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PHYSICS

9702/41

Paper 4 A Level Structured Questions

May/June 2017

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.

You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.

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

This document consists of **22** printed pages and **2** 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	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
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.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
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	$W = \frac{1}{2} QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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

- 1 (a) Explain how a satellite may be in a circular orbit around a planet.

.....

.....

.....[2]

- (b) The Earth and the Moon may be considered to be uniform spheres that are isolated in space. The Earth has radius R and mean density ρ . The Moon, mass m , is in a circular orbit about the Earth with radius nR , as illustrated in Fig. 1.1.

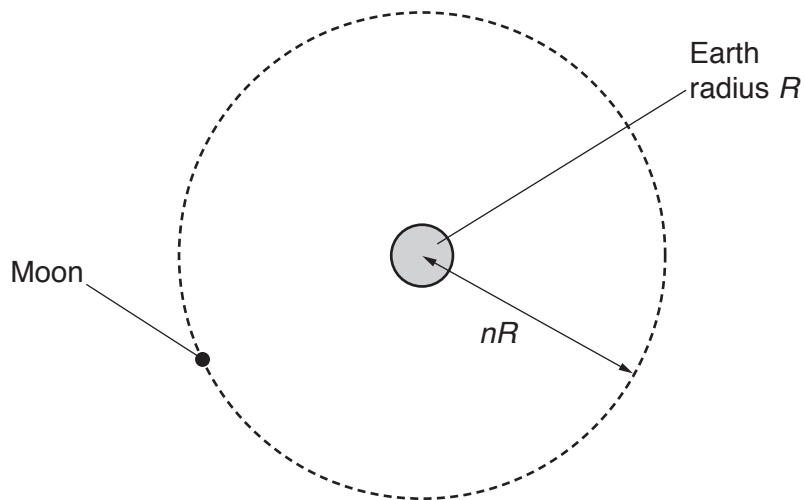


Fig. 1.1

The Moon makes one complete orbit of the Earth in time T .
Show that the mean density ρ of the Earth is given by the expression

$$\rho = \frac{3\pi n^3}{GT^2}.$$

[4]

- (c) The radius R of the Earth is $6.38 \times 10^3 \text{ km}$ and the distance between the centre of the Earth and the centre of the Moon is $3.84 \times 10^5 \text{ km}$.
The period T of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in (b) to calculate ρ .

$$\rho = \dots\dots\dots \text{ kg m}^{-3} \text{ [3]}$$

[Total: 9]

- 2 A bar magnet of mass 180 g is suspended from the free end of a spring, as illustrated in Fig. 2.1.

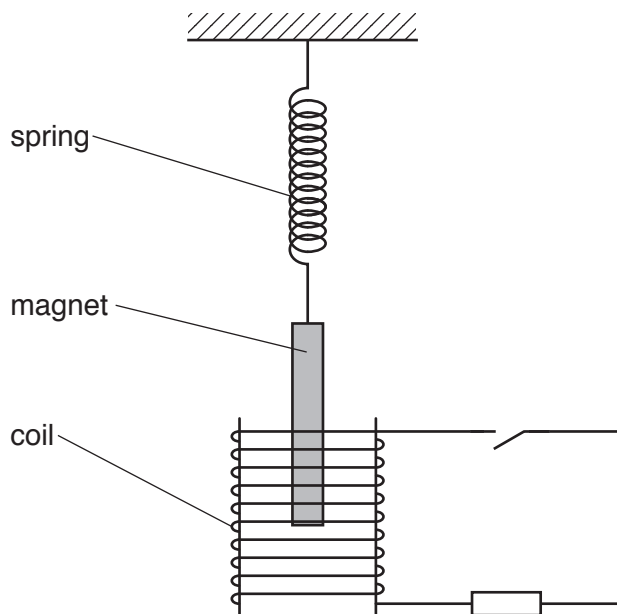


Fig. 2.1

The magnet hangs so that one pole is near the centre of a coil of wire.

The coil is connected in series with a resistor and a switch. The switch is open.

The magnet is displaced vertically and then allowed to oscillate with one pole remaining inside the coil. The other pole remains outside the coil.

At time $t = 0$, the magnet is oscillating freely as it passes through its equilibrium position. At time $t = 3.0$ s, the switch in the circuit is closed.

The variation with time t of the vertical displacement y of the magnet is shown in Fig. 2.2.

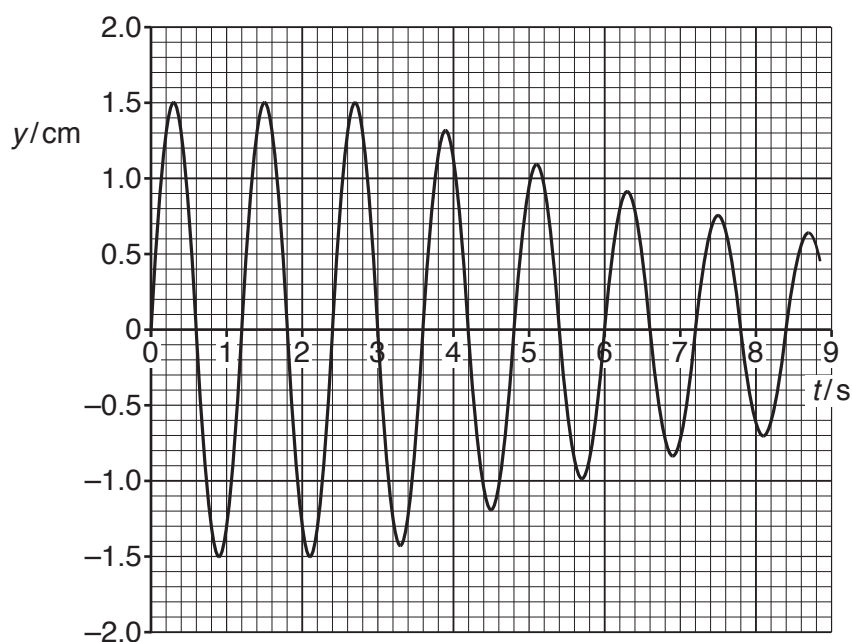


Fig. 2.2

- (a) Determine, to two significant figures, the frequency of oscillation of the magnet.

frequency = ... Hz [2]

- (b) State whether the closing of the switch gives rise to light, heavy or critical damping.

.....[1]

- (c) Calculate the change in the energy ΔE of oscillation of the magnet between time $t = 2.7$ s and time $t = 7.5$ s. Explain your working.

$\Delta E =$ J [6]

[Total: 9]

- 3 The digital transmission of speech may be illustrated using the block diagram of Fig. 3.1.

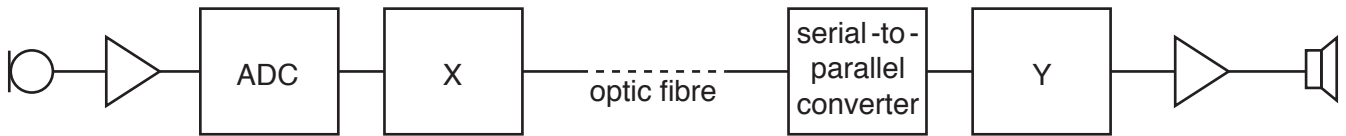


Fig. 3.1

- (a) (i) State what is meant by a *digital signal*.

.....
[1]

- (ii) State the names of the components labelled X and Y on Fig. 3.1.

X:

Y:
[2]

- (iii) Describe the function of the ADC.

.....

[2]

- (b) The optic fibre has length 84 km and the attenuation per unit length in the fibre is 0.19 dB km^{-1} .

The input power to the optic fibre is 9.7 mW. At the output from the optic fibre, the signal-to-noise ratio is 28 dB.

Calculate

- (i) in dB, the ratio

$$\frac{\text{input power to optic fibre}}{\text{noise power at output of optic fibre}},$$

ratio = ... dB [2]

- (ii) the noise power at the output of the optic fibre.

noise power = ... W [3]

[Total: 10]

- 4 (a) Describe the motion of molecules in a gas, according to the kinetic theory of gases.

.....

 [2]

- (b) Describe what is observed when viewing Brownian motion that provides evidence for your answer in (a).

.....

 [2]

- (c) At a pressure of $1.05 \times 10^5 \text{ Pa}$ and a temperature of 27°C , 1.00 mol of helium gas has a volume of 0.0240 m^3 .

The mass of 1.00 mol of helium gas, assumed to be an ideal gas, is 4.00 g .

- (i) Calculate the root-mean-square (r.m.s.) speed of an atom of helium gas for a temperature of 27°C .

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

- (ii) Using your answer in (i), calculate the r.m.s. speed of the atoms at 177°C .

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

[Total: 10]

- 5 An α -particle is travelling in a vacuum towards the centre of a gold nucleus, as illustrated in Fig. 5.1.



Fig. 5.1

The gold nucleus has charge $79e$.

The gold nucleus and the α -particle may be assumed to behave as point charges.

At a large distance from the gold nucleus, the α -particle has energy $7.7 \times 10^{-13} \text{ J}$.

- (a) The α -particle does not collide with the gold nucleus. Show that the radius of the gold nucleus must be less than $4.7 \times 10^{-14} \text{ m}$.

[3]

- (b) Determine the acceleration of the α -particle for a separation of $4.7 \times 10^{-14} \text{ m}$ between the centres of the gold nucleus and of the α -particle.

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

- (c) In an α -particle scattering experiment, the beam of α -particles is incident on a very thin gold foil.

Suggest why the gold foil must be very thin.

.....

..... [1]

[Total: 7]

- 6 A comparator circuit is designed to switch on a mains lamp when the ambient light level reaches a set value.

An incomplete diagram of the circuit is shown in Fig. 6.1.

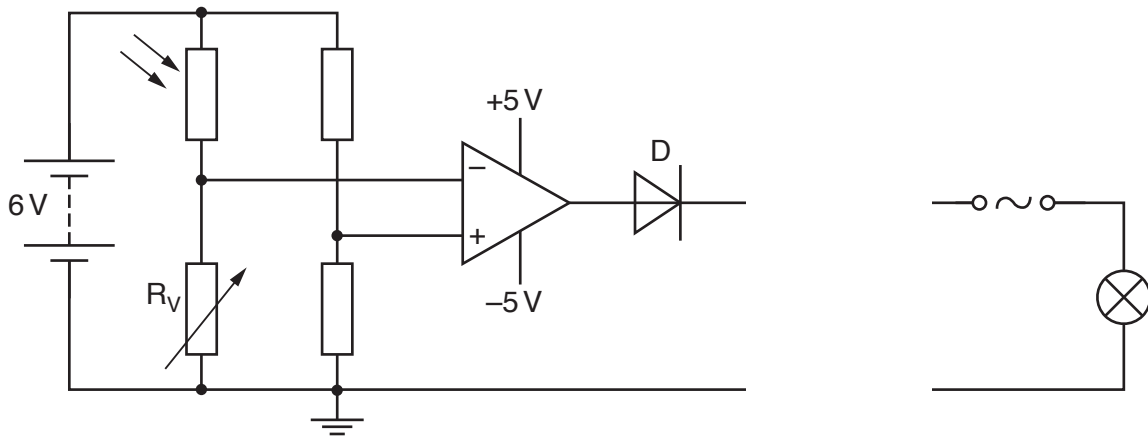


Fig. 6.1

- (a) (i) A relay is required as part of the output device. This is not shown in Fig. 6.1. Explain why a relay is required.

.....

 [2]

- (ii) On Fig. 6.1, draw the symbol for a relay connected in the circuit as part of the output device. [2]

- (b) Describe the function of

- (i) the variable resistor R_V ,

.....
 [1]

- (ii) the diode D.

.....
 [1]

- (c) State whether the lamp will switch on as the light level increases or as it decreases. Explain your answer.

.....

.....

.....

.....

.....[3]

[Total: 9]

- 7 An electron having charge $-q$ and mass m is accelerated from rest in a vacuum through a potential difference V .
The electron then enters a region of uniform magnetic field of magnetic flux density B , as shown in Fig. 7.1.

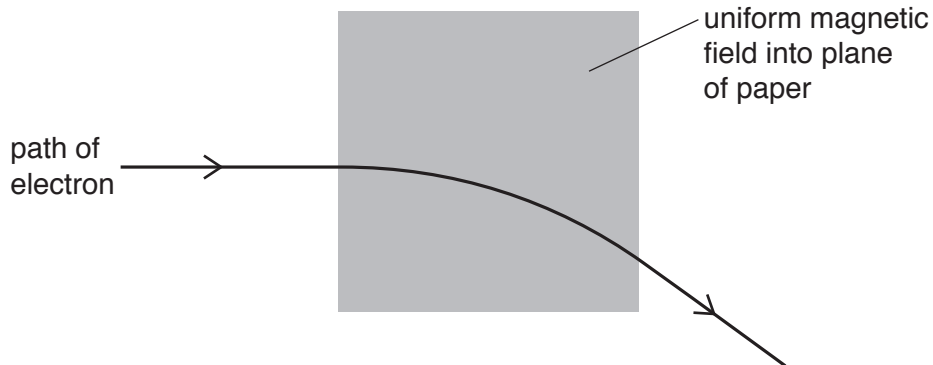


Fig. 7.1

The direction of the uniform magnetic field is into the plane of the paper.
The velocity of the electron as it enters the magnetic field is normal to the magnetic field.
The radius of the circular path of the electron in the magnetic field is r .

- (a) Explain why the path of the electron in the magnetic field is the arc of a circle.

.....

.....

.....

.....[3]

- (b) Show that the magnitude p of the momentum of the electron as it enters the magnetic field is given by

$$p = \sqrt{2mqV}.$$

[2]

- (c) The potential difference V is 120 V. The radius r of the circular arc is 7.4 cm.

Determine the magnitude B of the magnetic flux density.

$B = \dots\dots\dots$ T [3]

- (d) The potential difference V in (c) is increased. The magnetic flux density B remains unchanged.

By reference to the momentum of the electron, explain the effect of this increase on the radius r of the path of the electron in the magnetic field.

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

[Total: 10]

- 8** Explain the main principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain information about internal body structures.

.....[8]

[Total: 8]

- 9 A simple transformer is illustrated in Fig. 9.1.

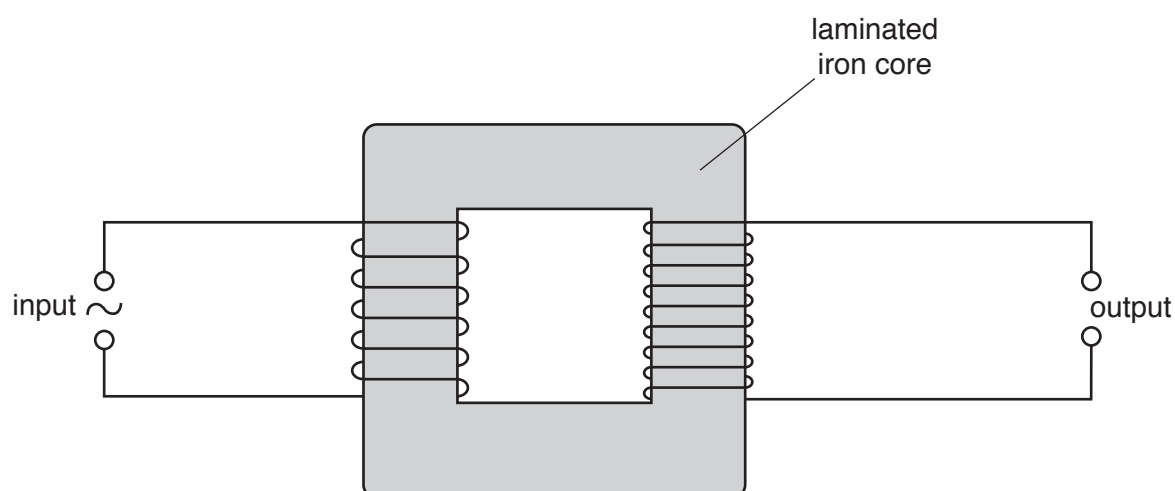


Fig. 9.1

- (a) (i) State why the transformer has an iron core, rather than having no core.

.....
[1]

- (ii) Explain why the core is laminated.

.....

[2]

- (b) By reference to the action of a transformer, explain why the input to the transformer is an alternating voltage, rather than a constant voltage.

.....

[3]

[Total: 6]

10 (a) State

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

.....

[2]

- (ii) how the hardness of an X-ray beam from an X-ray tube is increased.

.....
[1]

- (b) The same parallel beam of X-ray radiation is incident, separately, on samples of bone and of muscle.

Data for the thickness x of the samples of bone and of muscle, together with the linear attenuation (absorption) coefficients μ of the radiation in bone and in muscle, are given in Fig. 10.1.

	x/cm	μ/cm^{-1}
bone	1.5	2.9
muscle	4.0	0.95

Fig. 10.1

Determine the ratio

$$\frac{\text{intensity transmitted through bone}}{\text{intensity transmitted through muscle}}$$

ratio = ... [2]

[Total: 5]

- 11 A beam of light consists of a continuous range of wavelengths from 420 nm to 740 nm. The light passes through a cloud of cool gas, as shown in Fig. 11.1.

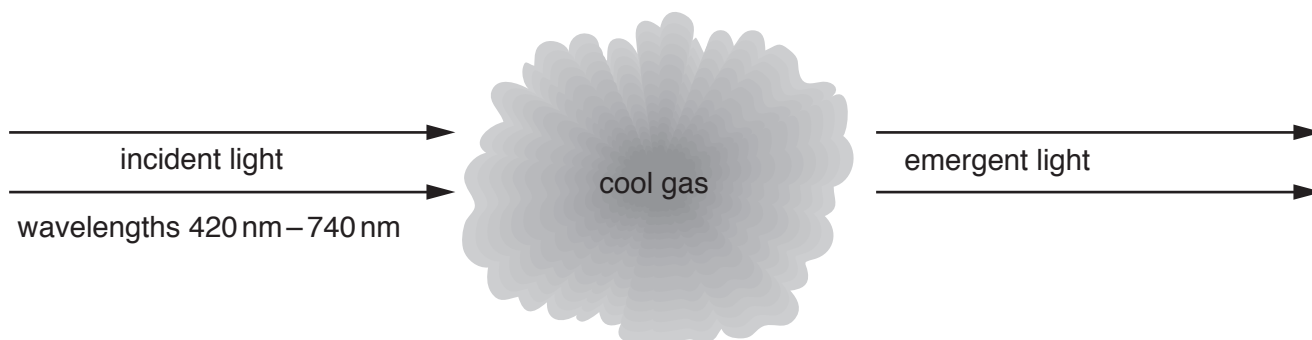


Fig. 11.1

- (a) The spectrum of the light emerging from the cloud of cool gas is viewed using a diffraction grating. Explain why this spectrum contains a number of dark lines.

.....

.....

.....

.....

.....

.....[4]

- (b) Some of the electron energy levels of the atoms in the cloud of gas are represented in Fig. 11.2.

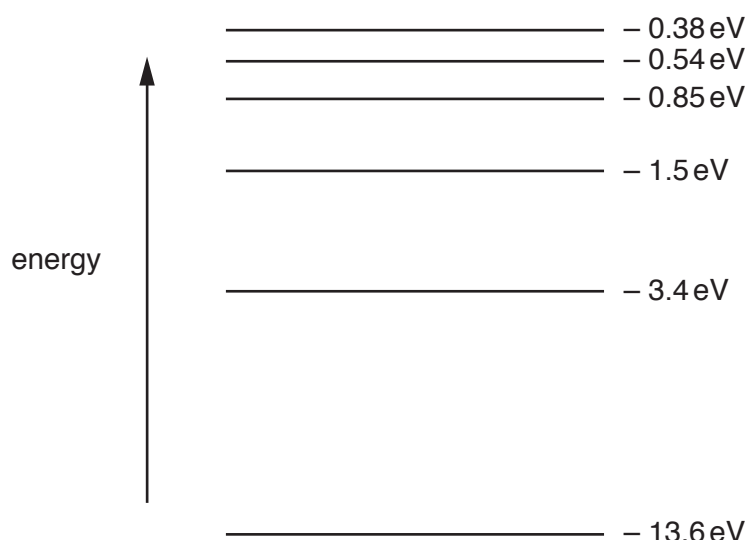


Fig. 11.2 (not to scale)

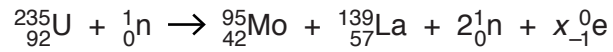
- (i) Light of wavelength 420 nm has a photon energy of 2.96 eV.
Calculate the photon energy, in eV, of light of wavelength 740 nm.

photon energy = ... eV [2]

- (ii) Use data from (i) and your answer in (i) to show, on Fig. 11.2, the changes in energy levels giving rise to the dark lines in (a). [2]

[Total: 8]

12 One possible nuclear reaction that takes place in a nuclear reactor is given by the equation



Data for the nuclei and particles are given in Fig. 12.1.

nucleus or particle	mass/u
${}_{92}^{235}\text{U}$	235.123
${}_{42}^{95}\text{Mo}$	94.945
${}_{57}^{139}\text{La}$	138.955
${}_0^1\text{n}$	1.00863
${}_{-1}^0\text{e}$	5.49×10^{-4}

Fig. 12.1

(a) Determine, for this nuclear reaction, the value of x .

$x = \dots\dots\dots[1]$

- (b) (i)** Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

- (ii)** Calculate the energy, in MeV, released in this reaction. Give your answer to three significant figures.

energy = ... MeV [3]

- (c)** Suggest the forms of energy into which the energy calculated in **(b)(ii)** is transformed.

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

[Total: 9]

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Data

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the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
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pressure of an ideal gas	$p = \frac{1}{3} \frac{Nm}{V} \langle c^2 \rangle$
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velocity of particle in s.h.m.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
electric potential	$V = \frac{Q}{4\pi\epsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \dots$
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energy of charged capacitor	$W = \frac{1}{2} QV$
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resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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

- 1 (a) Define *gravitational field strength*.

.....
[1]

- (b) The mass of a spherical comet of radius 3.6 km is approximately 1.0×10^{13} kg.

- (i) Assuming that the comet has constant density, calculate the gravitational field strength on the surface of the comet.

field strength = ... N kg^{-1} [2]

- (ii) A probe having a weight of 960 N on Earth lands on the comet.
 Using your answer in (i), determine the weight of the probe on the surface of the comet.

weight = ... N [2]

- (c) A second comet has a length of approximately 4.5 km and a width of approximately 2.6 km. Its outline is illustrated in Fig. 1.1.

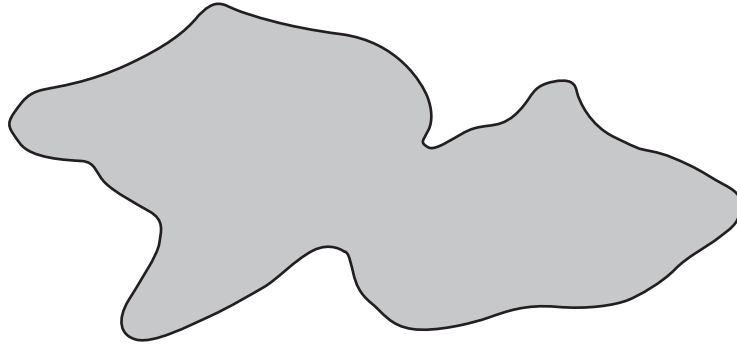


Fig. 1.1

Suggest one similarity and one difference between the gravitational fields at the surface of this comet and at the surface of the comet in (b).

similarity:

.....

difference:

.....

[2]

[Total: 7]

- 2 (a) The pressure p and volume V of an ideal gas are related to the density ρ of the gas by the expression

$$p = \frac{1}{3}\rho\langle c^2 \rangle.$$

- (i) State what is meant by the symbol $\langle c^2 \rangle$.

.....
[1]

- (ii) Use the expression to show that the mean kinetic energy E_K of a gas molecule is given by

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

where k is the Boltzmann constant and T is the thermodynamic temperature.

[3]

- (b) (i) An ideal gas containing 1.0 mol of molecules is heated at constant volume.
 Use the expression in (a)(ii) to show that the thermal energy required to raise the temperature of the gas by 1.0 K has a value of $\frac{3}{2}R$, where R is the molar gas constant.

[3]

- (ii) Nitrogen may be assumed to be an ideal gas. The molar mass of nitrogen gas is 28 g mol^{-1} . Use the answer in (b)(i) to calculate a value for the specific heat capacity, in $\text{J kg}^{-1} \text{ K}^{-1}$, at constant volume for nitrogen.

specific heat capacity = ... $\text{J kg}^{-1} \text{ K}^{-1}$ [2]

[Total: 9]

- 3 A bar magnet of mass 250 g is suspended from the free end of a spring, as illustrated in Fig. 3.1.

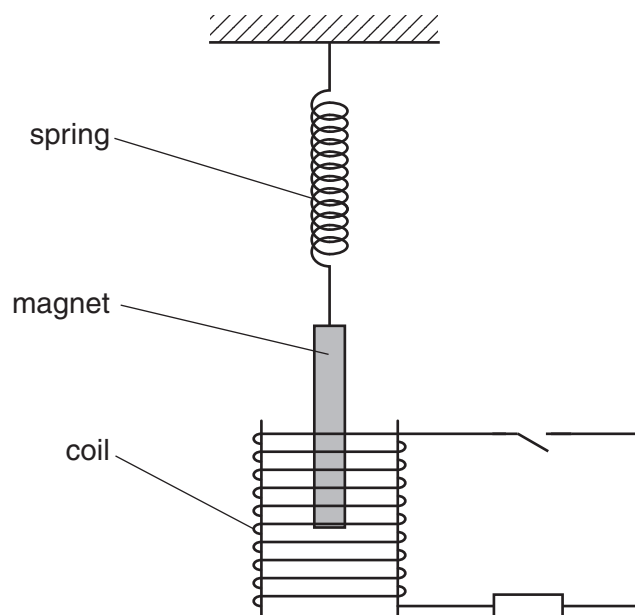


Fig. 3.1

The magnet hangs so that one pole is near the centre of a coil of wire.

The coil is connected in series with a resistor and a switch. The switch is open.

The magnet is displaced vertically and then allowed to oscillate with one pole remaining inside the coil. The other pole remains outside the coil.

At time $t = 0$, the magnet is oscillating freely as it passes through its equilibrium position. At time $t = 6.0\text{ s}$, the switch in the circuit is closed.

The variation with time t of the vertical displacement y of the magnet is shown in Fig. 3.2.

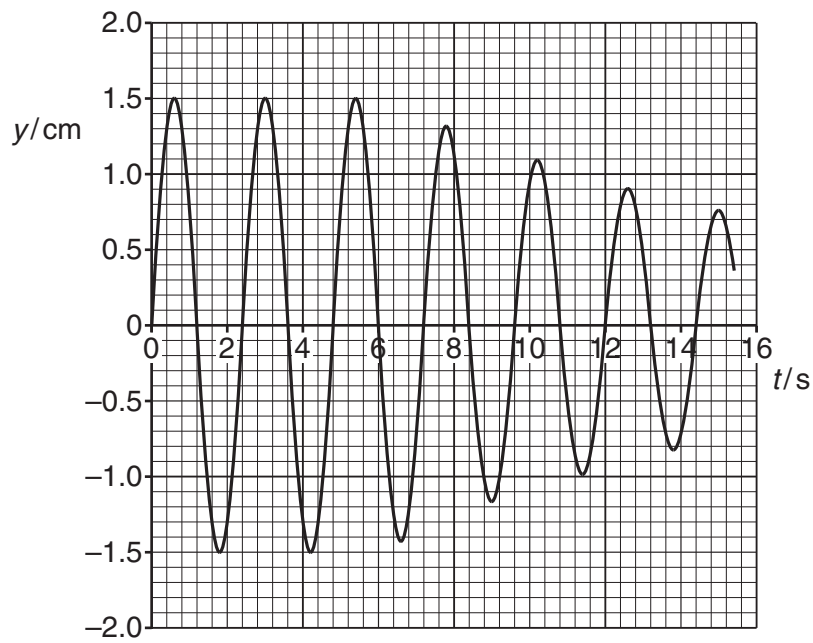


Fig. 3.2

(a) For the oscillating magnet, use data from Fig. 3.2 to calculate, to two significant figures,

(i) the frequency f ,

$f = \dots\dots\dots$ Hz [2]

(ii) the energy of the oscillations during the time $t = 0$ to time $t = 6.0$ s.

energy = $\dots\dots\dots$ J [3]

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

.....

.....

.....

.....[2]

- (ii) Use Faraday's law and energy conservation to explain why the amplitude of the oscillations of the magnet reduces after time $t = 6.0\text{ s}$.

.....

.....

.....

.....

.....

.....[3]

[Total: 10]

- 4 (a) Explain the main principles behind the **use** of ultrasound to obtain diagnostic information about internal body structures.

[6]

- (b) A parallel beam of ultrasound has intensity I_0 as it enters a muscle of thickness 4.6 cm, as illustrated in Fig. 4.1.

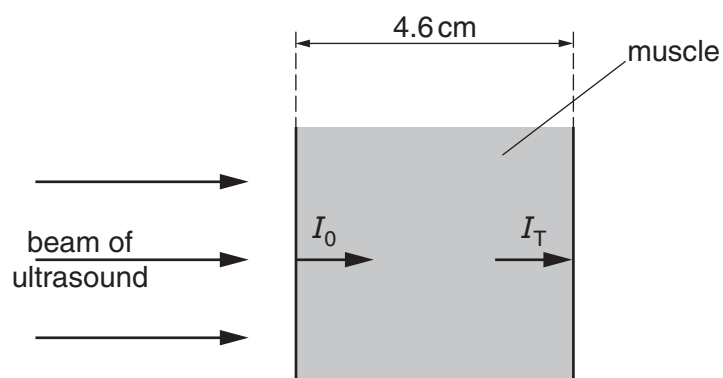


Fig. 4.1

The intensity of the beam just before it leaves the muscle is I_T .
The ratio I_0/I_T is found to be 2.9.

Calculate the linear attenuation (absorption) coefficient μ of the ultrasound in the layer of muscle.

$$\mu = \dots\dots\dots \text{cm}^{-1} \quad [3]$$

[Total: 9]

5 (a) State two advantages of the transmission of data in digital form rather than in analogue form.

1.
-
2.
-

[2]

(b) An analogue signal S_I is converted into a digital signal D using an analogue-to-digital converter (ADC). After transmission of the digital signal, it is converted back to an analogue signal S_T using a digital-to-analogue converter (DAC), as illustrated in Fig. 5.1.

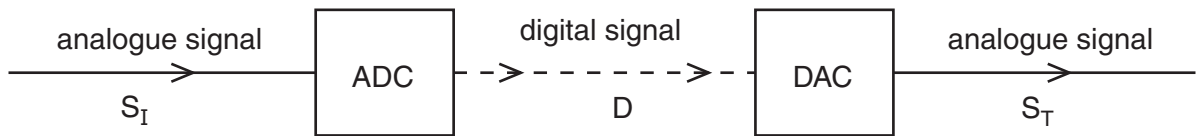


Fig. 5.1

(i) Outline the process by which the ADC converts the analogue signal S_I into the digital signal D .

-
-
-[2]

(ii) The ADC and the DAC operate with the same sampling rate and the same number of bits in each digital number.

State the effect on the transmitted analogue signal S_T when, for the ADC and the DAC,

1. the sampling rate is increased,

-
-

2. the number of bits in each digital number is increased.

-
-

[2]

[Total: 6]

- 6 (a) State Coulomb's law.

.....

.....

.....[2]

- (b) Two charged metal spheres A and B are situated in a vacuum, as illustrated in Fig. 6.1.

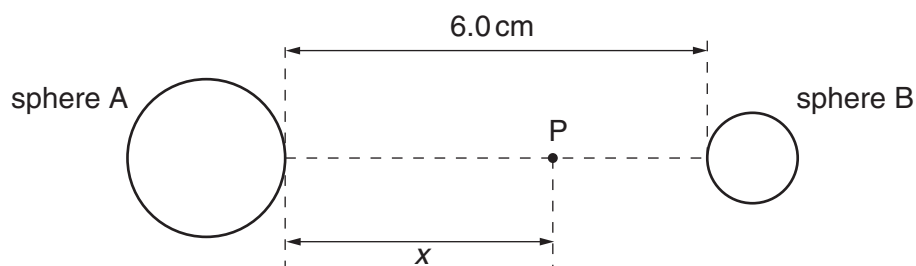


Fig. 6.1

The shortest distance between the surfaces of the spheres is 6.0 cm.

A movable point P lies along the line joining the centres of the two spheres, a distance x from the surface of sphere A.

The variation with distance x of the electric field strength E at point P is shown in Fig. 6.2.

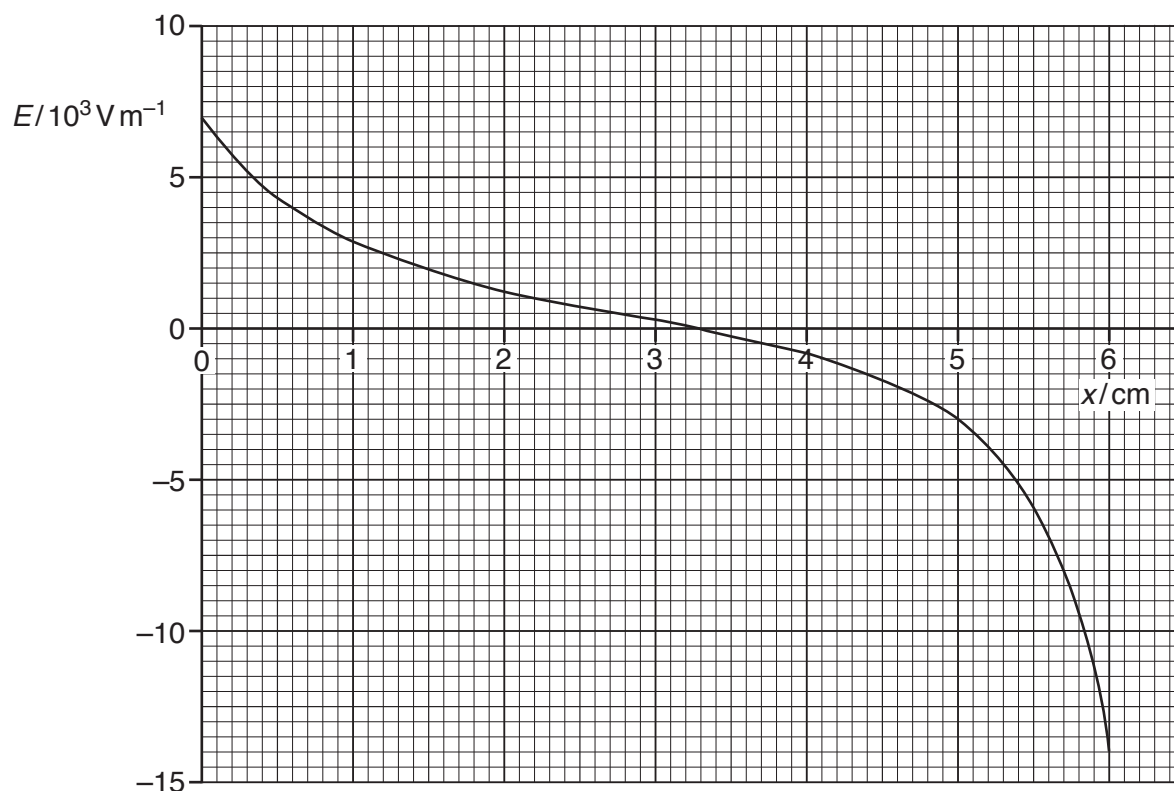


Fig. 6.2

- (i) Use Fig. 6.2 to explain whether the two spheres have charges of the same, or opposite, sign.

.....

.....

.....

..... [2]

- (ii) A proton is at point P where $x = 5.0\text{ cm}$.
Use data from Fig. 6.2 to determine the acceleration of the proton.

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

- (c) Use data from Fig. 6.2 to state the value of x at which the rate of change of electric potential is maximum. Give the reason for the value you have chosen.

.....

.....

..... [2]

[Total: 9]

- 7 A capacitor consists of two parallel metal plates, separated by an insulator, as shown in Fig. 7.1.

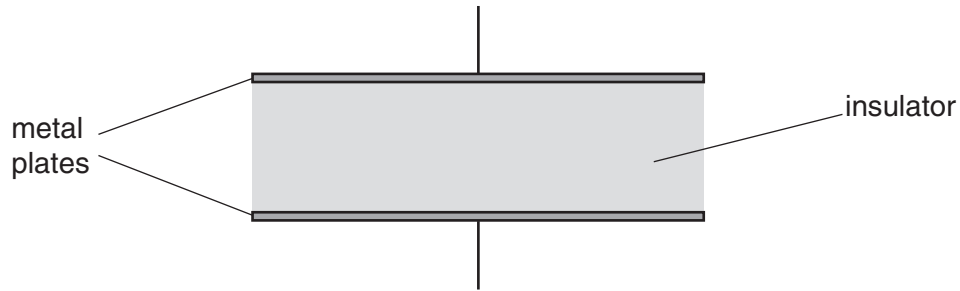


Fig. 7.1

- (a) Suggest why, when the capacitor is connected across the terminals of a battery, the capacitor stores energy, not charge.

.....

 [2]

- (b) Define the *capacitance* of the capacitor.

.....

 [2]

- (c) The capacitor is charged so that the potential difference between its plates is V_0 . The capacitor is then connected across a resistor for a short time. It is then disconnected. The energy stored in the capacitor is reduced to $\frac{1}{16}$ of its initial value.

Determine, in terms of V_0 , the potential difference across the capacitor.

potential difference = ... [2]

[Total: 6]

- 8 A student designs a circuit incorporating an operational amplifier (op-amp) as shown in Fig. 8.1.

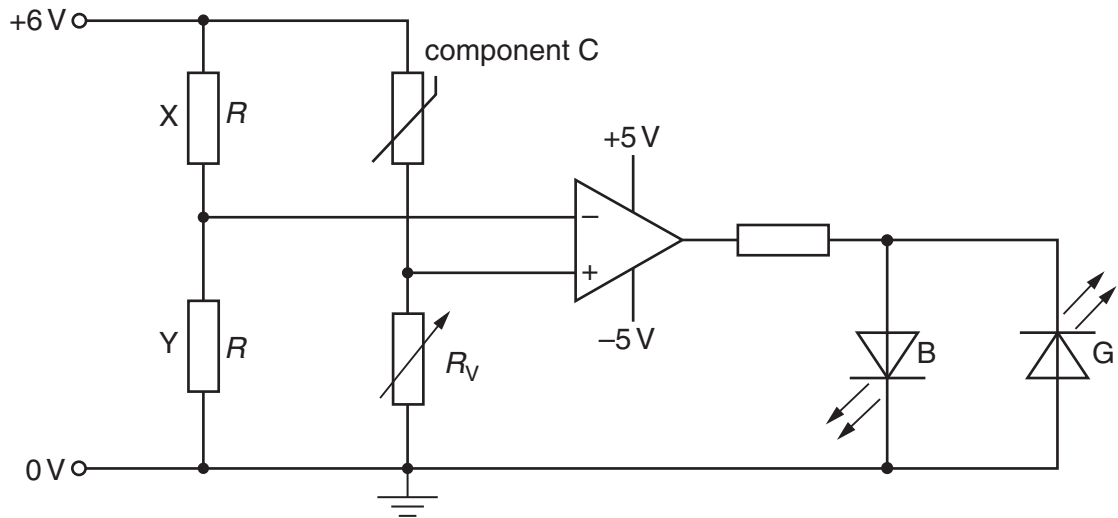


Fig. 8.1

- (a) (i) On Fig. 8.1, draw a circle around the output device. [1]

- (ii) State the purpose of this circuit.

.....

 [2]

- (b) The resistors X and Y each have resistance R .
 When conducting, the LED labelled B emits blue light and the LED labelled G emits green light.

- (i) State whether blue light or green light is emitted when the resistance of component C is greater than the resistance R_V of the variable resistor. Explain your answer.

.....

 [3]

- (ii) State and explain what is observed as the resistance of component C is reduced.

.....

.....

.....

.....

.....[3]

- (c) Suggest the function of the variable resistor.

.....

.....[1]

[Total: 10]

- 9 A Hall probe is placed near to one end of a current-carrying solenoid, as shown in Fig. 9.1.

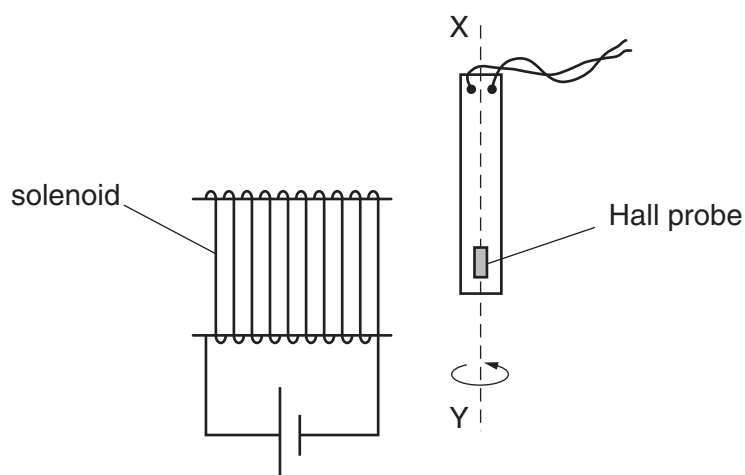


Fig. 9.1

The probe is rotated about the axis XY and is then held in a position so that the Hall voltage is maximum.

(a) Explain why

- (i)** a Hall probe is made from a *thin slice* of material,

.....

[2]

- (ii)** in order for consistent measurements of magnetic flux density to be made, the current in the probe must be constant.

.....
[1]

- (b) The probe is now rotated through an angle of 360° about the axis XY.
At angle $\theta = 0$, the Hall voltage V_H has maximum value V_{MAX} .

On Fig. 9.2, sketch the variation with angle θ of the Hall voltage V_H for one complete revolution of the probe about axis XY.

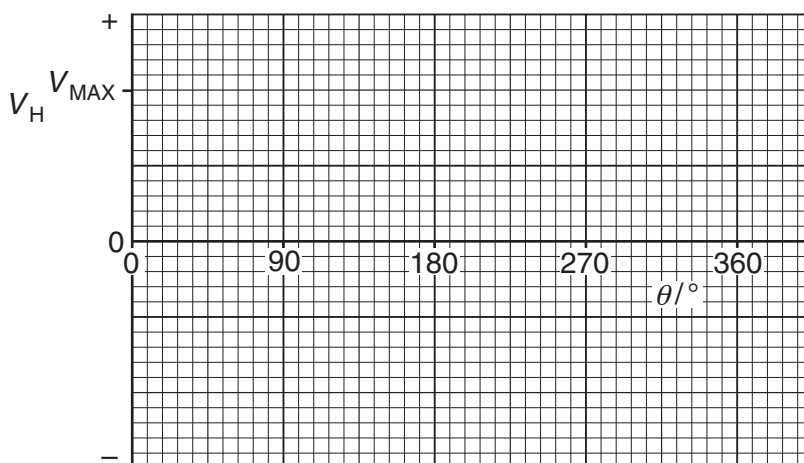


Fig. 9.2

[3]

[Total: 6]

- 10 (a) Briefly describe two phenomena associated with the photoelectric effect that cannot be explained using a wave theory of light.

1.

.....

2.

.....

[2]

- (b) The maximum energy E_{MAX} of electrons emitted from a metal surface when illuminated by light of wavelength λ is given by the expression

$$E_{MAX} = hc \left(\frac{1}{\lambda} - \frac{1}{\lambda_0} \right)$$

where h is the Planck constant and c is the speed of light.

- (i) Identify the symbol λ_0 .

.....[1]

- (ii) The variation with $\frac{1}{\lambda}$ of E_{MAX} for the metal surface is shown in Fig. 10.1.

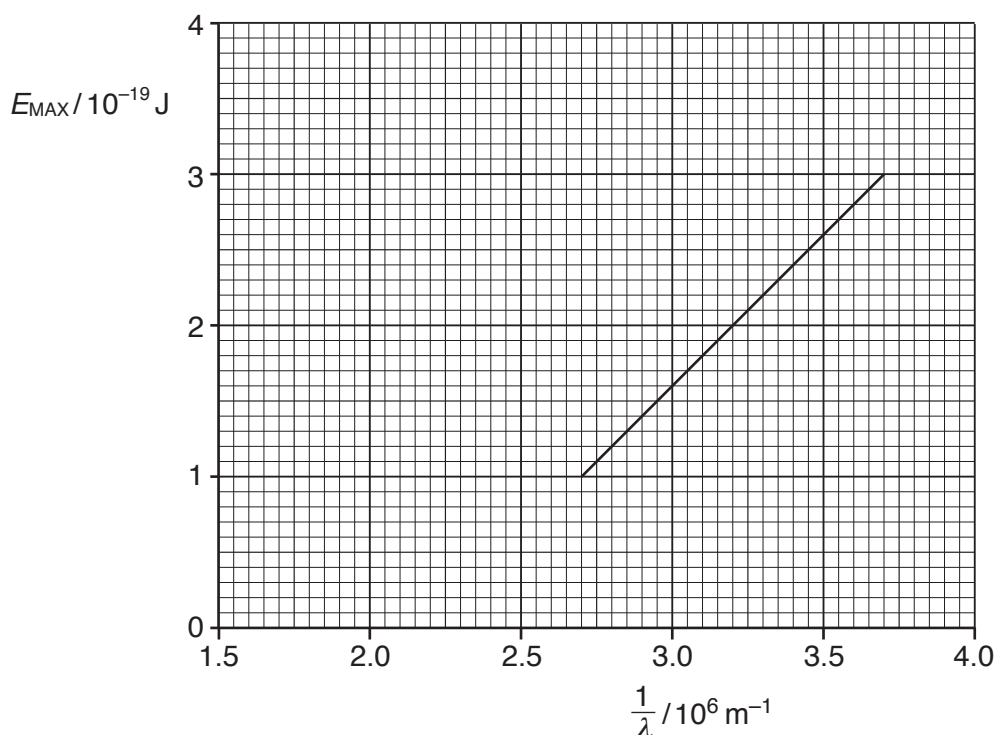


Fig. 10.1

1. Use Fig. 10.1 to determine the magnitude of λ_0 .

$$\lambda_0 = \dots\dots\dots \text{ m [1]}$$

2. Use the gradient of Fig. 10.1 to determine a value for the Planck constant h .

$$h = \dots\dots\dots \text{ Js [3]}$$

- (c) The metal surface in (b) becomes oxidised.
Photoelectric emission is still observed but the work function energy is increased.

On Fig. 10.1, draw a line to show the variation with $\frac{1}{\lambda}$ of E_{MAX} for the oxidised surface. [2]

[Total: 9]

- 11 An electron has charge $-q$ and mass m . It is accelerated from rest in a vacuum through a potential difference V .

(a) Show that the momentum p of the accelerated electron is given by

$$p = \sqrt{2mqV}.$$

[2]

(b) The potential difference V through which the electron is accelerated is 120 V.

(i) State what is meant by the *de Broglie wavelength*.

.....

 [2]

(ii) Calculate the de Broglie wavelength of the electron.

wavelength = ... m [3]

(c) The separation of copper atoms in a copper crystal is approximately 2×10^{-10} m.

By reference to your answer in (b)(ii), suggest whether electron diffraction could be observed using a beam of electrons that have been accelerated through a potential difference of 120 V and are then incident on a thin copper crystal.

.....

 [2]

[Total: 9]

- 12 One nuclear reaction that can take place in a nuclear reactor may be represented, in part, by the equation



Data for a nucleus and some particles are given in Fig. 12.1.

nucleus or particle	mass/u
${}_{57}^{139}\text{La}$	138.955
${}_0^1\text{n}$	1.00863
${}_1^1\text{p}$	1.00728
${}_{-1}^0\text{e}$	5.49×10^{-4}

Fig. 12.1

- (a) Complete the nuclear reaction shown above. [1]
- (b) (i) Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

- (ii) Calculate the binding energy per nucleon, in MeV, of lanthanum-139 (${}_{57}^{139}\text{La}$).

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

Question 12 continues on the next page.

- (c) State and explain whether the binding energy per nucleon of uranium-235 ($^{235}_{92}\text{U}$) will be greater, equal to or less than your answer in (b)(ii).

.....

.....

.....

.....[3]

[Total: 10]

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PHYSICS

9702/43

Paper 4 A Level Structured Questions

May/June 2017

2 hours

Candidates answer on the Question Paper.

No Additional Materials are required.

READ THESE INSTRUCTIONS FIRST

Write your Centre number, candidate number and name on all the work you hand in.

Write in dark blue or black pen.

You may use an HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

DO **NOT** WRITE IN ANY BARCODES.

Answer **all** questions.

Electronic calculators may be used.

You may lose marks if you do not show your working or if you do not use appropriate units.

At the end of the examination, fasten all your work securely together.

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

This document consists of **22** printed pages and **2** 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	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$
	$(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1})$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
unified atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
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.	$v = v_0 \cos \omega t$ $v = \pm \omega \sqrt{(x_0^2 - x^2)}$
Doppler effect	$f_o = \frac{f_s v}{v \pm v_s}$
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	$W = \frac{1}{2} QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \dots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \dots$
Hall voltage	$V_H = \frac{BI}{ntq}$
alternating current/voltage	$x = x_0 \sin \omega t$
radioactive decay	$x = x_0 \exp(-\lambda t)$
decay constant	$\lambda = \frac{0.693}{t_{\frac{1}{2}}}$

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

- 1 (a) Explain how a satellite may be in a circular orbit around a planet.

.....

.....

.....[2]

- (b) The Earth and the Moon may be considered to be uniform spheres that are isolated in space. The Earth has radius R and mean density ρ . The Moon, mass m , is in a circular orbit about the Earth with radius nR , as illustrated in Fig. 1.1.

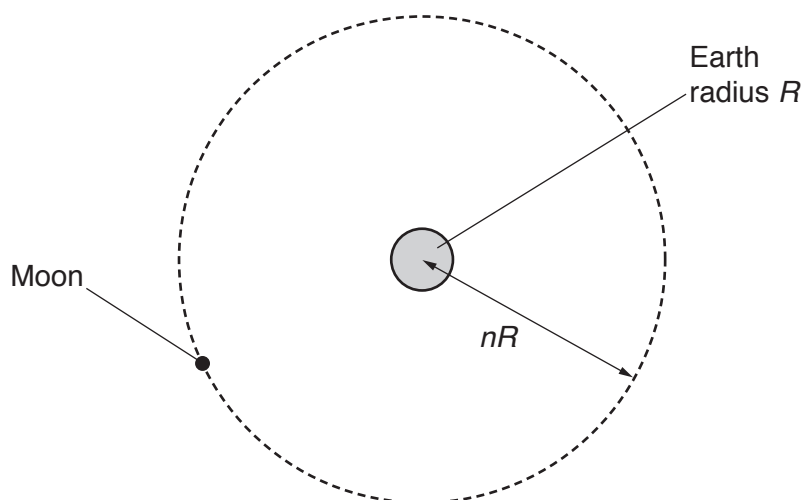


Fig. 1.1

The Moon makes one complete orbit of the Earth in time T .
Show that the mean density ρ of the Earth is given by the expression

$$\rho = \frac{3\pi n^3}{GT^2}.$$

[4]

- (c) The radius R of the Earth is $6.38 \times 10^3 \text{ km}$ and the distance between the centre of the Earth and the centre of the Moon is $3.84 \times 10^5 \text{ km}$.
The period T of the orbit of the Moon about the Earth is 27.3 days.
Use the expression in (b) to calculate ρ .

$$\rho = \dots\dots\dots \text{ kg m}^{-3} \text{ [3]}$$

[Total: 9]

- 2 A bar magnet of mass 180 g is suspended from the free end of a spring, as illustrated in Fig. 2.1.

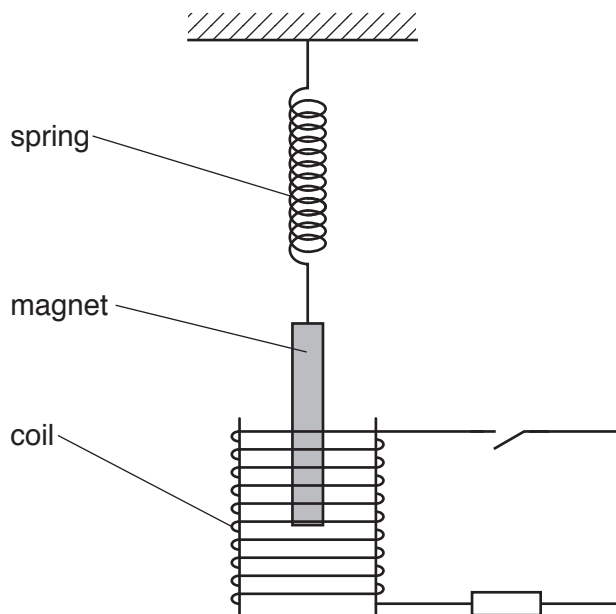


Fig. 2.1

The magnet hangs so that one pole is near the centre of a coil of wire.

The coil is connected in series with a resistor and a switch. The switch is open.

The magnet is displaced vertically and then allowed to oscillate with one pole remaining inside the coil. The other pole remains outside the coil.

At time $t = 0$, the magnet is oscillating freely as it passes through its equilibrium position. At time $t = 3.0$ s, the switch in the circuit is closed.

The variation with time t of the vertical displacement y of the magnet is shown in Fig. 2.2.

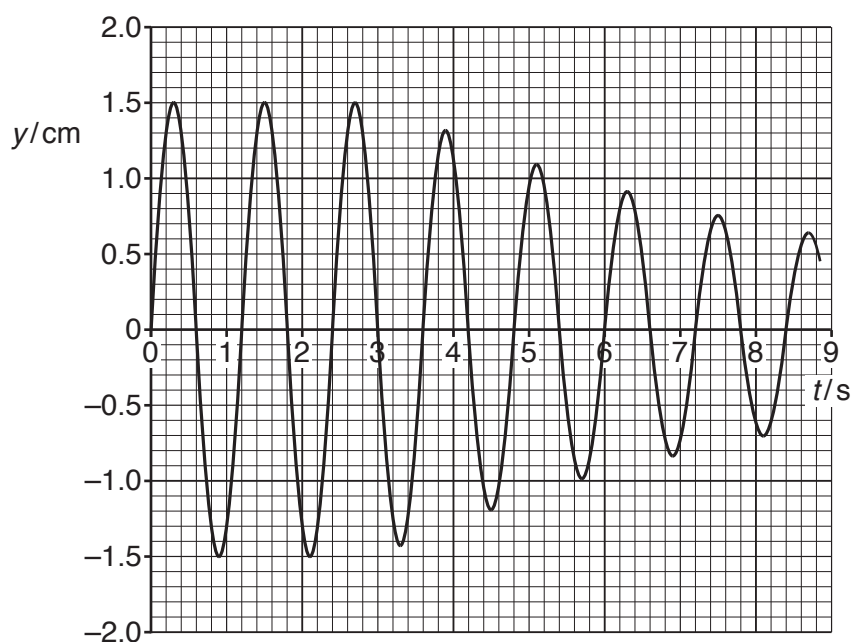


Fig. 2.2

- (a) Determine, to two significant figures, the frequency of oscillation of the magnet.

frequency = ... Hz [2]

- (b) State whether the closing of the switch gives rise to light, heavy or critical damping.

.....[1]

- (c) Calculate the change in the energy ΔE of oscillation of the magnet between time $t = 2.7$ s and time $t = 7.5$ s. Explain your working.

$\Delta E =$ J [6]

[Total: 9]

- 3 The digital transmission of speech may be illustrated using the block diagram of Fig. 3.1.

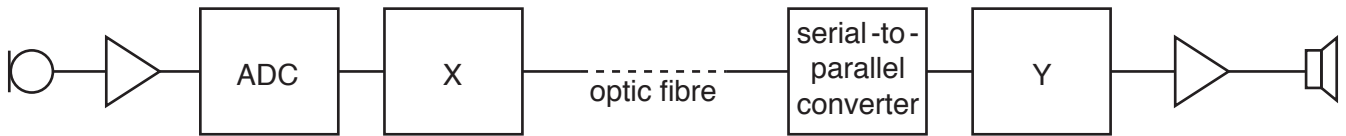


Fig. 3.1

- (a) (i) State what is meant by a *digital signal*.

.....
[1]

- (ii) State the names of the components labelled X and Y on Fig. 3.1.

X:

Y:
[2]

- (iii) Describe the function of the ADC.

.....

[2]

- (b) The optic fibre has length 84 km and the attenuation per unit length in the fibre is 0.19 dB km^{-1} .

The input power to the optic fibre is 9.7 mW. At the output from the optic fibre, the signal-to-noise ratio is 28 dB.

Calculate

- (i) in dB, the ratio

$$\frac{\text{input power to optic fibre}}{\text{noise power at output of optic fibre}},$$

ratio = ... dB [2]

- (ii) the noise power at the output of the optic fibre.

noise power = ... W [3]

[Total: 10]

- 4 (a) Describe the motion of molecules in a gas, according to the kinetic theory of gases.

.....

 [2]

- (b) Describe what is observed when viewing Brownian motion that provides evidence for your answer in (a).

.....

 [2]

- (c) At a pressure of $1.05 \times 10^5 \text{ Pa}$ and a temperature of 27°C , 1.00 mol of helium gas has a volume of 0.0240 m^3 .

The mass of 1.00 mol of helium gas, assumed to be an ideal gas, is 4.00 g .

- (i) Calculate the root-mean-square (r.m.s.) speed of an atom of helium gas for a temperature of 27°C .

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

- (ii) Using your answer in (i), calculate the r.m.s. speed of the atoms at 177°C .

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

[Total: 10]

- 5 An α -particle is travelling in a vacuum towards the centre of a gold nucleus, as illustrated in Fig. 5.1.



Fig. 5.1

The gold nucleus has charge $79e$.

The gold nucleus and the α -particle may be assumed to behave as point charges.

At a large distance from the gold nucleus, the α -particle has energy $7.7 \times 10^{-13} \text{ J}$.

- (a) The α -particle does not collide with the gold nucleus. Show that the radius of the gold nucleus must be less than $4.7 \times 10^{-14} \text{ m}$.

[3]

- (b) Determine the acceleration of the α -particle for a separation of $4.7 \times 10^{-14} \text{ m}$ between the centres of the gold nucleus and of the α -particle.

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

- (c) In an α -particle scattering experiment, the beam of α -particles is incident on a very thin gold foil.

Suggest why the gold foil must be very thin.

.....

..... [1]

[Total: 7]

- 6 A comparator circuit is designed to switch on a mains lamp when the ambient light level reaches a set value.

An incomplete diagram of the circuit is shown in Fig. 6.1.

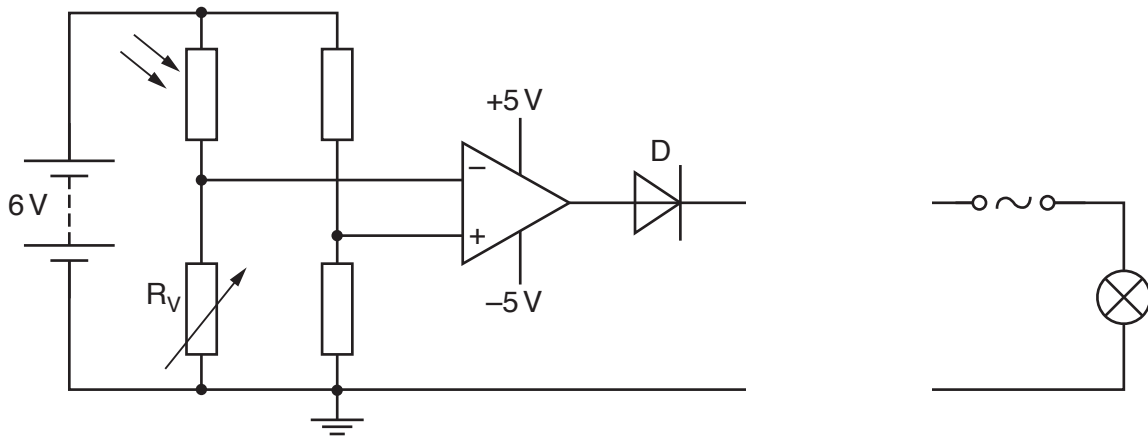


Fig. 6.1

- (a) (i) A relay is required as part of the output device. This is not shown in Fig. 6.1. Explain why a relay is required.

.....

 [2]

- (ii) On Fig. 6.1, draw the symbol for a relay connected in the circuit as part of the output device. [2]

- (b) Describe the function of

- (i) the variable resistor R_V ,

.....
 [1]

- (ii) the diode D.

.....
 [1]

- (c) State whether the lamp will switch on as the light level increases or as it decreases. Explain your answer.

.....

.....

.....

.....

.....[3]

[Total: 9]

- 7 An electron having charge $-q$ and mass m is accelerated from rest in a vacuum through a potential difference V . The electron then enters a region of uniform magnetic field of magnetic flux density B , as shown in Fig. 7.1.

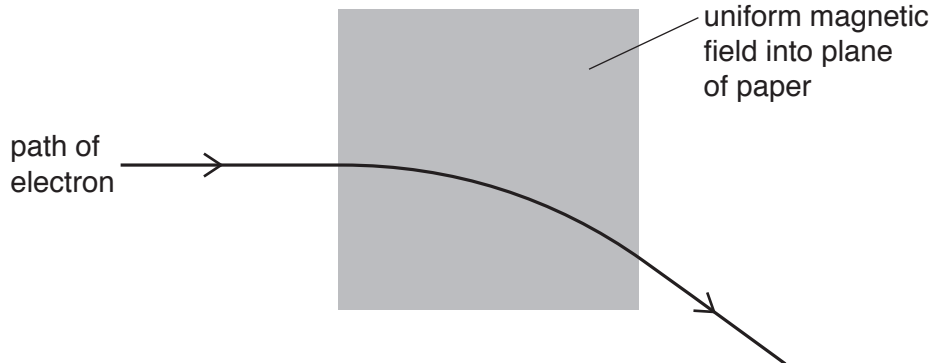


Fig. 7.1

The direction of the uniform magnetic field is into the plane of the paper.
 The velocity of the electron as it enters the magnetic field is normal to the magnetic field.
 The radius of the circular path of the electron in the magnetic field is r .

- (a) Explain why the path of the electron in the magnetic field is the arc of a circle.

.....

.....

.....

.....[3]

- (b) Show that the magnitude p of the momentum of the electron as it enters the magnetic field is given by

$$p = \sqrt{2mqV}.$$

[2]

- (c) The potential difference V is 120 V. The radius r of the circular arc is 7.4 cm.

Determine the magnitude B of the magnetic flux density.

$B = \dots\dots\dots$ T [3]

- (d) The potential difference V in (c) is increased. The magnetic flux density B remains unchanged.

By reference to the momentum of the electron, explain the effect of this increase on the radius r of the path of the electron in the magnetic field.

.....

 [2]

[Total: 10]

- 8** Explain the main principles behind the use of nuclear magnetic resonance imaging (NMRI) to obtain information about internal body structures.

.....[8]

[Total: 8]

- 9 A simple transformer is illustrated in Fig. 9.1.

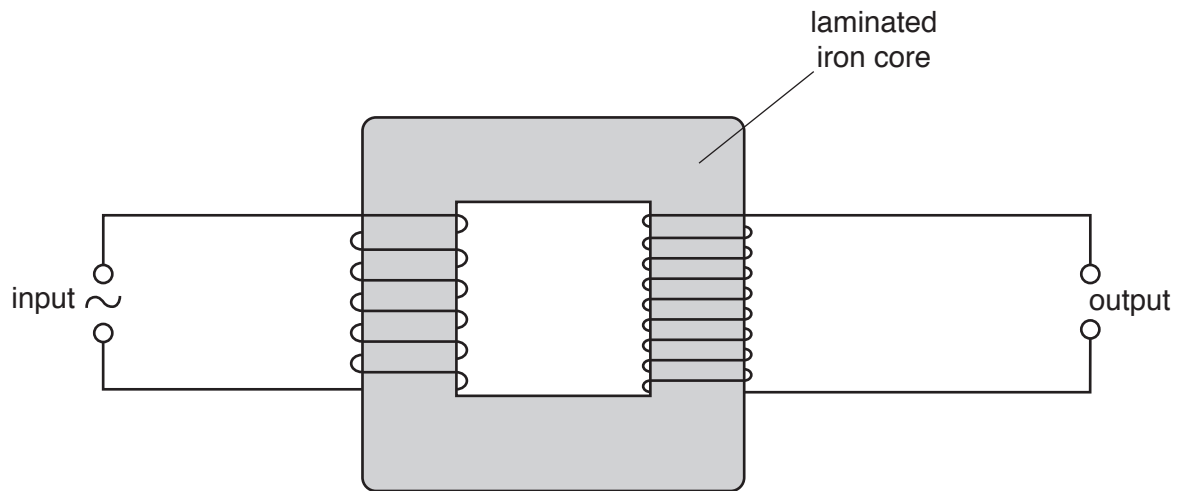


Fig. 9.1

- (a) (i) State why the transformer has an iron core, rather than having no core.

.....
[1]

- (ii) Explain why the core is laminated.

.....

[2]

- (b) By reference to the action of a transformer, explain why the input to the transformer is an alternating voltage, rather than a constant voltage.

.....

[3]

[Total: 6]

10 (a) State

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

.....

[2]

- (ii) how the hardness of an X-ray beam from an X-ray tube is increased.

.....
[1]

- (b) The same parallel beam of X-ray radiation is incident, separately, on samples of bone and of muscle.

Data for the thickness x of the samples of bone and of muscle, together with the linear attenuation (absorption) coefficients μ of the radiation in bone and in muscle, are given in Fig. 10.1.

	x/cm	μ/cm^{-1}
bone	1.5	2.9
muscle	4.0	0.95

Fig. 10.1

Determine the ratio

$$\frac{\text{intensity transmitted through bone}}{\text{intensity transmitted through muscle}}$$

ratio = ... [2]

[Total: 5]

- 11 A beam of light consists of a continuous range of wavelengths from 420 nm to 740 nm. The light passes through a cloud of cool gas, as shown in Fig. 11.1.

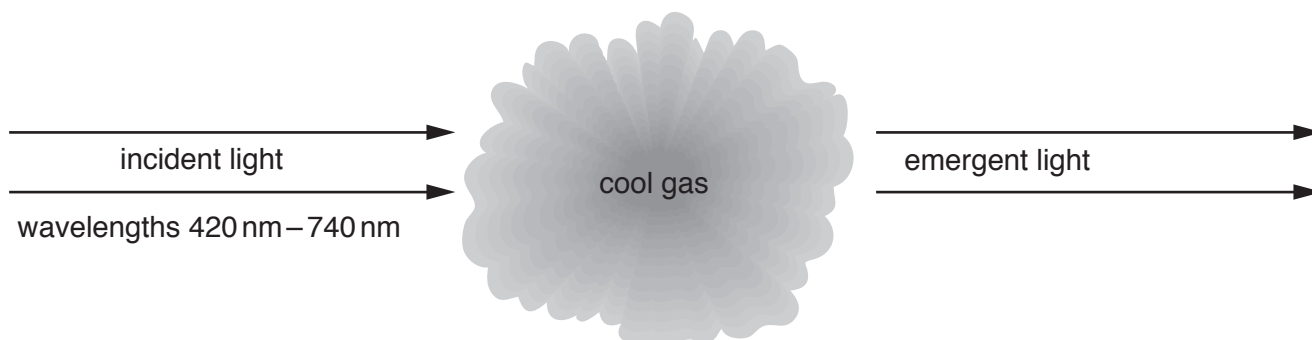


Fig. 11.1

- (a) The spectrum of the light emerging from the cloud of cool gas is viewed using a diffraction grating. Explain why this spectrum contains a number of dark lines.

.....

.....

.....

.....

.....

.....[4]

- (b) Some of the electron energy levels of the atoms in the cloud of gas are represented in Fig. 11.2.

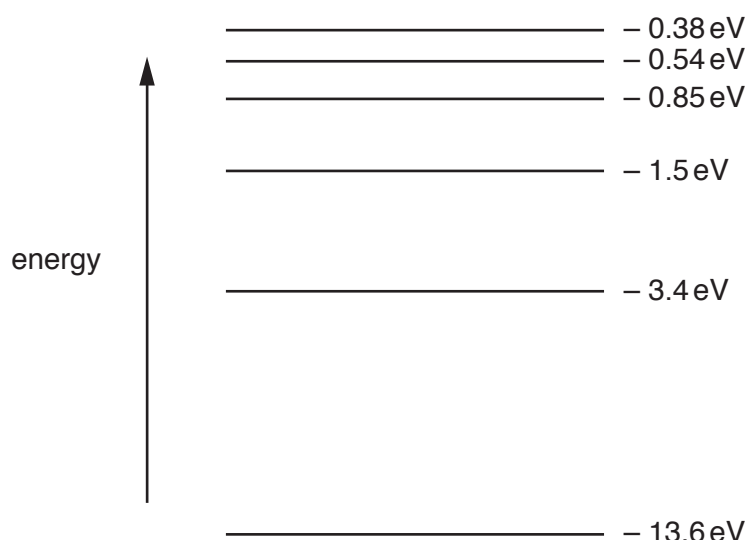


Fig. 11.2 (not to scale)

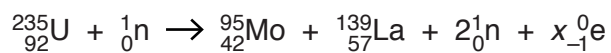
- (i) Light of wavelength 420 nm has a photon energy of 2.96 eV.
Calculate the photon energy, in eV, of light of wavelength 740 nm.

photon energy = ... eV [2]

- (ii) Use data from (i) and your answer in (i) to show, on Fig. 11.2, the changes in energy levels giving rise to the dark lines in (a). [2]

[Total: 8]

12 One possible nuclear reaction that takes place in a nuclear reactor is given by the equation



Data for the nuclei and particles are given in Fig. 12.1.

nucleus or particle	mass/u
${}_{92}^{235}\text{U}$	235.123
${}_{42}^{95}\text{Mo}$	94.945
${}_{57}^{139}\text{La}$	138.955
${}_0^1\text{n}$	1.00863
${}_{-1}^0\text{e}$	5.49×10^{-4}

Fig. 12.1

(a) Determine, for this nuclear reaction, the value of x .

$x = \dots\dots\dots[1]$

- (b) (i)** Show that the energy equivalent to 1.00 u is 934 MeV.

[3]

- (ii)** Calculate the energy, in MeV, released in this reaction. Give your answer to three significant figures.

energy = ... MeV [3]

- (c)** Suggest the forms of energy into which the energy calculated in **(b)(ii)** is transformed.

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

[Total: 9]

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