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9702/41

October/November 2010

1 hour 45 minutes

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

DO **NOT** WRITE IN ANY BARCODES.

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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12	
Total	

This document consists of **24** printed 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) Define *gravitational field strength*.

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

- (b) An isolated star has radius R . The mass of the star may be considered to be a point mass at the centre of the star.
The gravitational field strength at the surface of the star is g_s .

On Fig. 1.1, sketch a graph to show the variation of the gravitational field strength of the star with distance from its centre. You should consider distances in the range R to $4R$.

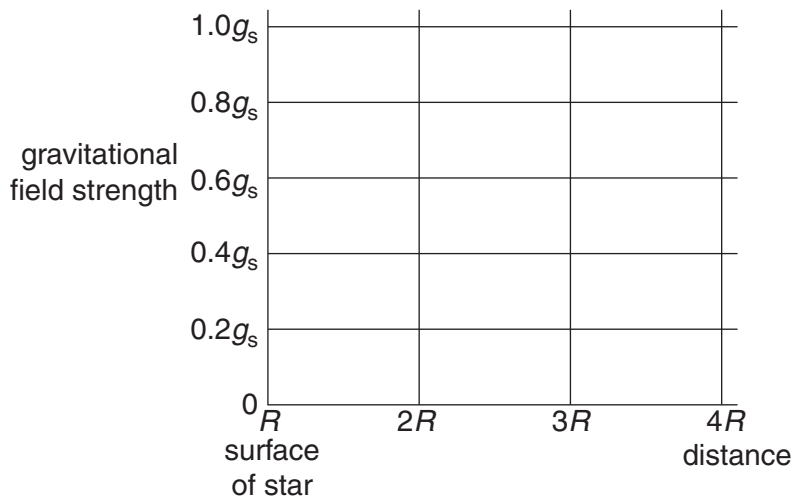


Fig. 1.1

[2]

- (c) The Earth and the Moon may be considered to be spheres that are isolated in space with their masses concentrated at their centres.
The masses of the Earth and the Moon are $6.00 \times 10^{24} \text{ kg}$ and $7.40 \times 10^{22} \text{ kg}$ respectively.
The radius of the Earth is R_E and the separation of the centres of the Earth and the Moon is $60 R_E$, as illustrated in Fig. 1.2.

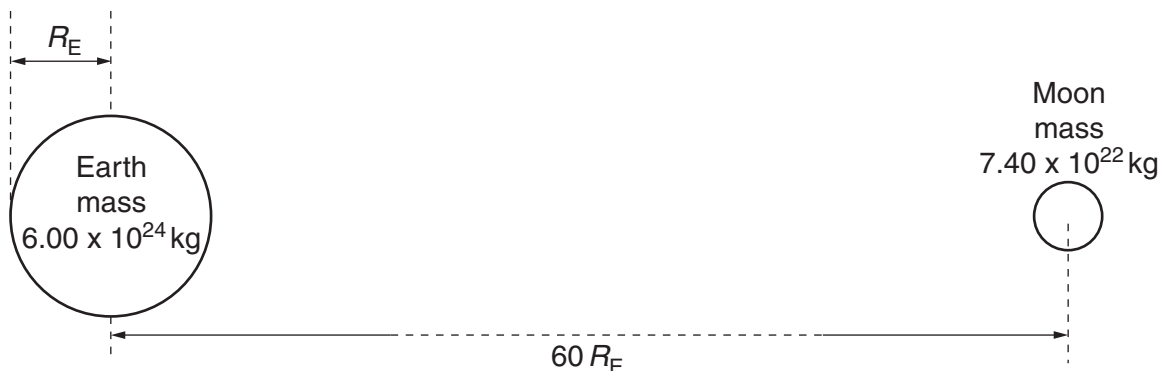


Fig. 1.2 (not to scale)

- (i) Explain why there is a point between the Earth and the Moon at which the gravitational field strength is zero.

.....

 [2]

- (ii) Determine the distance, in terms of R_E , from the centre of the Earth at which the gravitational field strength is zero.

distance = ... R_E [3]

- (iii) On the axes of Fig. 1.3, sketch a graph to show the variation of the gravitational field strength with position between the surface of the Earth and the surface of the Moon.

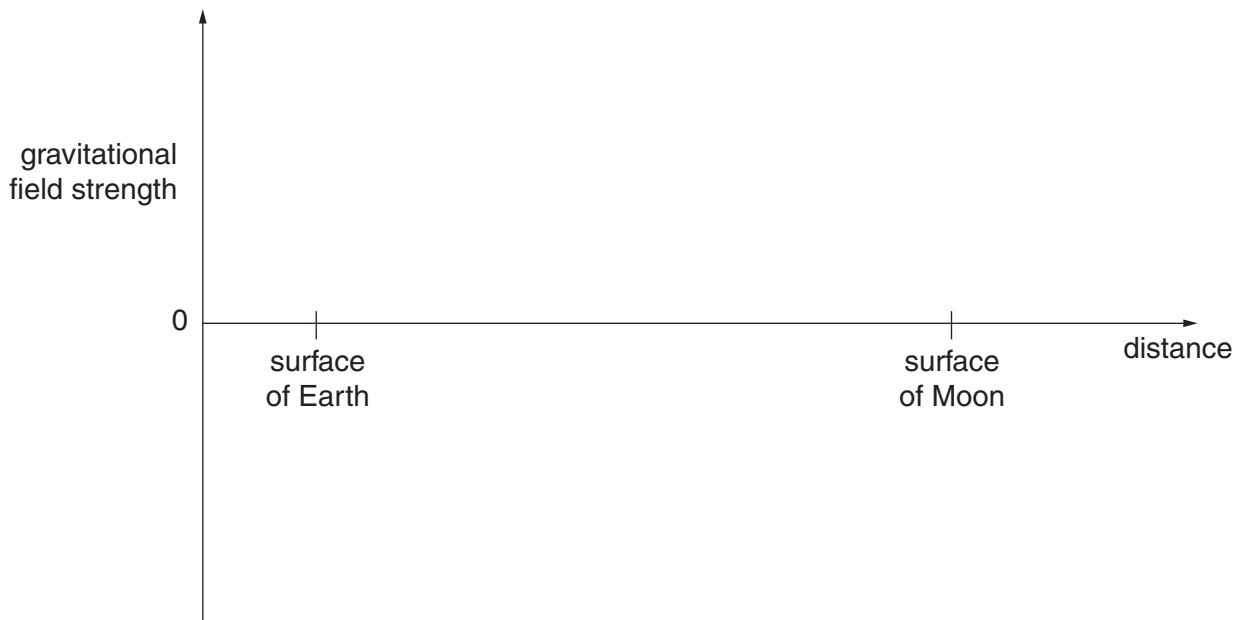


Fig. 1.3

[3]

- 2 (a) (i) State the basic assumption of the kinetic theory of gases that leads to the conclusion that the potential energy between the atoms of an ideal gas is zero.

For
Examiner's
Use

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

- (ii) State what is meant by the *internal energy* of a substance.

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

- (iii) Explain why an increase in internal energy of an ideal gas is directly related to a rise in temperature of the gas.

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

- (b) A fixed mass of an ideal gas undergoes a cycle PQRP of changes as shown in Fig. 2.1.

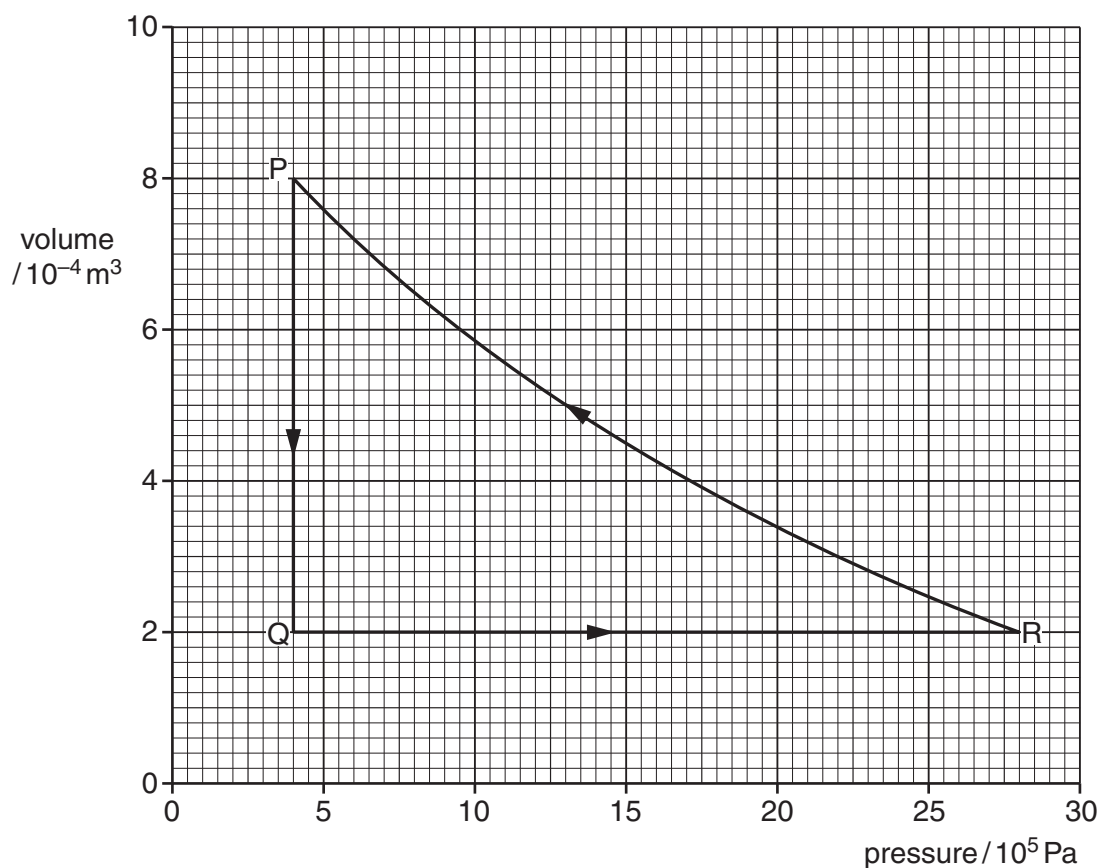


Fig. 2.1

- (i) State the change in internal energy of the gas during one complete cycle PQRP.

change = ... J [1]

- (ii) Calculate the work done on the gas during the change from P to Q.

work done = ... J [2]

- (iii) Some energy changes during the cycle PQRP are shown in Fig. 2.2.

change	work done on gas / J	heating supplied to gas / J	increase in internal energy / J
P → Q		−600	
Q → R	0	+720	
R → P		+480	

Fig. 2.2

Complete Fig. 2.2 to show all of the energy changes.

[3]

- 3 A student sets up the apparatus illustrated in Fig. 3.1 in order to investigate the oscillations of a metal cube suspended on a spring.

For
Examiner's
Use

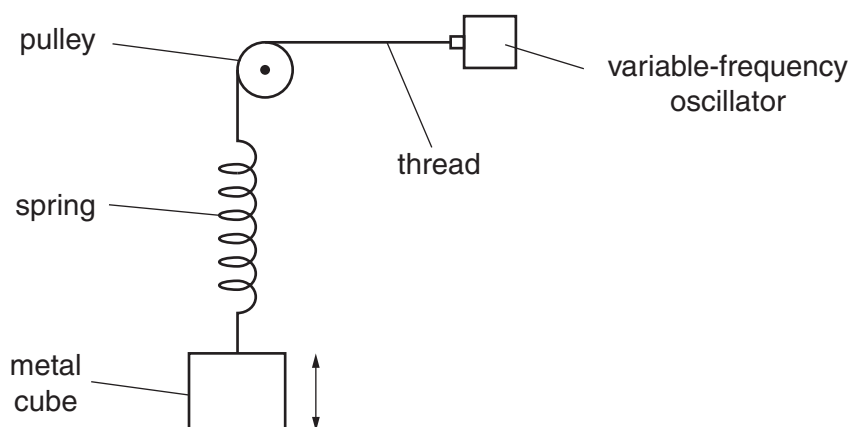


Fig. 3.1

The amplitude of the vibrations produced by the oscillator is constant. The variation with frequency of the amplitude of the oscillations of the metal cube is shown in Fig. 3.2.

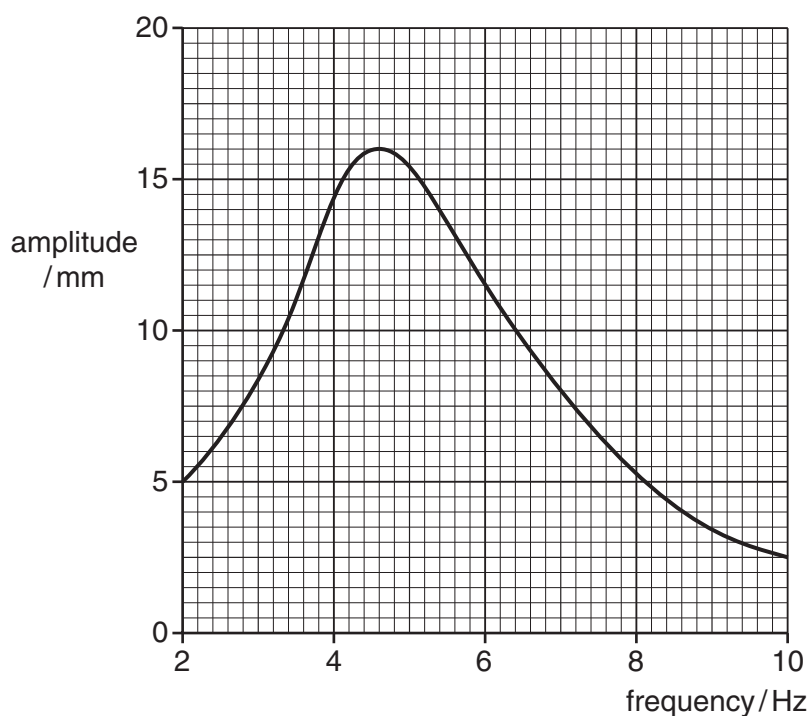


Fig. 3.2

- (a) (i) State the phenomenon illustrated in Fig. 3.2.

.....[1]

- (ii) For the maximum amplitude of vibration, state the magnitudes of the amplitude and the frequency.

amplitude = ... mm

frequency = ... Hz
[1]

- (b) The oscillations of the metal cube of mass 150g may be assumed to be simple harmonic.

Use your answers in (a)(ii) to determine, for the metal cube,

- (i) its maximum acceleration,

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

- (ii) the maximum resultant force on the cube.

force = ... N [2]

- (c) Some very light feathers are attached to the top surface of the cube so that the feathers extend outwards, beyond the vertical sides of the cube.

The investigation is now repeated.

On Fig. 3.2, draw a line to show the new variation with frequency of the amplitude of vibration for frequencies between 2 Hz and 10 Hz. [2]

- 4 (a) Define *capacitance*.

.....
 [1]

- (b) An isolated metal sphere has a radius r . When charged to a potential V , the charge on the sphere is q .
 The charge may be considered to act as a point charge at the centre of the sphere.

- (i) State an expression, in terms of r and q , for the potential V of the sphere.

..... [1]

- (ii) This isolated sphere has capacitance. Use your answers in (a) and (b)(i) to show that the capacitance of the sphere is proportional to its radius.

[1]

- (c) The sphere in (b) has a capacitance of 6.8 pF and is charged to a potential of 220 V.

Calculate

- (i) the radius of the sphere,

radius = ... m [3]

- (ii) the charge, in coulomb, on the sphere.

charge = ... C [1]

- (d) A second uncharged metal sphere is brought up to the sphere in (c) so that they touch. The combined capacitance of the two spheres is 18 pF.

Calculate

- (i) the potential of the two spheres,

potential = ... V [1]

- (ii) the change in the total energy stored on the spheres when they touch.

change = ... J [3]

- 5 Positive ions are travelling through a vacuum in a narrow beam. The ions enter a region of uniform magnetic field of flux density B and are deflected in a semi-circular arc, as shown in Fig. 5.1.

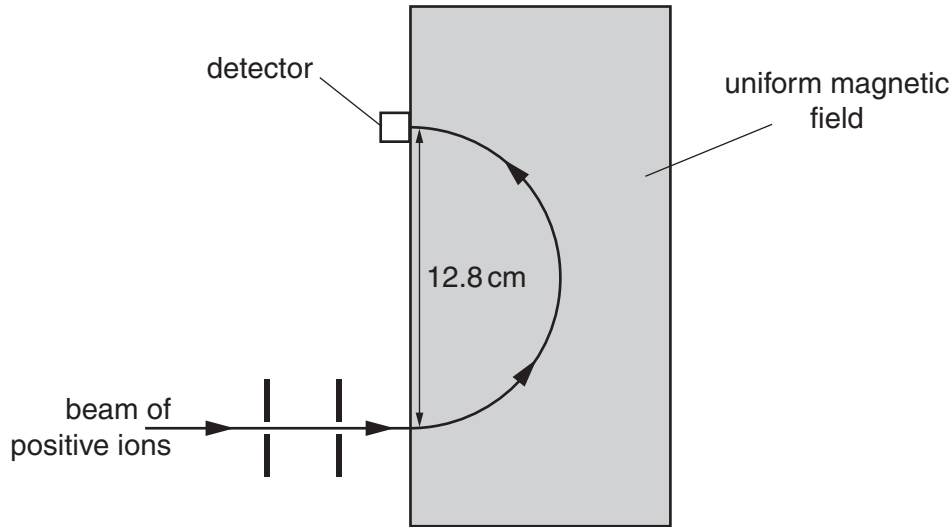


Fig. 5.1

The ions, travelling with speed $1.40 \times 10^5 \text{ ms}^{-1}$, are detected at a fixed detector when the diameter of the arc in the magnetic field is 12.8 cm.

- (a) By reference to Fig. 5.1, state the direction of the magnetic field.

.....[1]

- (b) The ions have mass 20 u and charge $+1.6 \times 10^{-19} \text{ C}$. Show that the magnetic flux density is 0.454 T . Explain your working.

[3]

(c) Ions of mass 22 u with the same charge and speed as those in (b) are also present in the beam.

(i) On Fig. 5.1, sketch the path of these ions in the magnetic field of magnetic flux density 0.454 T . [1]

(ii) In order to detect these ions at the fixed detector, the magnetic flux density is changed.
Calculate this new magnetic flux density.

magnetic flux density = ... T [2]

- 6 A simple iron-cored transformer is illustrated in Fig. 6.1.

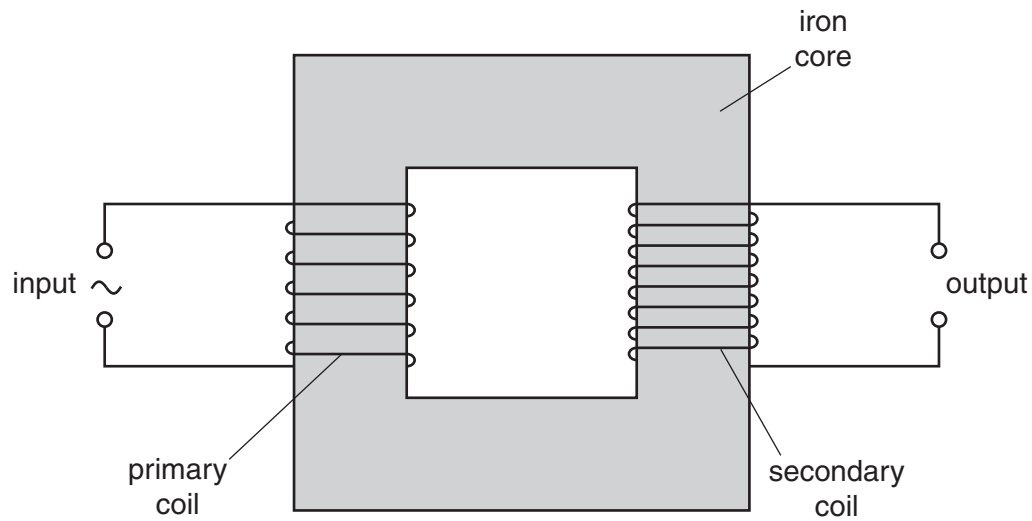


Fig. 6.1

- (a) (i) State why the primary and secondary coils are wound on a core made of iron.

.....

[1]

- (ii) Suggest why thermal energy is generated in the core when the transformer is in use.

.....

[3]

- (b) The root-mean-square (r.m.s.) voltage and current in the primary coil are V_P and I_P respectively.

The r.m.s. voltage and current in the secondary coil are V_S and I_S respectively.

For
Examiner's
Use

- (i) Explain, by reference to direct current, what is meant by the *root-mean-square* value of an alternating current.

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

- (ii) Show that, for an ideal transformer,

$$\frac{V_S}{V_P} = \frac{I_P}{I_S}.$$

[2]

7 (a) State an effect, one in each case, that provides evidence for

(i) the wave nature of a particle,

..... [1]

(ii) the particulate nature of electromagnetic radiation.

..... [1]

(b) Four electron energy levels in an atom are shown in Fig. 7.1.

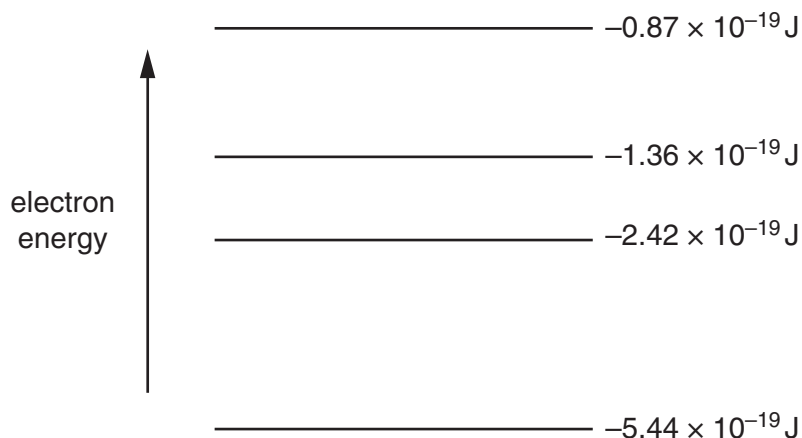


Fig. 7.1 (not to scale)

An emission spectrum is associated with the electron transitions between these energy levels.

For this spectrum,

(i) state the number of lines,

..... [1]

(ii) calculate the minimum wavelength.

wavelength = ... m [2]

8 In some power stations, nuclear fission is used as a source of energy.

(a) State what is meant by *nuclear fission*.

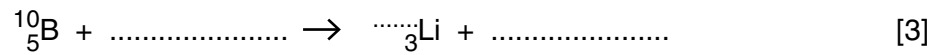
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.....[2]

(b) The nuclear fission reaction produces neutrons. In the power station, the neutrons may be absorbed by rods made of boron-10.

Complete the nuclear equation for the absorption of a single neutron by a boron-10 nucleus with the emission of an α -particle.



(c) Suggest why, when neutrons are absorbed in the boron rods, the rods become hot as a result of this nuclear reaction.

.....

.....

.....

.....[3]

Section B

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

For
Examiner's
Use

- 9 An amplifier circuit incorporating an operational amplifier (op-amp) is shown in Fig. 9.1.

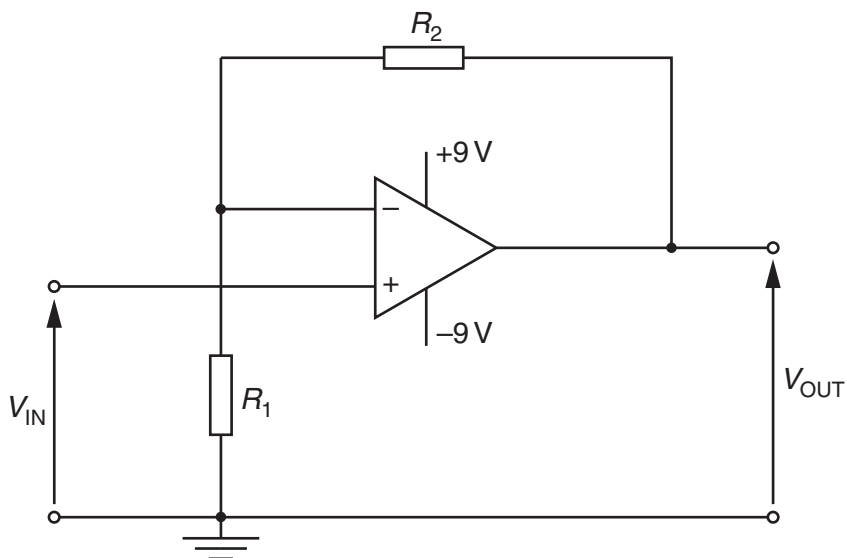


Fig. 9.1

(a) State

- (i) the name of this type of amplifier circuit,

.....[1]

- (ii) the gain G in terms of resistances R_1 and R_2 .

.....[1]

- (b) The value of R_1 is $820\ \Omega$. The resistor of resistance R_2 is replaced with a light-dependent resistor (LDR).

The input potential difference V_{IN} is 15 mV.

Calculate the output potential difference V_{OUT} for the LDR having a resistance of

- (i) $100\ \Omega$ (the LDR is in sunlight),

$$V_{OUT} = \dots\dots\dots \text{ V [2]}$$

- (ii) $1.0\ \text{M}\Omega$ (the LDR is in darkness).

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

For
Examiner's
Use

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

.....
 [1]

- (ii) Data for some media are given in Fig. 10.1.

medium	speed of ultrasound / ms^{-1}	acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$
air	330	4.3×10^2
gel	1500	1.5×10^6
soft tissue	1600	1.6×10^6
bone	4100	7.0×10^6

Fig. 10.1

Use data from Fig. 10.1 to calculate a value for the density of bone.

density = ... kg m^{-3} [1]

- (b) A parallel beam of ultrasound has intensity I . It is incident at right-angles to a boundary between two media, as shown in Fig. 10.2.

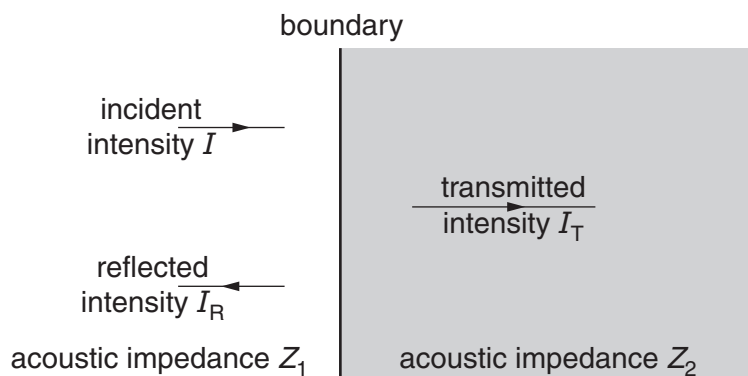


Fig. 10.2

The media have acoustic impedances of Z_1 and Z_2 . The transmitted intensity of the ultrasound beam is I_T and the reflected intensity is I_R .

- (i) State the relation between I , I_T and I_R .

..... [1]

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

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

Use data from Fig. 10.1 to determine the reflection coefficient α for a boundary between

1. gel and soft tissue,

$\alpha = \dots\dots\dots$ [2]

2. air and soft tissue.

$\alpha = \dots\dots\dots$ [1]

- (c) By reference to your answers in (b)(ii), explain the use of a gel on the surface of skin during ultrasound diagnosis.

.....

.....

.....

.....[3]

- 11 (a) Wire pairs provide one means of communication but they are subject to high levels of noise and attenuation.
Explain what is meant by

(i) *noise*,

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

(ii) *attenuation*.

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

- (b) A microphone is connected to a receiver using a wire pair, as shown in Fig. 11.1.

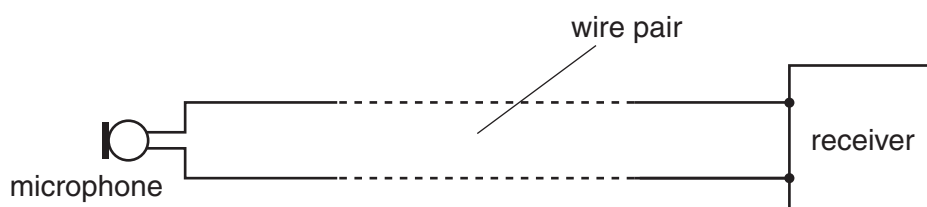


Fig. 11.1

The wire pair has an attenuation per unit length of 12 dB km^{-1} . The noise power in the wire pair is $3.4 \times 10^{-9} \text{ W}$.

The microphone produces a signal power of $2.9 \mu\text{W}$.

- (i) Calculate the maximum length of the wire pair so that the minimum signal-to-noise ratio is 24 dB.

length = ... m [4]

- (ii) Communication over distances greater than that calculated in (i) is required.
Suggest how the circuit of Fig. 11.1 may be modified so that the minimum signal-to-noise ratio at the receiver is not reduced.

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

- 12 (a)** Outline the principles of the use of a geostationary satellite for communication on Earth.

*For
Examiner's
Use*

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..... [4]

Question 12 continues on the next page.

- (b) Polar-orbiting satellites are also used for communication on Earth.
State and explain one advantage and one disadvantage of polar-orbiting satellites as compared with geostationary satellites.

For
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Use

advantage:

.....

.....

.....

disadvantage:

.....

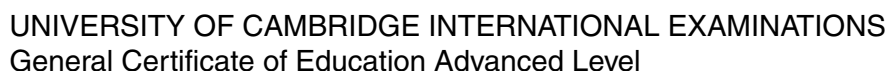
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9702/42

October/November 2010

1 hour 45 minutes

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.

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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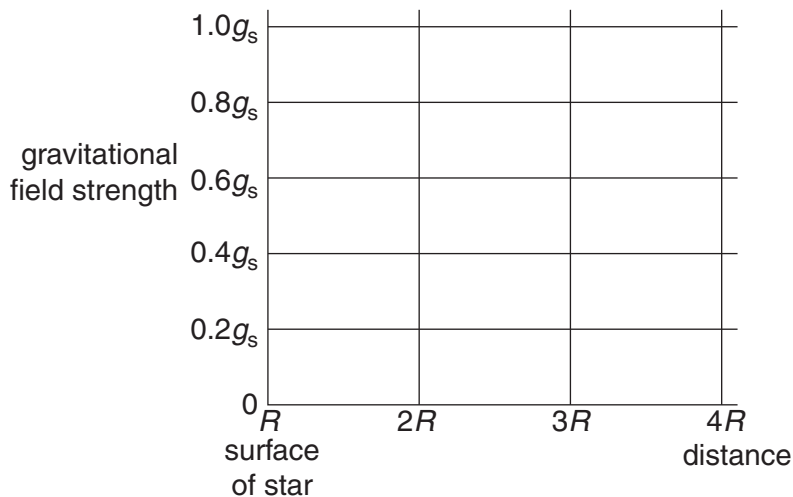


Fig. 1.1

[2]

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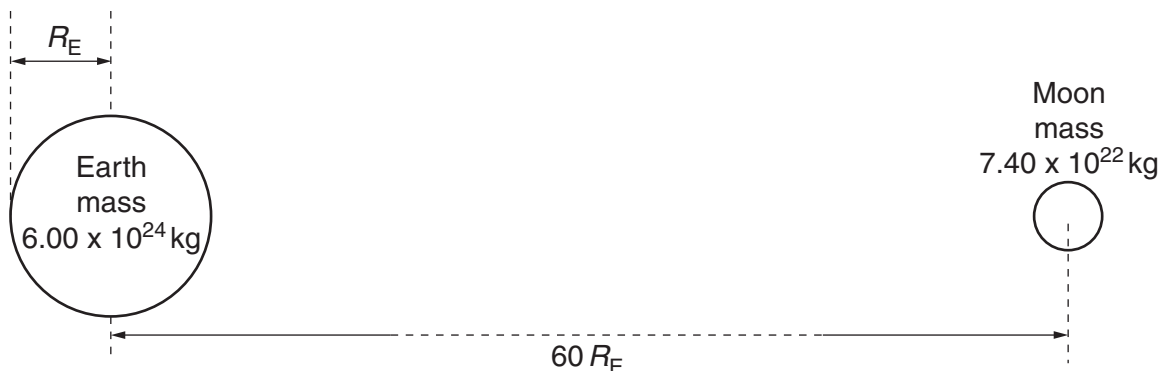


Fig. 1.2 (not to scale)

- (i) Explain why there is a point between the Earth and the Moon at which the gravitational field strength is zero.

.....

 [2]

- (ii) Determine the distance, in terms of R_E , from the centre of the Earth at which the gravitational field strength is zero.

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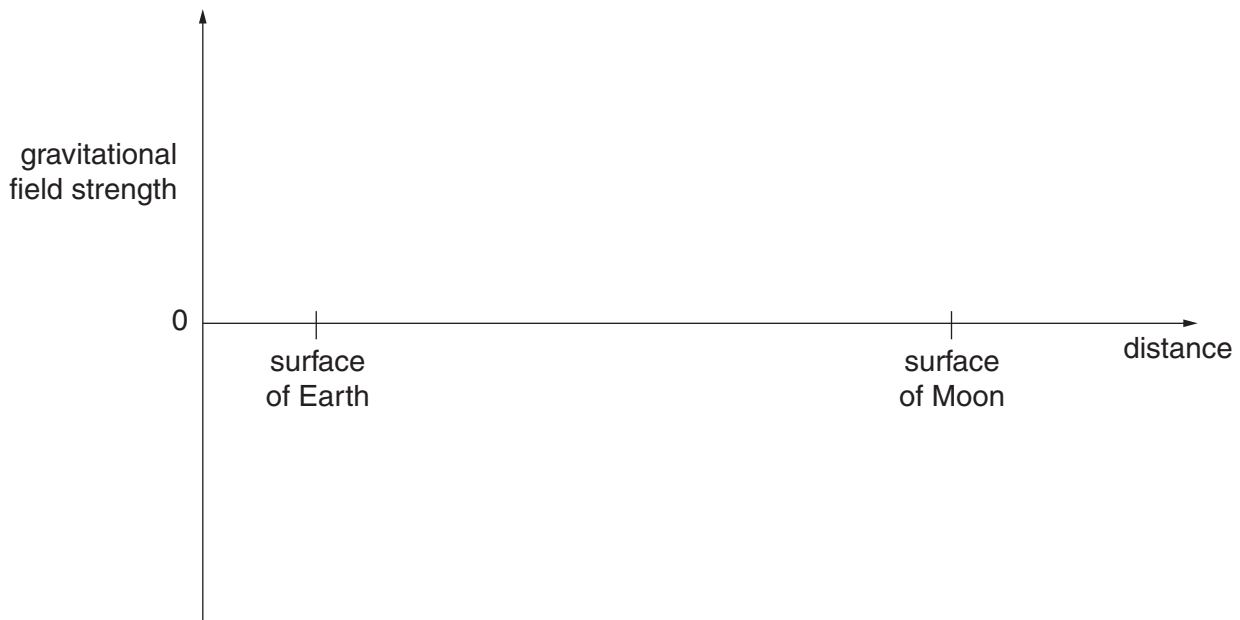


Fig. 1.3

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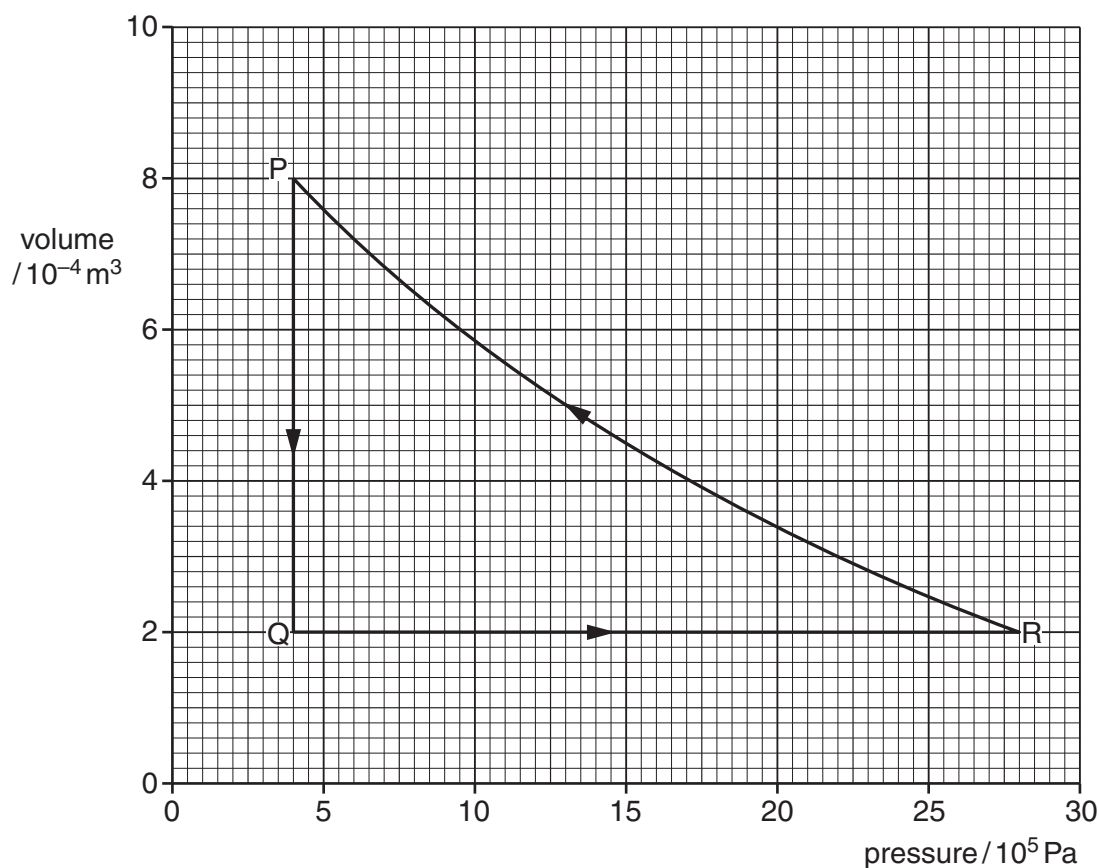


Fig. 2.1

- (i) State the change in internal energy of the gas during one complete cycle PQRP.

change = ... J [1]

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work done = ... J [2]

- (iii) Some energy changes during the cycle PQRP are shown in Fig. 2.2.

change	work done on gas / J	heating supplied to gas / J	increase in internal energy / J
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Q → R	0	+720	
R → P		+480	

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Examiner's
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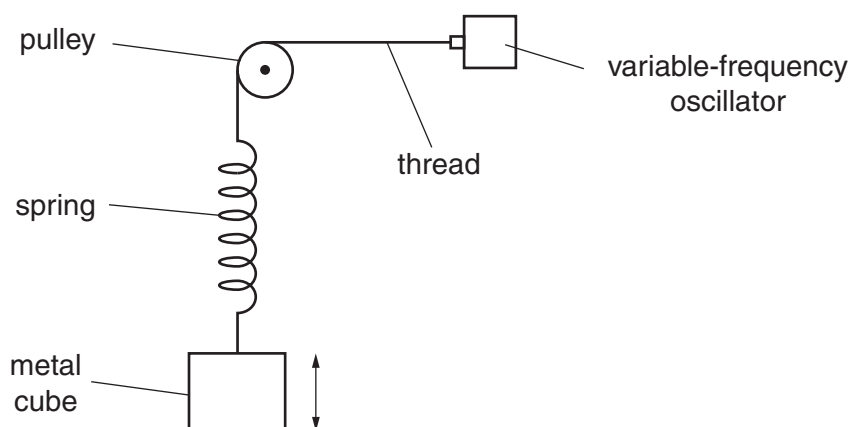


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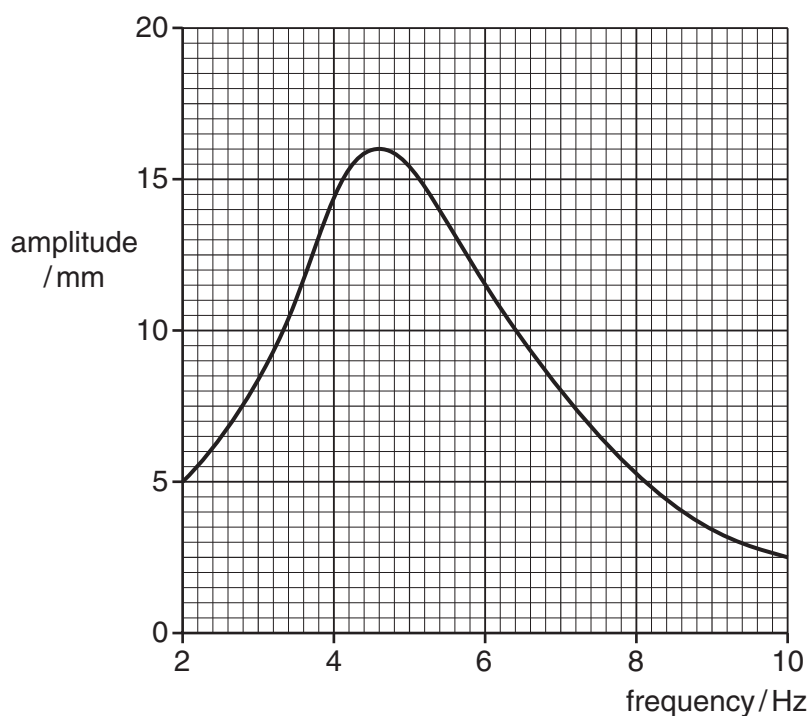


Fig. 3.2

- (a) (i) State the phenomenon illustrated in Fig. 3.2.

.....[1]

- (ii) For the maximum amplitude of vibration, state the magnitudes of the amplitude and the frequency.

amplitude = ... mm

frequency = ... Hz

[1]

- (b) The oscillations of the metal cube of mass 150g may be assumed to be simple harmonic.

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

- (ii) the maximum resultant force on the cube.

force = ... N [2]

- (c) Some very light feathers are attached to the top surface of the cube so that the feathers extend outwards, beyond the vertical sides of the cube.

The investigation is now repeated.

On Fig. 3.2, draw a line to show the new variation with frequency of the amplitude of vibration for frequencies between 2 Hz and 10 Hz. [2]

- 4 (a) Define *capacitance*.

.....
 [1]

- (b) An isolated metal sphere has a radius r . When charged to a potential V , the charge on the sphere is q .
 The charge may be considered to act as a point charge at the centre of the sphere.

- (i) State an expression, in terms of r and q , for the potential V of the sphere.

..... [1]

- (ii) This isolated sphere has capacitance. Use your answers in (a) and (b)(i) to show that the capacitance of the sphere is proportional to its radius.

[1]

- (c) The sphere in (b) has a capacitance of 6.8 pF and is charged to a potential of 220 V.

Calculate

- (i) the radius of the sphere,

radius = ... m [3]

- (ii) the charge, in coulomb, on the sphere.

charge = ... C [1]

- (d) A second uncharged metal sphere is brought up to the sphere in (c) so that they touch. The combined capacitance of the two spheres is 18 pF.

Calculate

- (i) the potential of the two spheres,

potential = ... V [1]

- (ii) the change in the total energy stored on the spheres when they touch.

change = ... J [3]

- 5 Positive ions are travelling through a vacuum in a narrow beam. The ions enter a region of uniform magnetic field of flux density B and are deflected in a semi-circular arc, as shown in Fig. 5.1.

For
Examiner's
Use

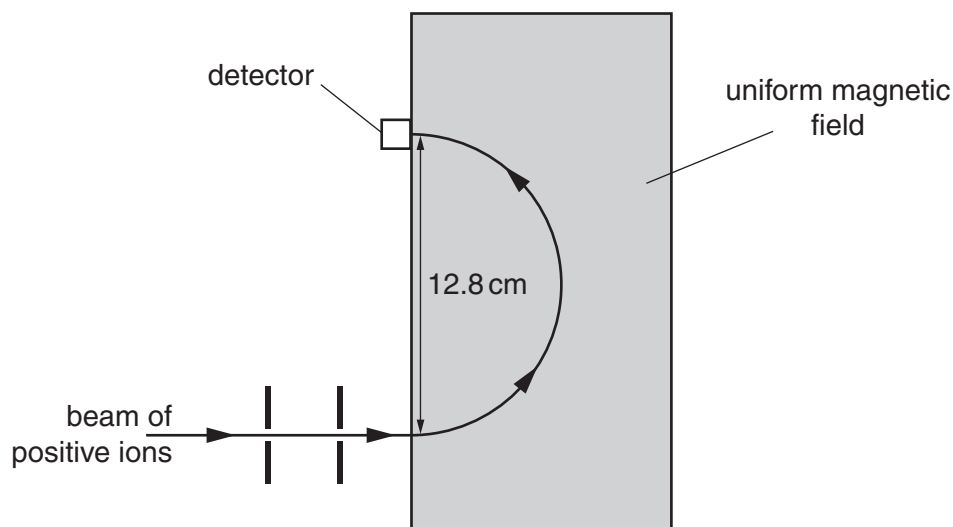


Fig. 5.1

The ions, travelling with speed $1.40 \times 10^5 \text{ ms}^{-1}$, are detected at a fixed detector when the diameter of the arc in the magnetic field is 12.8 cm.

- (a) By reference to Fig. 5.1, state the direction of the magnetic field.

.....[1]

- (b) The ions have mass 20 u and charge $+1.6 \times 10^{-19} \text{ C}$. Show that the magnetic flux density is 0.454 T . Explain your working.

[3]

(c) Ions of mass 22 u with the same charge and speed as those in (b) are also present in the beam.

(i) On Fig. 5.1, sketch the path of these ions in the magnetic field of magnetic flux density 0.454 T . [1]

(ii) In order to detect these ions at the fixed detector, the magnetic flux density is changed.
Calculate this new magnetic flux density.

magnetic flux density = ... T [2]

- 6 A simple iron-cored transformer is illustrated in Fig. 6.1.

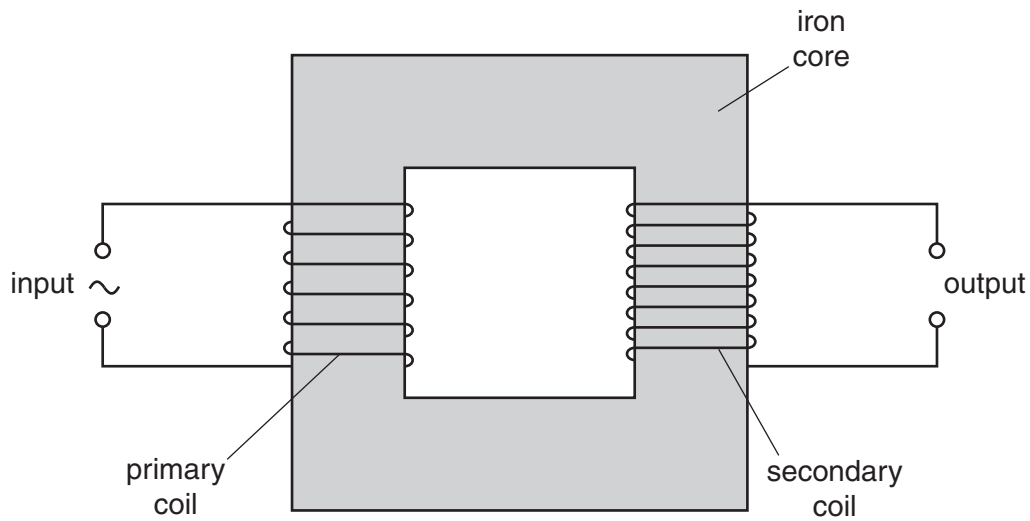


Fig. 6.1

- (a) (i) State why the primary and secondary coils are wound on a core made of iron.

.....

[1]

- (ii) Suggest why thermal energy is generated in the core when the transformer is in use.

.....

[3]

- (b) The root-mean-square (r.m.s.) voltage and current in the primary coil are V_P and I_P respectively.

The r.m.s. voltage and current in the secondary coil are V_S and I_S respectively.

For
Examiner's
Use

- (i) Explain, by reference to direct current, what is meant by the *root-mean-square* value of an alternating current.

.....

 [2]

- (ii) Show that, for an ideal transformer,

$$\frac{V_S}{V_P} = \frac{I_P}{I_S}.$$

[2]

7 (a) State an effect, one in each case, that provides evidence for

(i) the wave nature of a particle,

..... [1]

(ii) the particulate nature of electromagnetic radiation.

..... [1]

(b) Four electron energy levels in an atom are shown in Fig. 7.1.

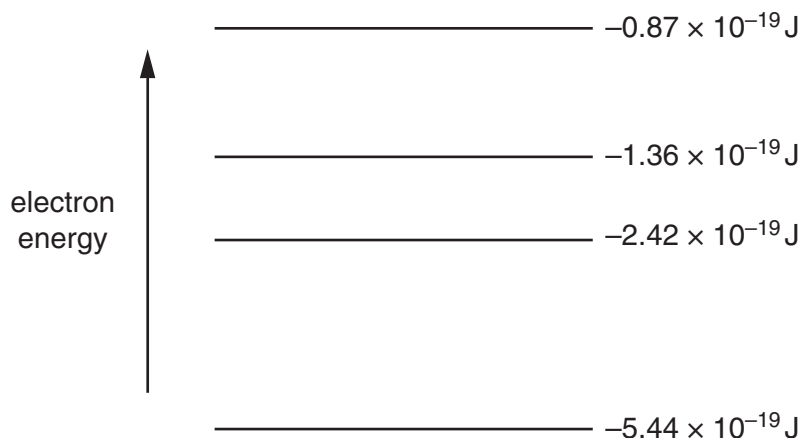


Fig. 7.1 (not to scale)

An emission spectrum is associated with the electron transitions between these energy levels.

For this spectrum,

(i) state the number of lines,

..... [1]

(ii) calculate the minimum wavelength.

wavelength = ... m [2]

8 In some power stations, nuclear fission is used as a source of energy.

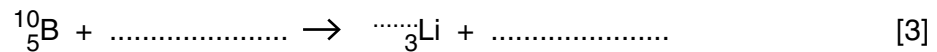
(a) State what is meant by *nuclear fission*.

.....

.....

.....[2]

(b) The nuclear fission reaction produces neutrons. In the power station, the neutrons may be absorbed by rods made of boron-10. Complete the nuclear equation for the absorption of a single neutron by a boron-10 nucleus with the emission of an α -particle.



(c) Suggest why, when neutrons are absorbed in the boron rods, the rods become hot as a result of this nuclear reaction.

.....

.....

.....

.....[3]

Section B

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

For
Examiner's
Use

- 9 An amplifier circuit incorporating an operational amplifier (op-amp) is shown in Fig. 9.1.

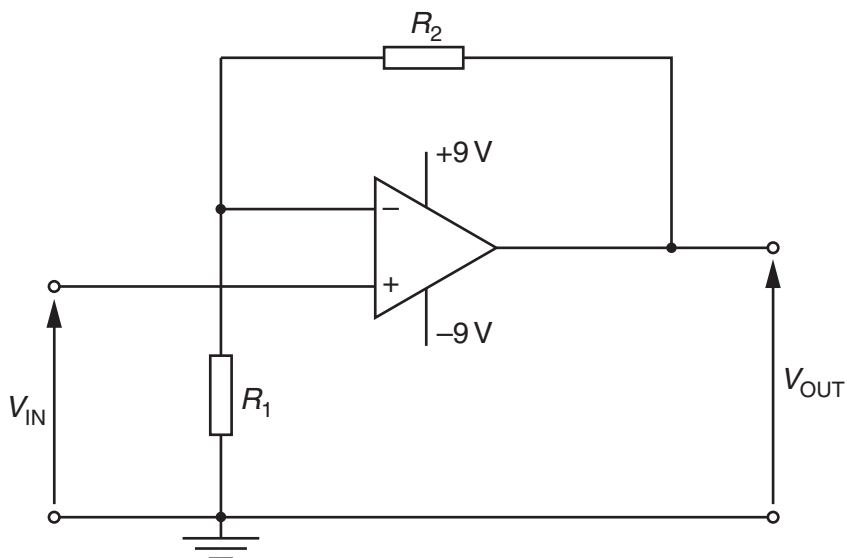


Fig. 9.1

(a) State

- (i) the name of this type of amplifier circuit,

.....[1]

- (ii) the gain G in terms of resistances R_1 and R_2 .

.....[1]

- (b) The value of R_1 is $820\ \Omega$. The resistor of resistance R_2 is replaced with a light-dependent resistor (LDR).

The input potential difference V_{IN} is 15 mV.

Calculate the output potential difference V_{OUT} for the LDR having a resistance of

- (i) $100\ \Omega$ (the LDR is in sunlight),

$$V_{OUT} = \dots\dots\dots \text{ V [2]}$$

- (ii) $1.0\ \text{M}\Omega$ (the LDR is in darkness).

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

For
Examiner's
Use

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

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

- (ii) Data for some media are given in Fig. 10.1.

medium	speed of ultrasound / ms^{-1}	acoustic impedance / $\text{kg m}^{-2} \text{s}^{-1}$
air	330	4.3×10^2
gel	1500	1.5×10^6
soft tissue	1600	1.6×10^6
bone	4100	7.0×10^6

Fig. 10.1

Use data from Fig. 10.1 to calculate a value for the density of bone.

density = ... kg m^{-3} [1]

- (b) A parallel beam of ultrasound has intensity I . It is incident at right-angles to a boundary between two media, as shown in Fig. 10.2.

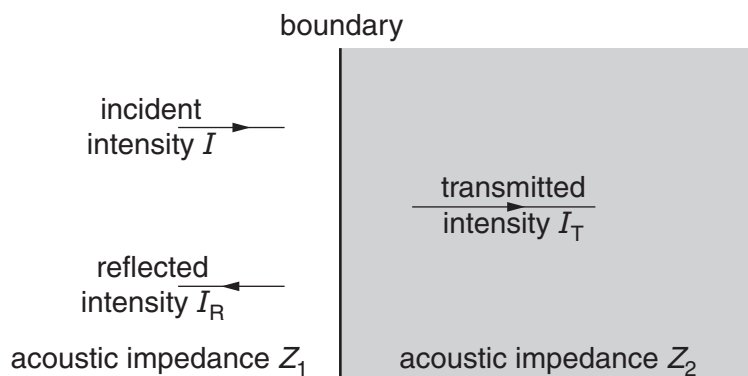


Fig. 10.2

The media have acoustic impedances of Z_1 and Z_2 . The transmitted intensity of the ultrasound beam is I_T and the reflected intensity is I_R .

- (i) State the relation between I , I_T and I_R .

..... [1]

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

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

Use data from Fig. 10.1 to determine the reflection coefficient α for a boundary between

1. gel and soft tissue,

$\alpha = \dots\dots\dots$ [2]

2. air and soft tissue.

$\alpha = \dots\dots\dots$ [1]

- (c) By reference to your answers in (b)(ii), explain the use of a gel on the surface of skin during ultrasound diagnosis.

.....

.....

.....

.....[3]

- 11 (a) Wire pairs provide one means of communication but they are subject to high levels of noise and attenuation.
Explain what is meant by

(i) *noise*,

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

(ii) *attenuation*.

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

- (b) A microphone is connected to a receiver using a wire pair, as shown in Fig. 11.1.

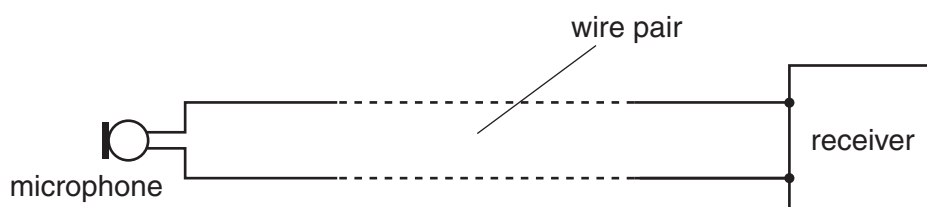


Fig. 11.1

The wire pair has an attenuation per unit length of 12 dB km^{-1} . The noise power in the wire pair is $3.4 \times 10^{-9} \text{ W}$.

The microphone produces a signal power of $2.9 \mu\text{W}$.

- (i) Calculate the maximum length of the wire pair so that the minimum signal-to-noise ratio is 24 dB.

length = ... m [4]

- (ii) Communication over distances greater than that calculated in (i) is required.
Suggest how the circuit of Fig. 11.1 may be modified so that the minimum signal-to-noise ratio at the receiver is not reduced.

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

- 12 (a)** Outline the principles of the use of a geostationary satellite for communication on Earth.

*For
Examiner's
Use*

.....

.....

.....

.....

.....

.....

.....

.....

..... [4]

Question 12 continues on the next page.

- (b) Polar-orbiting satellites are also used for communication on Earth.
State and explain one advantage and one disadvantage of polar-orbiting satellites as compared with geostationary satellites.

For
Examiner's
Use

advantage:

.....

.....

.....

disadvantage:

.....

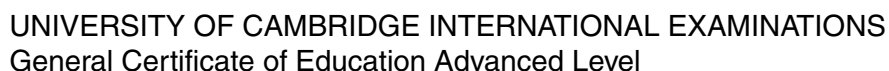
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[4]

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9702/43

October/November 2010

1 hour 45 minutes

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

DO **NOT** WRITE IN ANY BARCODES.

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

For Examiner's Use	
1	
2	
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12	
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 planet of mass m is in a circular orbit of radius r about the Sun of mass M , as illustrated in Fig. 1.1.

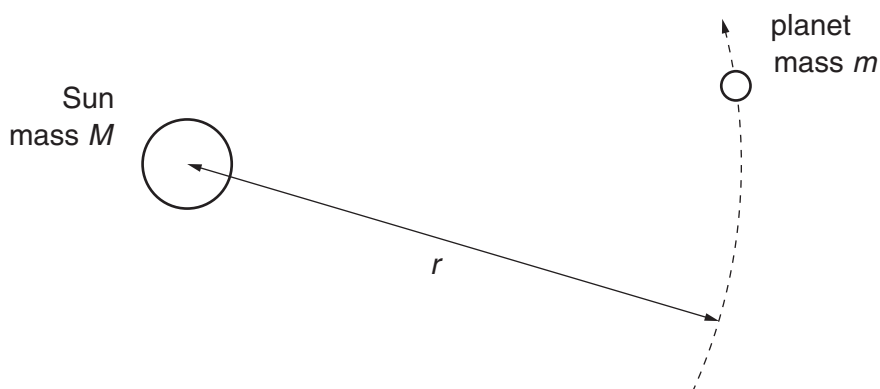


Fig. 1.1

The magnitude of the angular velocity and the period of revolution of the planet about the Sun are ω and T respectively.

(a) State

- (i) what is meant by *angular velocity*,

.....

 [2]

- (ii) the relation between ω and T .

..... [1]

- (b) Show that, for a planet in a circular orbit of radius r , the period T of the orbit is given by the expression

$$T^2 = cr^3$$

where c is a constant. Explain your working.

[4]

(c) Data for the planets Venus and Neptune are given in Fig. 1.2.

planet	$r / 10^8 \text{ km}$	T / years
Venus	1.08	0.615
Neptune	45.0	

Fig. 1.2

Assume that the orbits of both planets are circular.

(i) Use the expression in (b) to calculate the value of T for Neptune.

$T = \dots\dots\dots \text{ years} \quad [2]$

(ii) Determine the linear speed of Venus in its orbit.

speed = $\dots\dots\dots \text{ km s}^{-1} \quad [2]$

For
Examiner's
Use

- 2 (a) State the basic assumptions of the kinetic theory of gases.

For
Examiner's
Use

.....

.....

.....

.....

.....

.....[4]

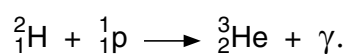
- (b) Use equations for the pressure of an ideal gas to deduce that the average translational kinetic energy $\langle E_K \rangle$ of a molecule of an ideal gas is given by the expression

$$\langle E_K \rangle = \frac{3}{2} \frac{R}{N_A} T$$

where R is the molar gas constant, N_A is the Avogadro constant and T is the thermodynamic temperature of the gas.

[3]

- (c) A deuterium nucleus ${}^2_1\text{H}$ and a proton collide. A nuclear reaction occurs, represented by the equation



- (i) State and explain whether the reaction represents nuclear fission or nuclear fusion.

.....

.....

..... [2]

- (ii) For the reaction to occur, the minimum total kinetic energy of the deuterium nucleus and the proton is $2.4 \times 10^{-14} \text{ J}$.
Assuming that a sample of a mixture of deuterium nuclei and protons behaves as an ideal gas, calculate the temperature of the sample for this reaction to occur.

For
Examiner's
Use

temperature = ... K [3]

- (iii) Suggest why the assumption made in (ii) may not be valid.

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

- 3 A cylinder and piston, used in a car engine, are illustrated in Fig. 3.1.

For
Examiner's
Use

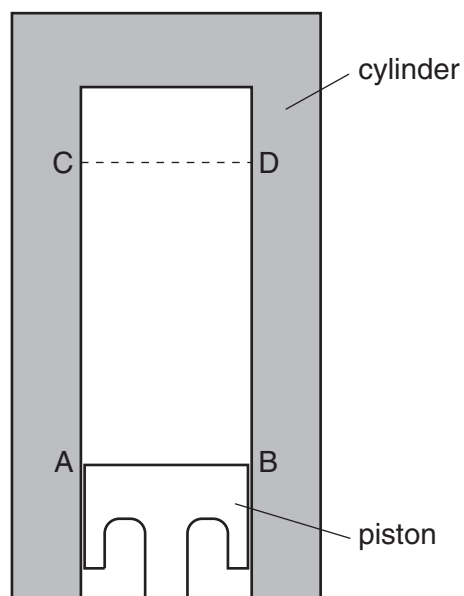


Fig. 3.1

The vertical motion of the piston in the cylinder is assumed to be simple harmonic. The top surface of the piston is at AB when it is at its lowest position; it is at CD when at its highest position, as marked in Fig. 3.1.

- (a) The displacement d of the piston may be represented by the equation

$$d = -4.0 \cos(220t)$$

where d is measured in centimetres.

- (i) State the distance between the lowest position AB and the highest position CD of the top surface of the piston.

distance = ... cm [1]

- (ii) Determine the number of oscillations made per second by the piston.

For
Examiner's
Use

number = ... [2]

- (iii) On Fig. 3.1, draw a line to represent the top surface of the piston in the position where the speed of the piston is maximum. [1]

- (iv) Calculate the maximum speed of the piston.

speed = ... cm s^{-1} [2]

- (b) The engine of a car has several cylinders. Three of these cylinders are shown in Fig. 3.2.

For
Examiner's
Use

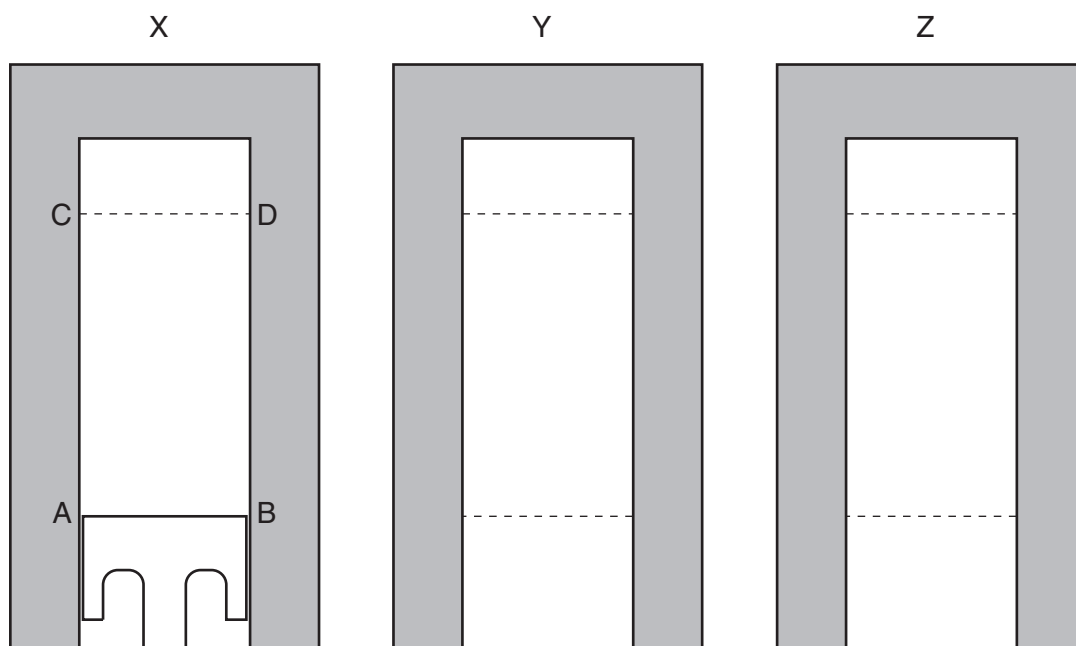


Fig. 3.2

X is the same cylinder and piston as in Fig. 3.1.

Y and Z are two further cylinders, with the lowest and the highest positions of the top surface of each piston indicated.

The pistons in the cylinders each have the same frequency of oscillation, but they are not in phase.

At a particular instant in time, the position of the top of the piston in cylinder X is as shown.

- (i) In cylinder Y, the oscillations of the piston lead those of the piston in cylinder X by a phase angle of 120° ($\frac{2}{3}\pi$ rad).

Complete the diagram of cylinder Y, for this instant, by drawing

1. a line to show the top surface of the piston, [1]
2. an arrow to show the direction of movement of the piston. [1]

- (ii) In cylinder Z, the oscillations of the piston lead those of the piston in cylinder X by a phase angle of 240° ($\frac{4}{3}\pi$ rad).

For
Examiner's
Use

Complete the diagram of cylinder Z, for this instant, by drawing

1. a line to show the top surface of the piston, [1]
 2. an arrow to show the direction of movement of the piston. [1]
- (iii) For the piston in cylinder Y, calculate its speed for this instant.

speed = ... cm s^{-1} [2]

- 4 (a) (i) State what is meant by *electric potential* at a point.

For
Examiner's
Use

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

- (ii) Define *capacitance*.

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

- (b) The variation of the potential V of an isolated metal sphere with charge Q on its surface is shown in Fig. 4.1.

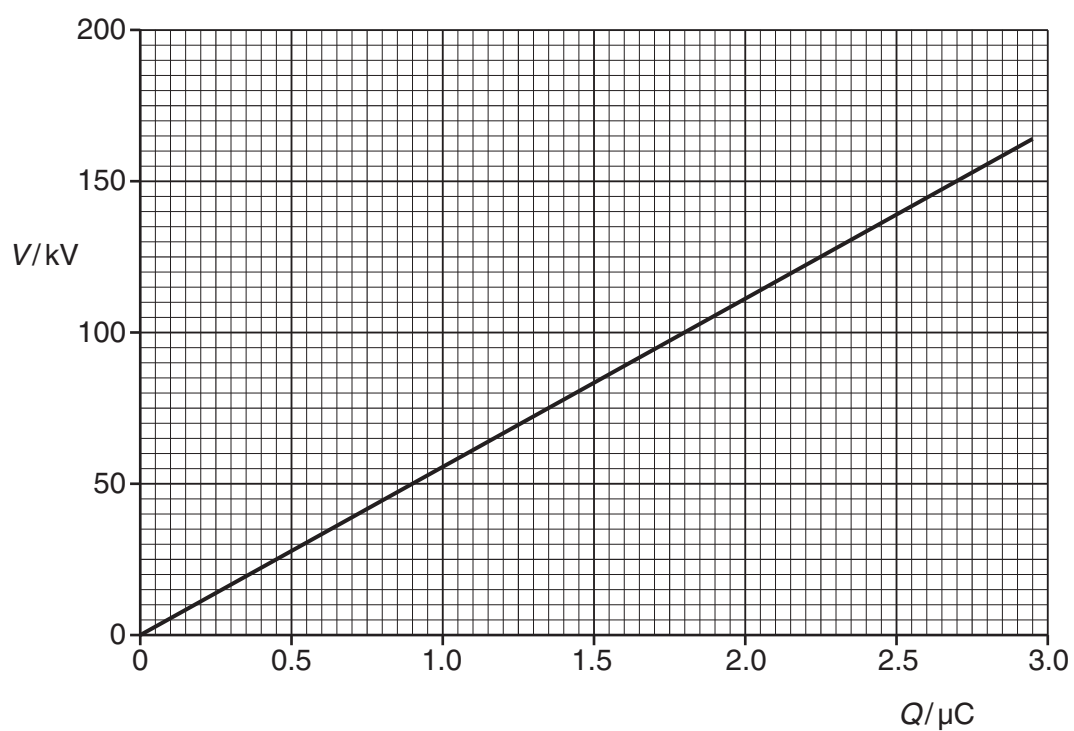


Fig. 4.1

An isolated metal sphere has capacitance.

Use Fig. 4.1 to determine

- (i) the capacitance of the sphere,

capacitance = ... F [2]

- (ii) the electric potential energy stored on the sphere when charged to a potential of 150 kV.

energy = ... J [2]

- (c) A spark reduces the potential of the sphere from 150 kV to 75 kV.
Calculate the energy lost from the sphere.

energy = ... J [2]

For
Examiner's
Use

- 5 The poles of a horseshoe magnet measure $5.0\text{ cm} \times 2.4\text{ cm}$, as shown in Fig. 5.1.

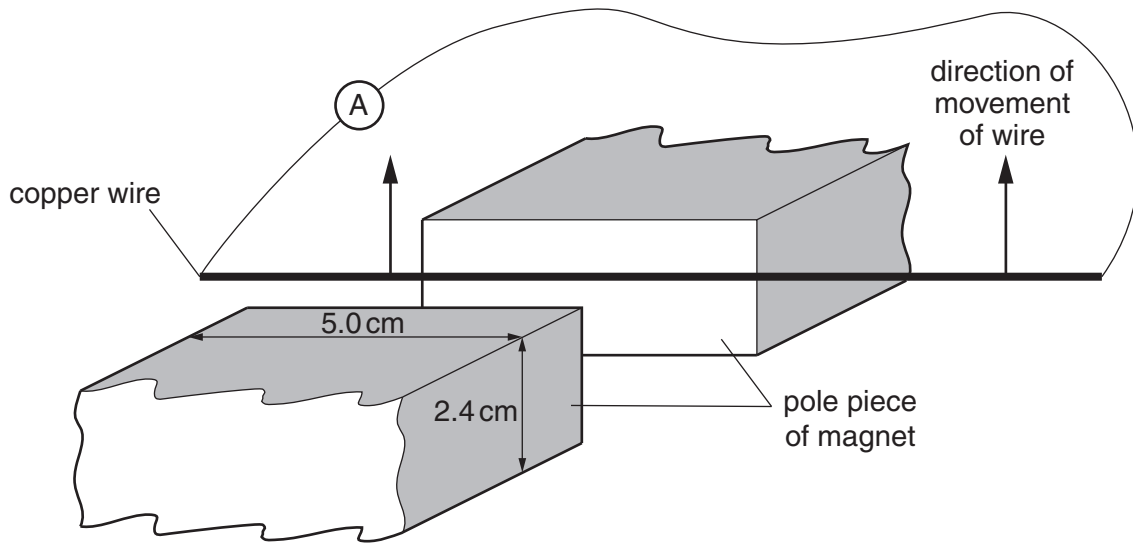


Fig. 5.1

The uniform magnetic flux density between the poles of the magnet is 89 mT . Outside the region of the poles, the magnetic flux density is zero.

A stiff copper wire is connected to a sensitive ammeter of resistance $0.12\ \Omega$. A student moves the wire at a constant speed of 1.8 m s^{-1} between the poles in a direction parallel to the faces of the poles.

- (a) Calculate the magnetic flux between the poles of the magnet.

magnetic flux = ... Wb [2]

- (b) (i) Use your answer in (a) to determine, for the wire moving between the poles of the magnet, the e.m.f. induced in the wire.

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

- (ii) Show that the reading on the ammeter is approximately 70 mA.

For
Examiner's
Use

[1]

- (c) By reference to Lenz's law, a force acts on the wire to oppose the motion of the wire. The student who moved the wire between the poles of the magnet claims not to have felt this force.
Explain quantitatively a reason for this claim.

.....

..... [3]

- 6 The variation with time t of the current I in a resistor is shown in Fig. 6.1.

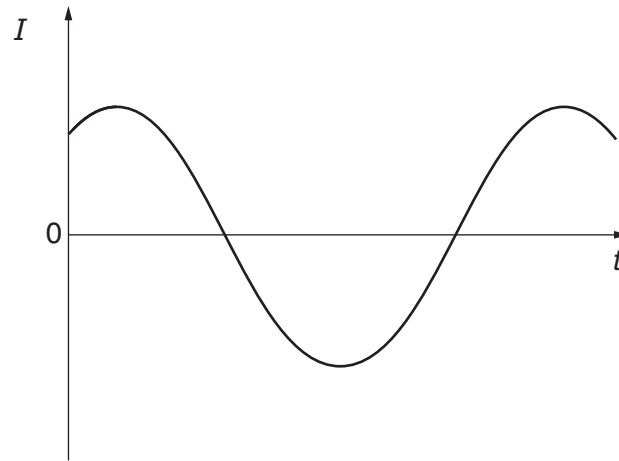


Fig. 6.1

The variation of the current with time is sinusoidal.

- (a) Explain why, although the current is not in one direction only, power is converted in the resistor.

.....

 [2]

- (b) Using the relation between root-mean-square (r.m.s.) current and peak current, deduce the value of the ratio

$$\frac{\text{average power converted in the resistor}}{\text{maximum power converted in the resistor}} .$$

ratio = ... [3]

- 7 Electrons are moving through a vacuum in a narrow beam. The electrons have speed v . The electrons enter a region of uniform magnetic field of flux density B . Initially, the electrons are travelling at a right-angle to the magnetic field. The path of a single electron is shown in Fig. 7.1.

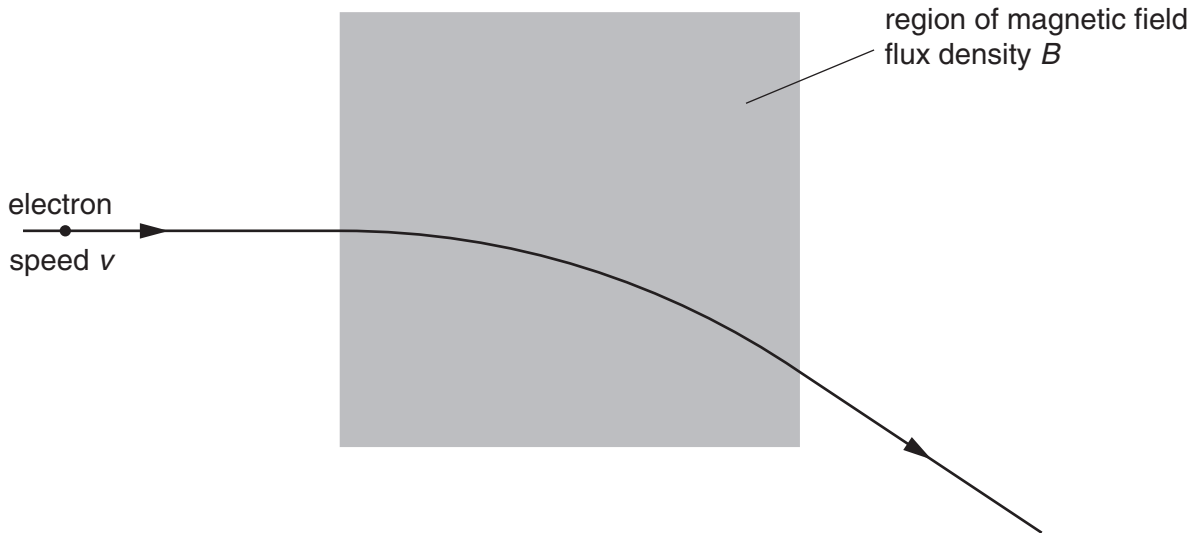


Fig. 7.1

The electrons follow a curved path in the magnetic field.

A uniform electric field of field strength E is now applied in the same region as the magnetic field.

The electrons pass undeviated through the region of the two fields. Gravitational effects may be neglected.

- (a) Derive a relation between v , E and B for the electrons not to be deflected. Explain your working.

.....

.....

.....

.....

..... [3]

- (b) An α -particle has speed v and approaches the region of the two fields along the same path as the electron. Describe and explain the path of the α -particle as it passes through the region of the two fields.

.....

.....

..... [2]

- 8 (a) By reference to the photoelectric effect, state what is meant by the *threshold frequency*.

.....

.....

..... [2]

- (b) The surface of a zinc plate has a work function of 5.8×10^{-19} J.
In a particular laboratory experiment, ultraviolet light of wavelength 120 nm is incident on the zinc plate. A photoelectric current I is detected.
In order to view the apparatus more clearly, a second lamp emitting light of wavelength 450 nm is switched on. No change is made to the ultraviolet lamp.

Using appropriate calculations, state and explain the effect on the photoelectric current of switching on this second lamp.

.....

..... [4]

Section B

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

For
Examiner's
Use

- 9 (a) (i) State, with reference to X-ray images, what is meant by *sharpness*.

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

- (ii) Describe briefly two factors that affect the sharpness of an X-ray image.

1.
.....
2.
.....[3]

- (b) An X-ray image is taken of the skull of a patient. Another patient has a CT scan of his head.

By reference to the formation of the image in each case, suggest why the exposure to radiation differs between the two imaging techniques.

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

10 (a) State three properties of an ideal operational amplifier (op-amp).

1.
2.
3.

[3]

(b) A circuit incorporating an ideal op-amp is to be used to indicate whether a door is open or closed.

Resistors, each of resistance R , are connected to the inputs of the op-amp, as shown in Fig. 10.1.

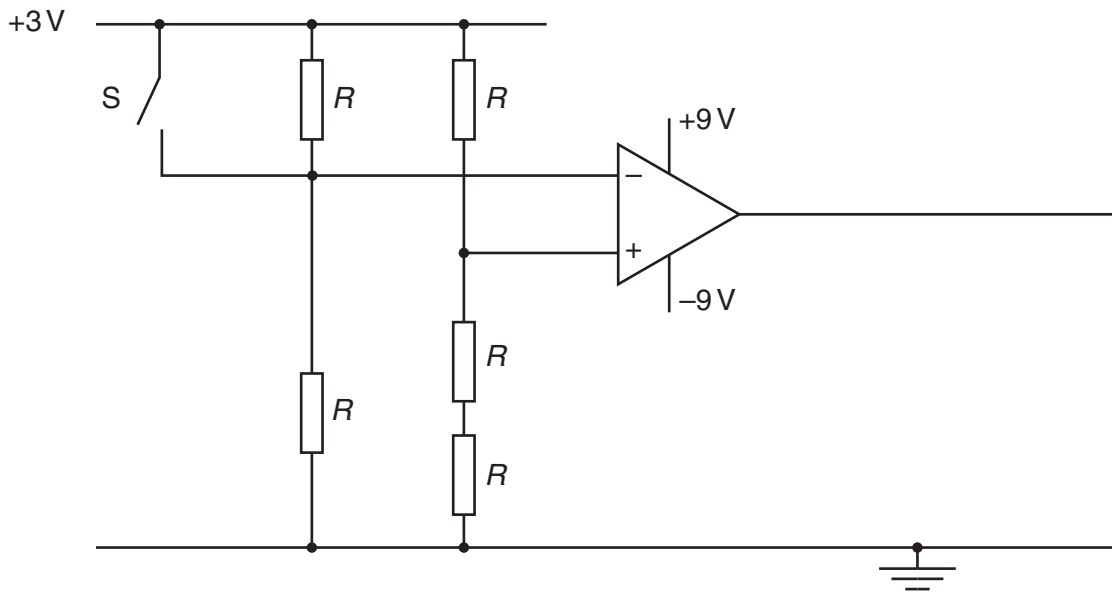


Fig. 10.1

The switch S is attached to the door so that, when the door is open, the switch is open. The switch closes when the door is closed.

- (i) Explain why the polarity of the output of the op-amp changes when the switch closes.

.....

.....

.....

..... [3]

- (ii) A red light-emitting diode (LED) is to be used to indicate when the door is open.
A green LED is to indicate when the door is closed.

On Fig. 10.1,

1. draw symbols for the LEDs to show how they are connected to the output of the op-amp, [1]
2. identify the green LED with the letter G. [1]

Please turn over for Question 11.

- 11 The linear attenuation (absorption) coefficient μ for X-ray radiation in bone, fat and muscle is given in Fig. 11.1.

For
Examiner's
Use

	μ / cm^{-1}
bone	2.9
fat	0.90
muscle	0.95

Fig. 11.1

- (a) A parallel X-ray beam of intensity I_0 is incident either on some bone or on some muscle.

The emergent beam has intensity I .

Calculate the ratio $\frac{I}{I_0}$ for a thickness of

- (i) 1.5 cm of bone,

ratio = ... [2]

- (ii) 4.6 cm of muscle.

ratio = ... [1]

- (b) Suggest why, on an X-ray plate, the contrast between bone and muscle is much greater than that between fat and muscle.

.....

 [3]

12 (a) Data may be transmitted as an analogue signal or as a digital signal.

(i) Explain what is meant by

1. an *analogue* signal,

.....

.....

.....

2. a *digital* signal.

.....

.....

.....

[3]

(ii) State two advantages of the transmission of data in digital form.

1.

.....

2.

.....

[2]

(b) The block diagram of Fig. 12.1 represents a system for the digital transmission of analogue data.



Fig. 12.1

(i) Describe the function of the ADC (analogue-to-digital converter).

.....

.....

.....

[2]

(ii) Suggest why the transmission cable has a number of channels.

.....

.....

[1]

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