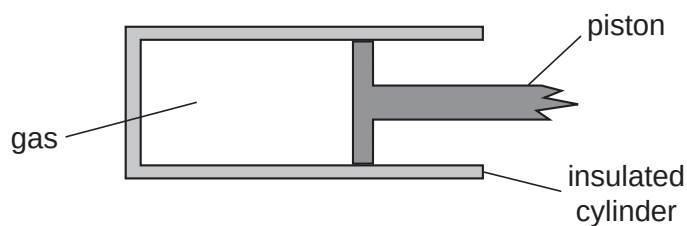


Fig. 2.1

Atmospheric pressure is $1.0 \times 10^5 \text{ Pa}$.

The volume of the gas is suddenly increased from $1.8 \times 10^3 \text{ cm}^3$ to $2.1 \times 10^3 \text{ cm}^3$.

For the expansion of the gas,

- (i) calculate the work done by the gas and hence show that the internal energy changes by 30 J,

[3]

- (ii) determine the temperature change of the gas and state whether the change is an increase or a decrease.

For
Examiner's
Use

change = ... K

.....
[3]

- 3 The variation with displacement x of the acceleration a of the centre of the cone of a loudspeaker is shown in Fig. 3.1.

For
Examiner's
Use

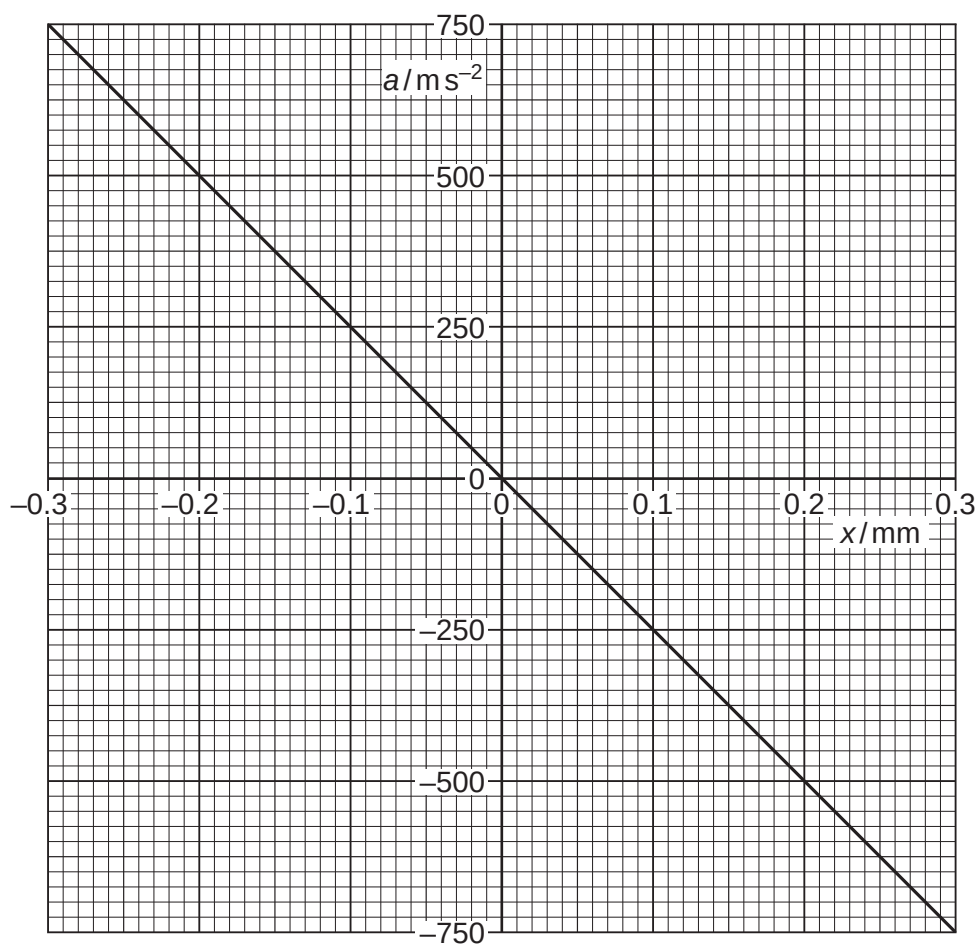


Fig. 3.1

- (a) State the two features of Fig. 3.1 that show that the motion of the cone is simple harmonic.

1.

2.

[2]

- (b) Use data from Fig. 3.1 to determine the frequency, in hertz, of vibration of the cone.

frequency = ... Hz [3]

- (c) The frequency of vibration of the cone is now reduced to one half of that calculated in (b).

*For
Examiner's
Use*

The amplitude of vibration remains unchanged.

On the axes of Fig. 3.1, draw a line to represent the variation with displacement x of the acceleration a of the centre of the loudspeaker cone.

[2]

- 4 (a) Define *capacitance*.

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

- (b) An isolated metal sphere of radius R has a charge $+Q$ on it.

The charge may be considered to act as a point charge at the centre of the sphere.

Show that the capacitance C of the sphere is given by the expression

$$C = 4\pi\epsilon_0 R$$

where ϵ_0 is the permittivity of free space.

[1]

- (c) In order to investigate electrical discharges (lightning) in a laboratory, an isolated metal sphere of radius 63 cm is charged to a potential of $1.2 \times 10^6 \text{ V}$.

At this potential, there is an electrical discharge in which the sphere loses 75% of its energy.

Calculate

- (i) the capacitance of the sphere, stating the unit in which it is measured,

capacitance = ... [3]

- (ii) the potential of the sphere after the discharge has taken place.

For
Examiner's
Use

potential = ... V [3]

- 5 Two long straight vertical wires X and Y pass through a horizontal card, as shown in Fig. 5.1.

For
Examiner's
Use

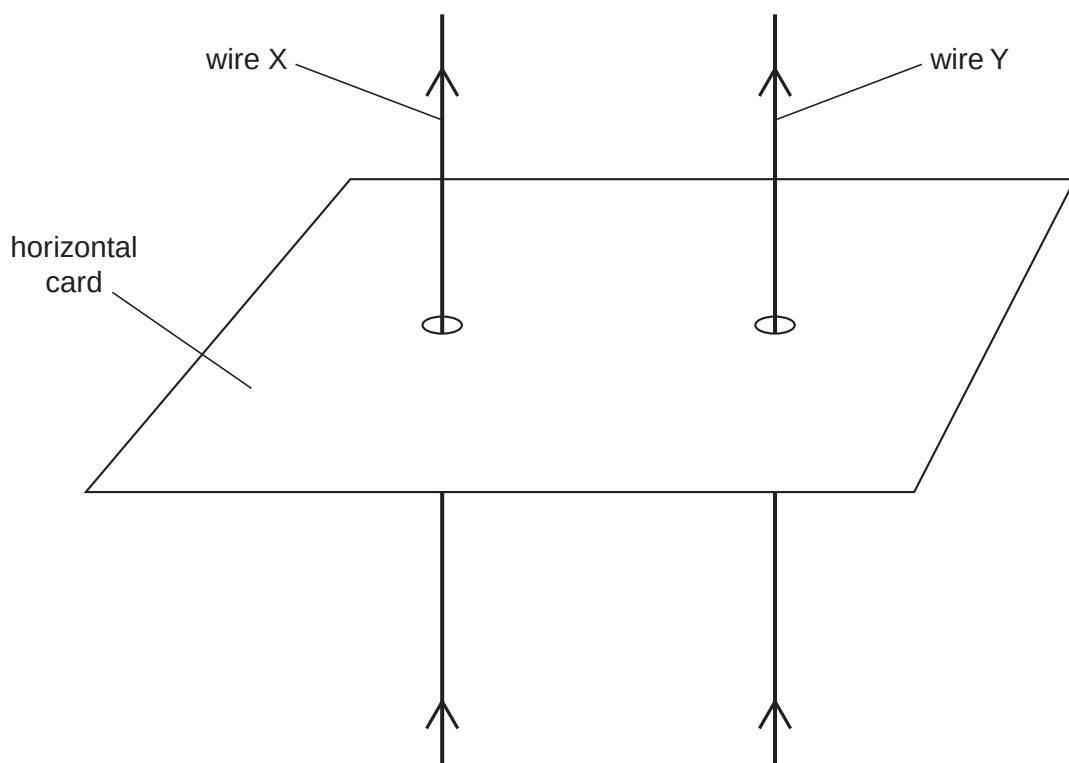


Fig. 5.1

The current in each wire is in the upward direction.

The top view of the card, seen by looking vertically downwards at the card, is shown in Fig. 5.2.

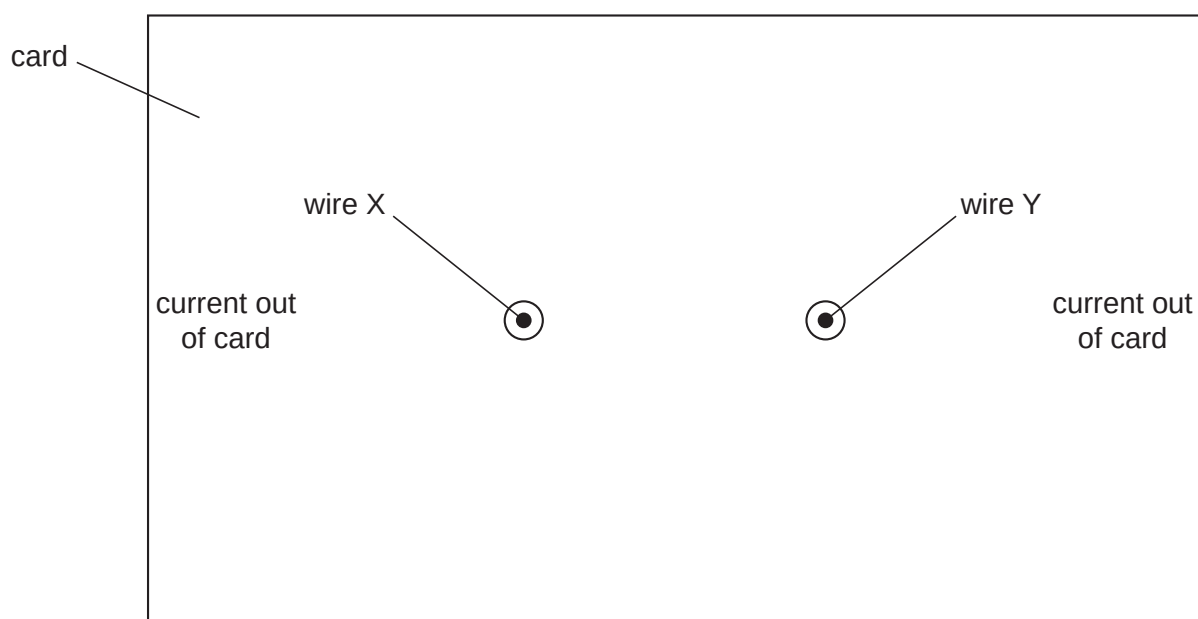


Fig. 5.2 (not to scale)

(a) On Fig. 5.2,

(i) draw four field lines to represent the pattern of the magnetic field around wire X due solely to the current in wire X, [2]

(ii) draw an arrow to show the direction of the force on wire Y due to the magnetic field of wire X. [1]

(b) The magnetic flux density B at a distance x from a long straight wire due to a current I in the wire is given by the expression

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

where μ_0 is the permeability of free space.

The current in wire X is 5.0 A and that in wire Y is 7.0 A. The separation of the wires is 2.5 cm.

(i) Calculate the force per unit length on wire Y due to the current in wire X.

force per unit length = ... N m^{-1} [4]

(ii) The currents in the wires are not equal.

State and explain whether the forces on the two wires are equal in magnitude.

.....

 [2]

- 6 An ideal transformer is illustrated in Fig. 6.1.

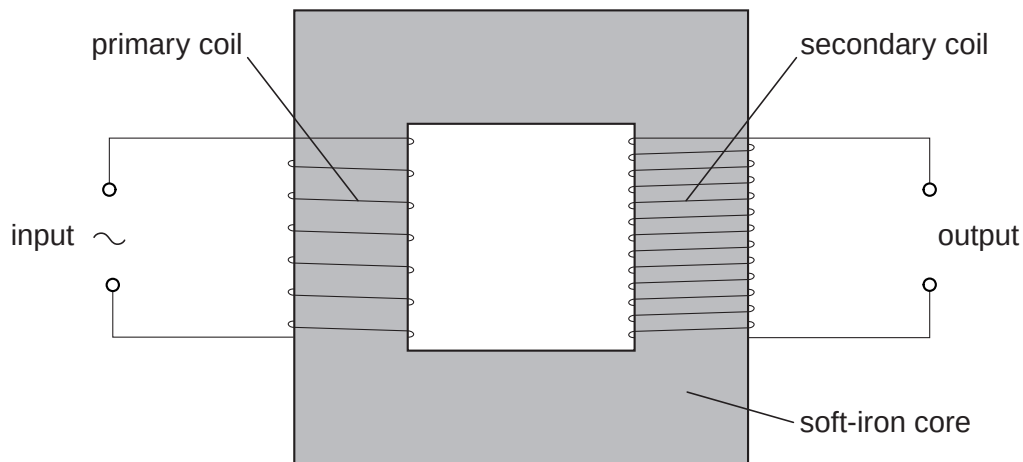


Fig. 6.1

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

.....

 [2]

- (ii) Use the law to explain why a transformer will not operate using a direct current input.

.....

 [2]

- (b) (i) State Lenz's law.

.....

 [2]

- (ii) Use Lenz's law to explain why the input potential difference and the output e.m.f. are not in phase.

.....

 [2]

- (c) Electrical energy is usually transmitted using alternating high voltages.

Suggest one advantage, for the transmission of electrical energy, of using

(i) alternating voltage, ...

..... [1]

(ii) high voltage.

..... [1]

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- 7 (a) Explain how a line emission spectrum leads to an understanding of the existence of discrete electron energy levels in atoms.

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Use

.....

.....

.....

..... [3]

- (b) Some of the lines of the emission spectrum of atomic hydrogen are shown in Fig. 7.1.

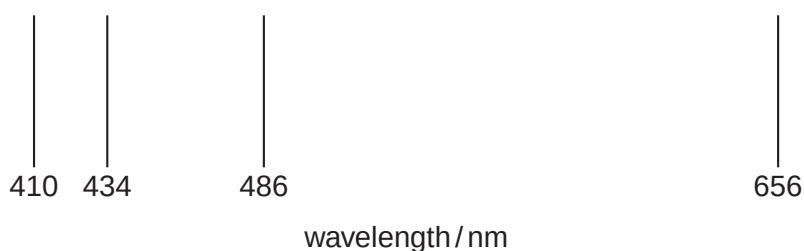


Fig. 7.1

The photon energies associated with some of these lines are shown in Fig. 7.2.

wavelength / nm	photon energy / 10^{-19} J
410	4.85
434	4.58
486	
656	3.03

Fig. 7.2

- (i) Complete Fig. 7.2 by calculating the photon energy for a wavelength of 486 nm.

[2]

(ii) Energy levels of a single electron in a hydrogen atom are shown in Fig. 7.3.

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Use

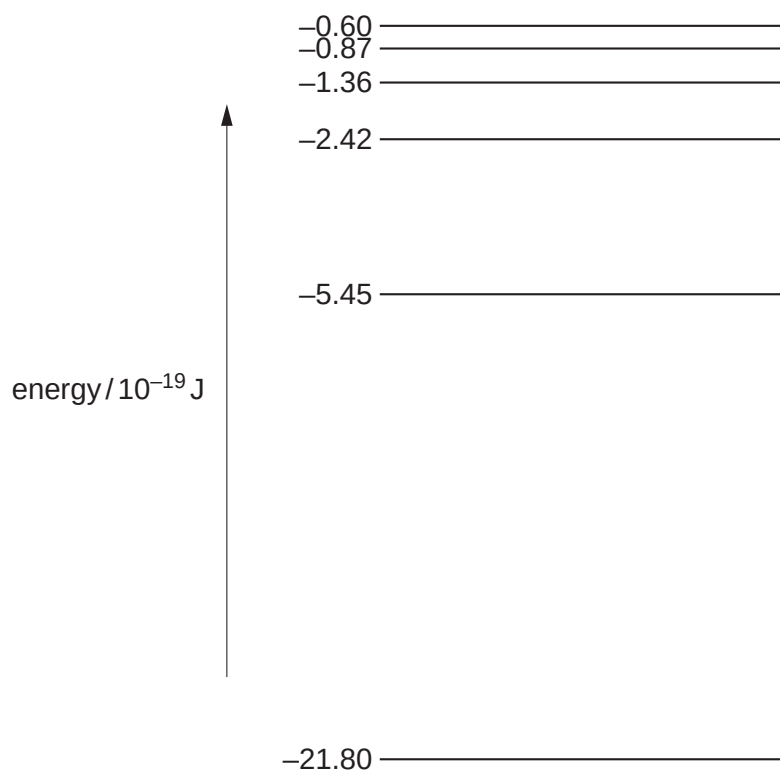


Fig. 7.3 (not to scale)

Use data from (i) to show, on Fig. 7.3, the transitions associated with each of the four spectral lines shown in Fig. 7.1. Show each transition with an arrow. [2]

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

.....

.....

..... [2]

- (b) Show that the decay constant λ is related to the half-life $t_{\frac{1}{2}}$ by the expression

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

[3]

- (c) Cobalt-60 is a radioactive isotope with a half-life of 5.26 years (1.66×10^8 s).

A cobalt-60 source for use in a school laboratory has an activity of 1.8×10^5 Bq.

Calculate the mass of cobalt-60 in the source.

mass = ... g [3]

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Please turn over for Section B.

Section B

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

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- 9 An amplifier incorporating an operational amplifier (op-amp) has three inputs A, B and C, as shown in Fig. 9.1.

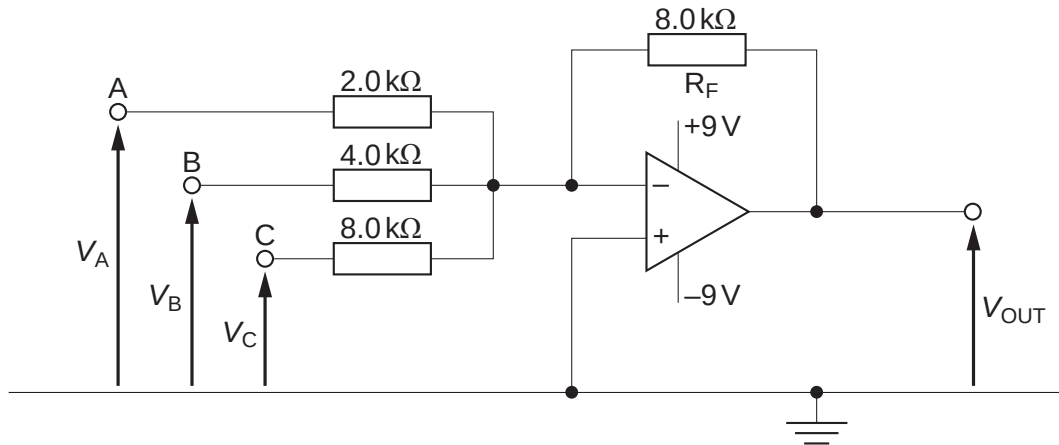


Fig. 9.1

Negative feedback is provided by the resistor R_F of resistance $8.0\text{ k}\Omega$.

For each of the inputs A, B and C, the amplifier may be considered as a single input amplifier. That is, each input is independent of the other two.

When the amplifier is not saturated, the output potential V_{OUT} is given by the expression

$$V_{\text{OUT}} = -(4V_A + GV_B + V_C),$$

where V_A , V_B and V_C are the input potentials of the inputs A, B and C respectively and G is a constant.

- (a) State two effects of negative feedback on an amplifier.

1.
-
2.
-

[2]

- (b) In the expression for the output potential V_{OUT} , the constant G is the gain associated with input B. Show that the numerical value of G is 2.

For
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Use

[1]

- (c) The input potentials V_A , V_B and V_C are either zero or 1.0V.

The magnitudes of some output potentials for different combinations of V_A , V_B and V_C are shown in Fig. 9.2.

V_A/V	V_B/V	V_C/V	V_{OUT}/V
0	0	1	1
0	1	0	
1	0	0	4
1	0	1	5
1	1	0	
1	1	1	

Fig. 9.2

- (i) Complete Fig. 9.2 for the three remaining values of V_{OUT} . [1]
- (ii) Suggest a use for this circuit.

..... [1]

- 10 (a)** A typical spectrum of the X-ray radiation produced by electron bombardment of a metal target is illustrated in Fig. 10.1.

For
Examiner's
Use

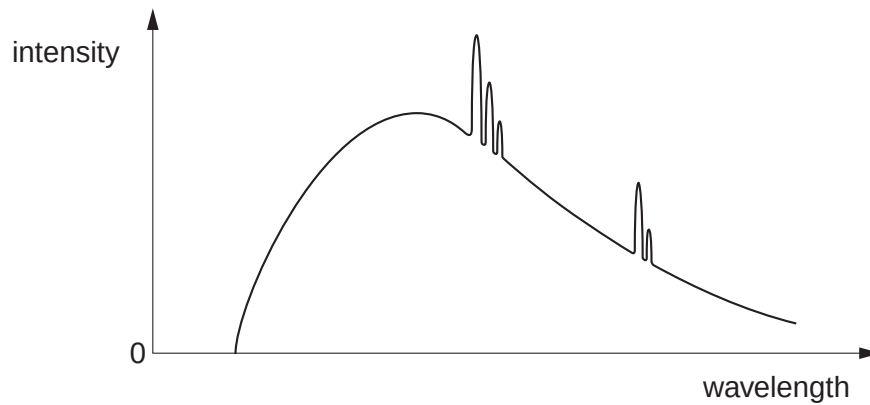


Fig. 10.1

Explain why

- (i)** a continuous spectrum of wavelengths is produced,

.....

 [3]

- (ii)** the spectrum has a sharp cut-off at short wavelengths.

.....
 [1]

- (b) The variation with photon energy E of the linear absorption coefficient μ of X-rays in soft tissue is illustrated in Fig. 10.2.

For
Examiner's
Use

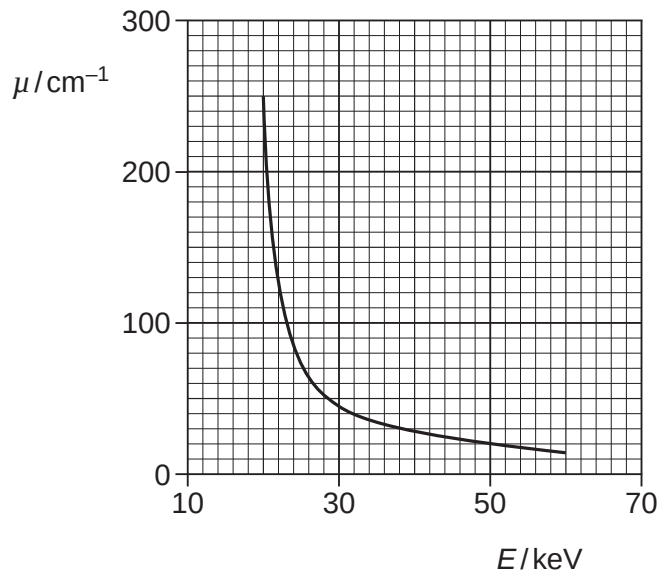


Fig. 10.2

- (i) Explain what is meant by *linear absorption coefficient*

.....

 [3]

- (ii) For one particular application of X-ray imaging, electrons in the X-ray tube are accelerated through a potential difference of 50 kV.

Use Fig. 10.2 to explain why it is advantageous to filter out low-energy photons from the X-ray beam.

.....

 [3]

- 11 The variation with time of the signal transmitted from an aerial is shown in Fig. 11.1.

For
Examiner's
Use

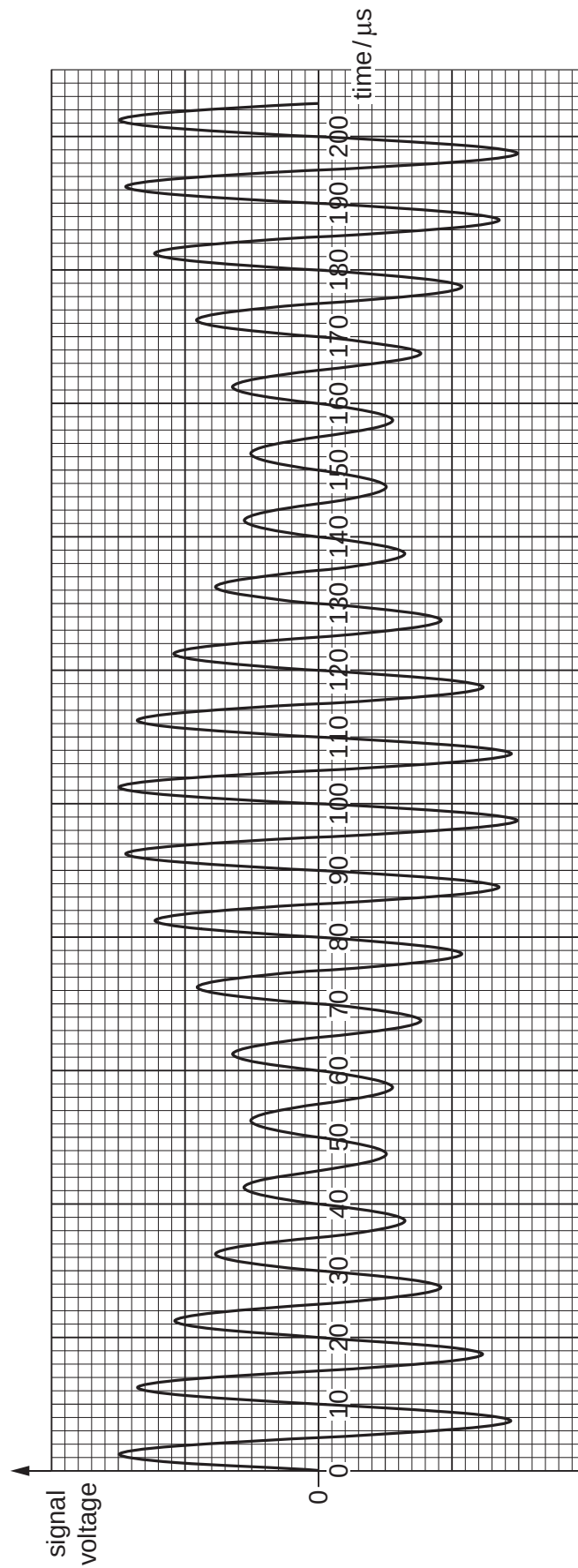


Fig. 11.1

- (a) State the name of this type of modulated transmission.

..... [1]

- (b) Use Fig. 11.1 to determine the frequency of

- (i) the carrier wave,

frequency = ... Hz [2]

- (ii) the information signal.

frequency = ... Hz [1]

- (c) (i) On the axes of Fig. 11.2, draw the frequency spectrum (the variation with frequency of the signal voltage) of the signal from the aerial. Mark relevant values on the frequency axis.

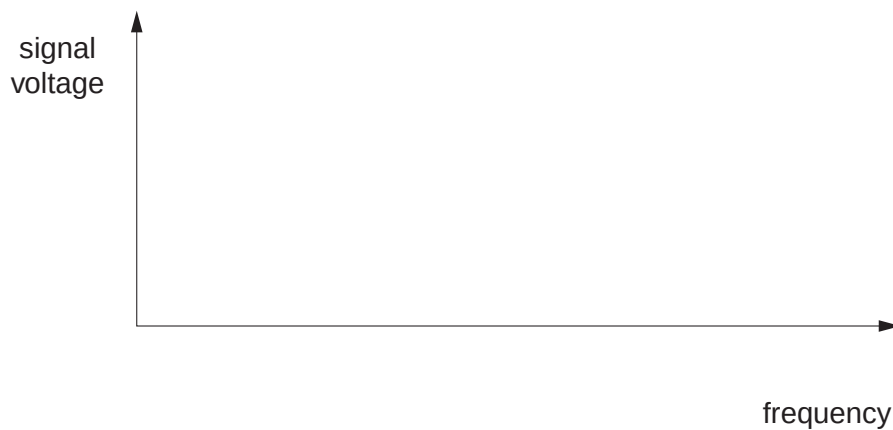


Fig. 11.2

[3]

- (ii) Determine the bandwidth of the signal.

bandwidth = ... Hz [1]

For
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Use

12 A block diagram representing part of a mobile phone network is shown in Fig. 12.1.

For
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Use

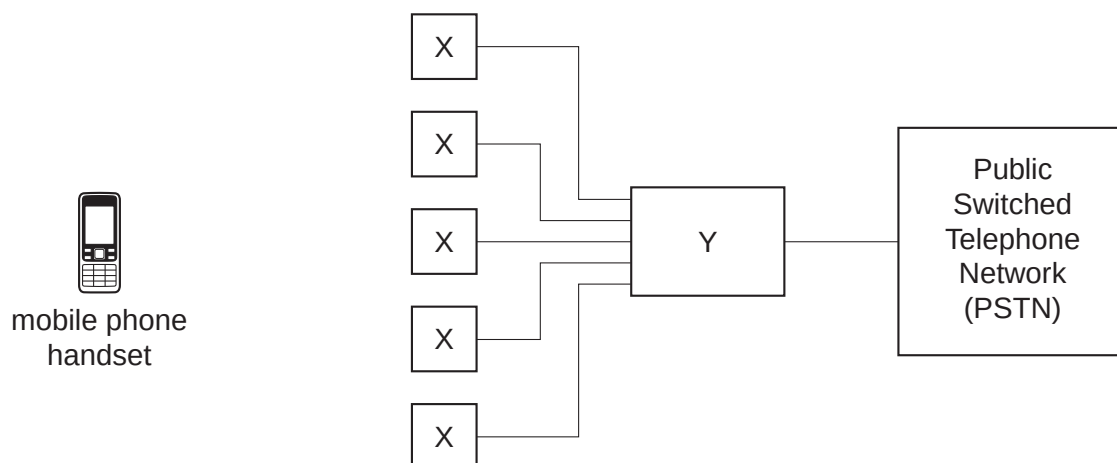


Fig. 12.1

(a) State what is represented by

(i) the blocks labelled X,

..... [1]

(ii) the block labelled Y.

..... [1]

(b) A user of a mobile phone is making a call.

Explain the role of the components in the boxes labelled X and Y during the call.

.....

.....

.....

.....

.....

.....

.....

.....

..... [5]

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