Cambridge Assessment International Education

Cambridge International AS & A Level

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PHYSICS **9702/42**

Paper 4 A Level Structured Questions **February/March 2020**

2 hours

You must answer on the question paper.

No additional materials are needed.

INSTRUCTIONS

- Answer **all** questions.
- Use a black or dark blue pen. You may use an HB pencil for any diagrams or graphs.
- Write your name, centre number and candidate number in the boxes at the top of the page.
- Write your answer to each question in the space provided.
- Do **not** use an erasable pen or correction fluid.
- Do **not** write on any bar codes.
- You may use a calculator.
- You should show all your working and use appropriate units.

INFORMATION

- The total mark for this paper is 100.
- The number of marks for each question or part question is shown in brackets [ ].

This document has **28** pages. Blank pages are indicated.

DC (ST/CT) 180485/4

Data

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

Formulae

uniformly accelerated motion	$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$
work done on/by a gas	$W = p\Delta V$
gravitational potential	$\phi = -\frac{Gm}{r}$
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	$V = \frac{Q}{4\pi\varepsilon_0 r}$
capacitors in series	$1/C = 1/C_1 + 1/C_2 + \ldots$
capacitors in parallel	$C = C_1 + C_2 + \ldots$
energy of charged capacitor	$W = \frac{1}{2}QV$
electric current	$I = Anvq$
resistors in series	$R = R_1 + R_2 + \ldots$
resistors in parallel	$1/R = 1/R_1 + 1/R_2 + \ldots$
Hall voltage	$V_H = \frac{BI}{ntq}$
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 potential* at a point.

It is the work done per unit mass, in bringing a small test mass from infinity to a point in a gravitational field

[2]

(b) TESS is a satellite of mass 360 kg in a circular orbit about the Earth as shown in Fig. 1.1.

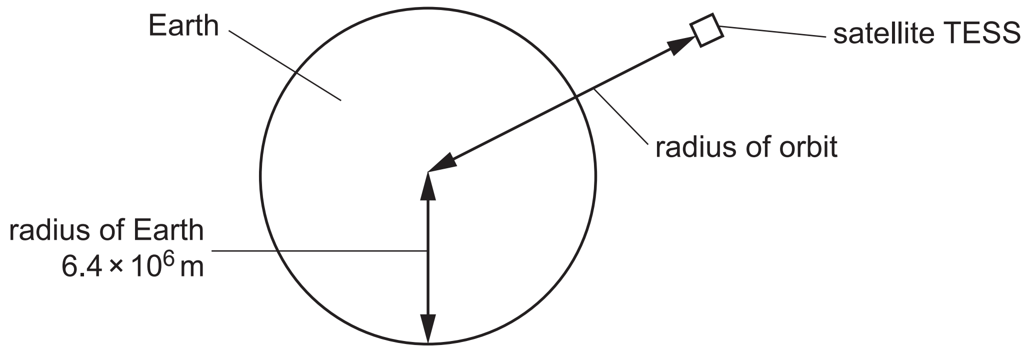

Fig. 1.1 (not to scale)

The radius of the Earth is 6.4×10^6 m and the mass of the Earth, considered to be a point mass at its centre, is 6.0×10^{24} kg.

(i) It takes TESS 13.7 days to orbit the Earth.

Show that the radius of orbit of TESS is 2.4×10^8 m.

13.7 days = 1183680 seconds

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM}$$

$$r = \sqrt[3]{\frac{T^2 GM}{4\pi^2}}$$

$$= \sqrt[3]{\frac{1183680^2 \times G \times 6 \times 10^{24}}{4\pi^2}}$$

$$= 2.422 \times 10^8 \approx 2.4 \times 10^8 \text{ m}$$

[3]

(ii) Calculate the change in gravitational potential energy between TESS in orbit and TESS on a launch pad on the surface of the Earth.

$$-GMm\left(\frac{1}{r_2}-\frac{1}{r_1}\right)$$

$$-G\times 6\times 10^{24}\times 360\left(\frac{1}{2.422\times 10^{8}}-\frac{1}{6.4\times 10^{6}}\right)$$

$$= 2.19298\times 10^{8}$$

change in gravitational potential energy = 2.2×10^{8} J [3]

3

(iii) Use the information in **(b)(i)** to calculate the ratio:

$$\frac{\text{gravitational field strength on surface of Earth}}{\text{gravitational field strength at location of TESS in orbit}}.$$

$(ab)^2 = a^2b^2$

~~ab^2~~

$$\frac{g_e}{g_T} = \frac{\;\frac{\cancel{GM}}{r_e^2}\;}{\frac{\cancel{GM}}{r_T^2}}$$

$$\frac{g_e}{g_T} = \frac{r_T^2}{r_e^2} = \frac{2.422^2\times 10^{16}}{6.4^2\times 10^{12}} = 1432.49$$

ratio = 1.4×10^{3} [2]

2

[Total: 10]

10

2 A large container of volume $85\,m^3$ is filled with 110 kg of an ideal gas. The pressure of the gas is $1.0 \times 10^5\,Pa$ at temperature T.

The mass of 1.0 mol of the gas is 32 g.

(a) Show that the temperature T of the gas is approximately 300 K.

1 mol = 0.032 kg

3437.5 = 110

$PV = nRT$

$T = \frac{PV}{nR} = \frac{1 \times 10^5 \times 85}{3437.5 \times 8.31}$

$= 297.5 \approx 300\,K$

[3]

(b) The temperature of the gas is increased to 350 K at constant volume. The specific heat capacity of the gas for this change is $0.66\,J\,kg^{-1}\,K^{-1}$.

Calculate the energy supplied to the gas by heating.

$q = mc\Delta t$

$= 110 \times 0.66 \times 50 = 3630\,J$

energy = 3600 J [2]

(c) Explain how movement of the gas molecules causes pressure in the container.

The molecules have momentum as they are moving and when they collide with the walls, their is a change in momentum, change in momentum is force, force over an area is pressure

[3]

X **(d)** The temperature of a gas depends on the root-mean-square (r.m.s.) speed of its molecules.

Calculate the ratio:

$$\frac{\text{r.m.s. speed of gas molecules at 350 K}}{\text{r.m.s. speed of gas molecules at 300 K}}.$$

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

2

$\frac{rms_1}{\sqrt{T_1}} = \frac{rms_2}{\sqrt{T_2}}$

$= \frac{\sqrt{350}}{\sqrt{300}} = 1.08 \approx 1.1$

ratio = 1.1 .... [2] 0

[Total: 10]

8/10

3 **(a)** A body undergoes simple harmonic motion.

The variation with displacement x of its velocity v is shown in Fig. 3.1.

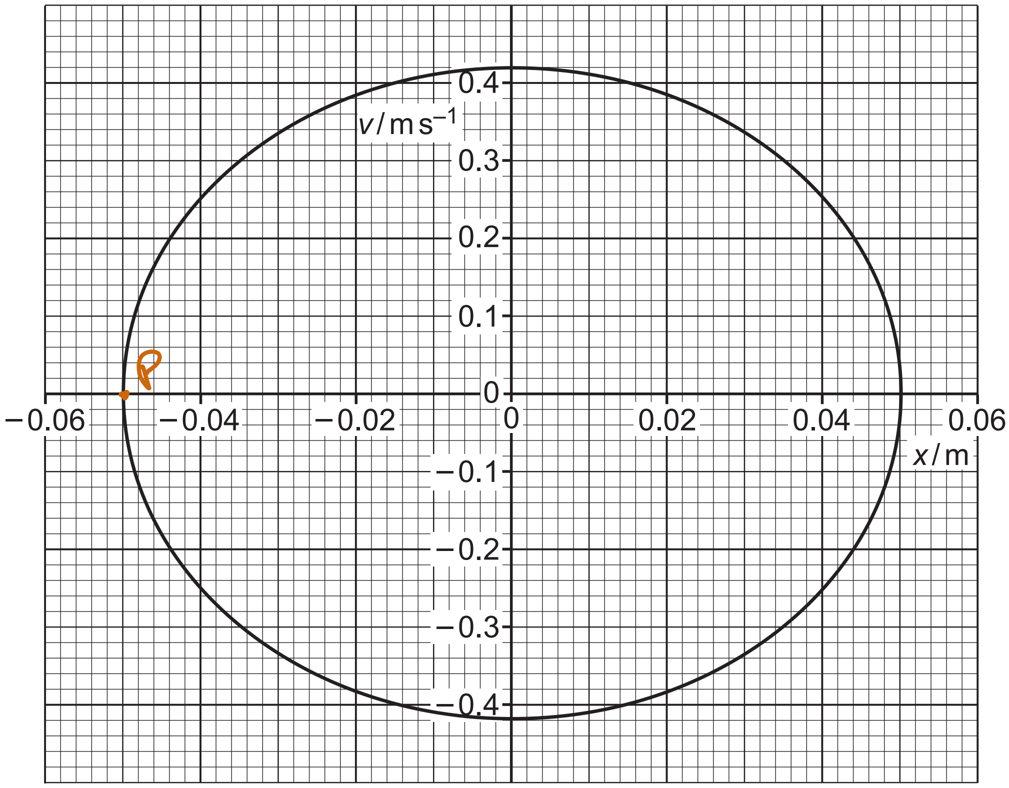

Fig. 3.1

(i) State the amplitude x_o of the oscillations.

x_o = ...0.05...... m [1]

(ii) Calculate the period T of the oscillations.

$V_{max} = x_0 \omega$

$\omega = \frac{V_{max}}{x_0}$

$\frac{2\pi}{T} = \frac{V_{max}}{x_0}$

$T = \frac{2\pi x_0}{V_{max}} = \left(\frac{2\pi \times 0.05}{0.42}\right) = 0.74799$

T = ...0.75...... s [3]

(iii) On Fig. 3.1, label with a P a point where the body has **maximum** potential energy. [1]

(b) A bar magnet is suspended from the free end of a spring, as shown in Fig. 3.2.

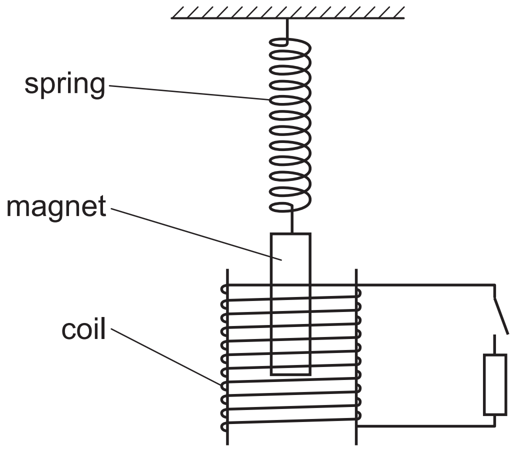

Fig. 3.2

One pole of the magnet is situated in a coil of wire. The coil is connected in series with a switch and a resistor. The switch is open.

The magnet is displaced vertically and then released. The magnet oscillates with simple harmonic motion.

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

It states that the induced emf is proportional to the rate of change of M flux linkage.

[2]

* **(ii)** The switch is now closed. Explain why the oscillations of the magnet are damped.

The current in the circuit is because of the magnet ocillating with a KE, so when switch is closed, the resistor heats up and this energy is lost to surroundings and so magnet loses energy

2 [3]

[Total: 10]

9

4 **(a)** **(i)** Explain why ultrasound used in medical diagnosis is emitted in pulses.

....

....

.... [2]

(ii) Explain the principles of the **detection** of ultrasound waves used in medical diagnosis.

....

....

....

....

.... [3]

(b) The specific acoustic impedances Z of some media are given in Table 4.1.

Table 4.1

media	Z / kg m^{-2} s^{-1}
air	4.3×10^2
gel	1.5×10^6
soft tissue	1.6×10^6

(i) The specific acoustic impedances of two media are Z_1 and Z_2. The intensity reflection coefficient α for the boundary of these two media is given by:

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

Calculate, to three significant figures, the fraction of the ultrasound intensity that is reflected at a boundary between air and soft tissue.

$$\frac{(4.3\times10^2 - 1.6\times10^6)^2}{(4.3\times10^2 + 1.6\times10^6)^2} = 0.998925$$

α = ...0.999.......................... [1]

(ii) Use your value in **(b)(i)** to explain why gel is applied to the surface of the skin during an ultrasound scan.

Without the gel, most of the ultrasound will be reflected, and to decrease this reflection, values of z are similar.

[2] -2

[Total: 8]

6/8

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

1. Encryption

2. noise will be eliminated.

[2]

(b) Optic fibres are used for the transmission of data.

(i) A signal in an optic fibre is carried by an electromagnetic wave of frequency 1.36×10^{14} Hz. The speed of the wave in the fibre is $2.07 \times 10^{8}\,\text{m}\,\text{s}^{-1}$.

For this electromagnetic wave, determine the ratio:

$$\frac{\text{wavelength in free space}}{\text{wavelength in fibre}}.$$

$v = f\lambda$

$$\frac{\lambda_s}{\lambda_f} = \frac{\frac{V_s}{f}}{\frac{V_f}{f}} = \frac{V_s}{V_f} = \frac{3 \times 10^8}{2.07 \times 10^8} = 1.449$$

ratio = 1.45 [2]

(ii) The attenuation per unit length of the signal in the fibre is $0.40\,\text{dB}\,\text{km}^{-1}$. The input power is 1.5 mW and the output power is 0.060 mW.

Calculate the length of the fibre.

$$\text{Att} = 10 \log\left(\frac{0.06}{1.5}\right) = -14$$

$$\text{length} = \frac{A}{\text{APUL}} \quad \frac{14}{0.4} = 35 =$$

length = 35 km [3]

[Total: 7]

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6 Two positively charged identical metal spheres A and B have their centres separated by a distance of 24 cm, as shown in Fig. 6.1.

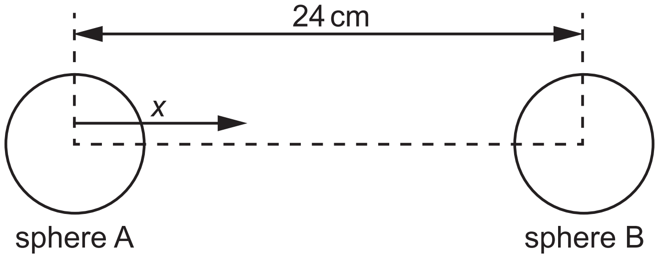


Fig. 6.1 (not to scale)

The variation with distance x from the centre of A of the electric field strength E due to the two spheres, along the line joining their centres, is represented in Fig. 6.2.

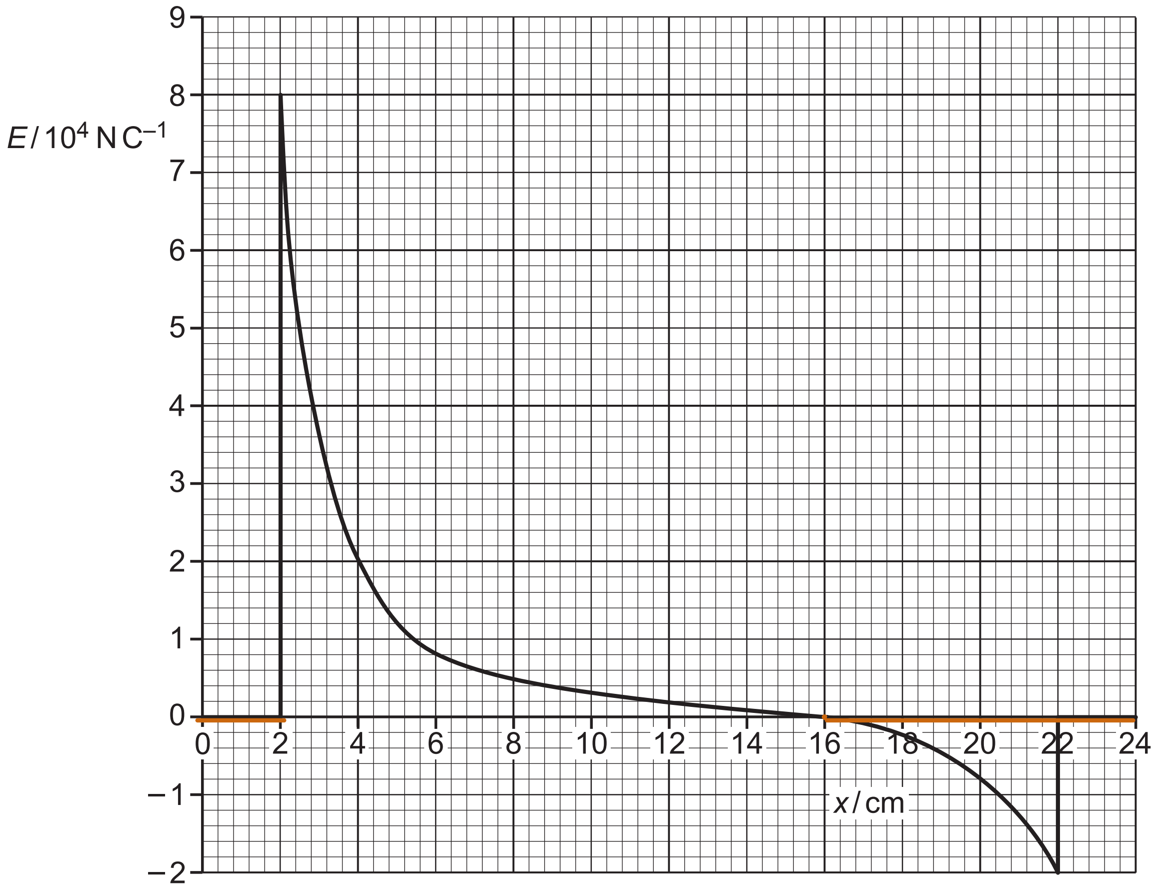


Fig. 6.2

(a) State the radius of the two spheres.

radius = ...2.. cm [1]

(b) The charge on sphere A is 3.6×10^{-9} C. Determine the charge Q_B on sphere B.

Assume that spheres A and B can be treated as point charges at their centres.

Explain your working.

Because at null point, E is same

$$\frac{\cancel{k}Q_A}{r_1^2} = \frac{\cancel{k}Q_B}{r_2^2}$$

$$Q_B = \frac{Q_A r_2^2}{r_1^2} = \frac{(3.6 \times 10^{-9})(0.08)^2}{(0.16)^2}$$

$$= 9 \times 10^{-10}$$

Q_B = 9×10^{-10} C [3]

(c) **(i)** Sphere B is removed.

Use information from **(b)** to determine the electric potential on the surface of sphere A.

$$\frac{kQ}{r} = \frac{(9 \times 10^9) \times (3.6 \times 10^{-9})}{0.02} = 1620$$

electric potential = 1600 V [2]

(ii) Calculate the capacitance of sphere A.

$q = CV$

$$C = \frac{q}{V} = \frac{\cancel{q}}{\frac{k\cancel{q}}{r}} = \frac{r}{k} = \frac{0.02}{9 \times 10^9}$$

capacitance = 2.2×10^{-12} F [2]

[Total: 8]

7 **(a)** On Fig. 7.1, sketch the temperature characteristic of a negative temperature coefficient (n.t.c.) thermistor. Label the axes with quantity and unit.

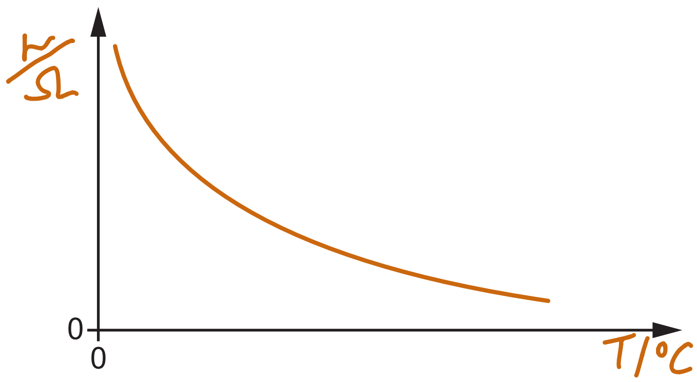


Fig. 7.1

[2]

(b) An n.t.c. thermistor and a resistor are connected as shown in Fig. 7.2.

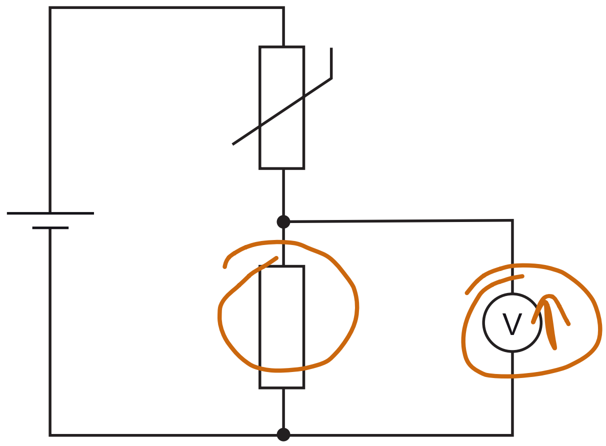


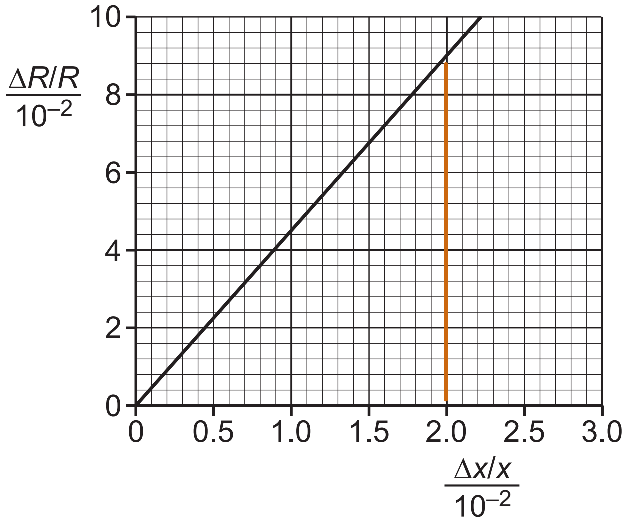
Fig. 7.2

The temperature of the thermistor is increased.

State and explain the change, if any, to the reading on the voltmeter.

as temp across n.t.c increases, its R decreases, hence potential across it decreases, and as a result, potential across V increases .... [2]

(c) The variation with the fractional change in length $\Delta x/x$ of the fractional change in resistance $\Delta R/R$ for a strain gauge is shown in Fig. 7.3.



$r \propto \Delta x$

Fig. 7.3

The unstrained resistance of the gauge is 120 Ω. Calculate the new resistance of the gauge when it is extended to a strain of 0.020.

$0.09 = \frac{\Delta R}{R}$ when strain = 0.02

$\Delta R = 0.09R$

$\Delta R = 120 \times 0.09$

$\Delta R = 10.8\,\Omega$

$120 + 10.8 = 130.8$

resistance = 131 Ω [3]

0

[Total: 7]

8 **(a)** Explain what is meant by a *magnetic field*.

It is a region of space where a charge or current carrying conductor experience a force

moving charge

[1] 0

(b) The apparatus shown in Fig. 8.1 is used in an experiment to find the magnetic flux density B between the poles of a horseshoe magnet. Assume the magnetic field is uniform between the poles of the magnet and zero elsewhere.

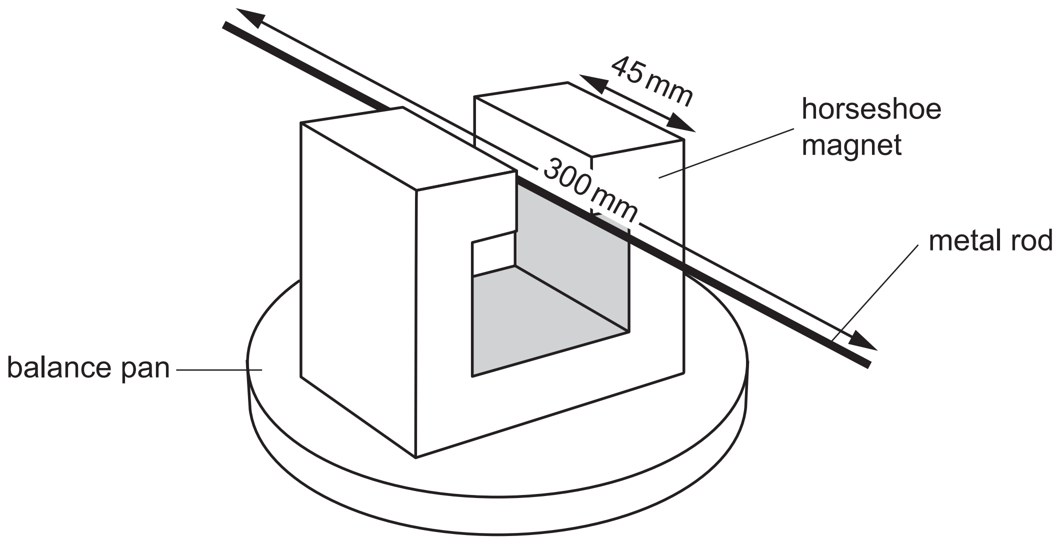


Fig. 8.1

The rigid metal rod of length 300 mm is fixed in position perpendicular to the direction of the magnetic field. The poles of the magnet are both 45 mm long. There is a current in the rod that causes a force on the rod. The balance is used to determine the magnitude of the force.

The variation with current I of the force F on the rod is shown in Fig. 8.2.

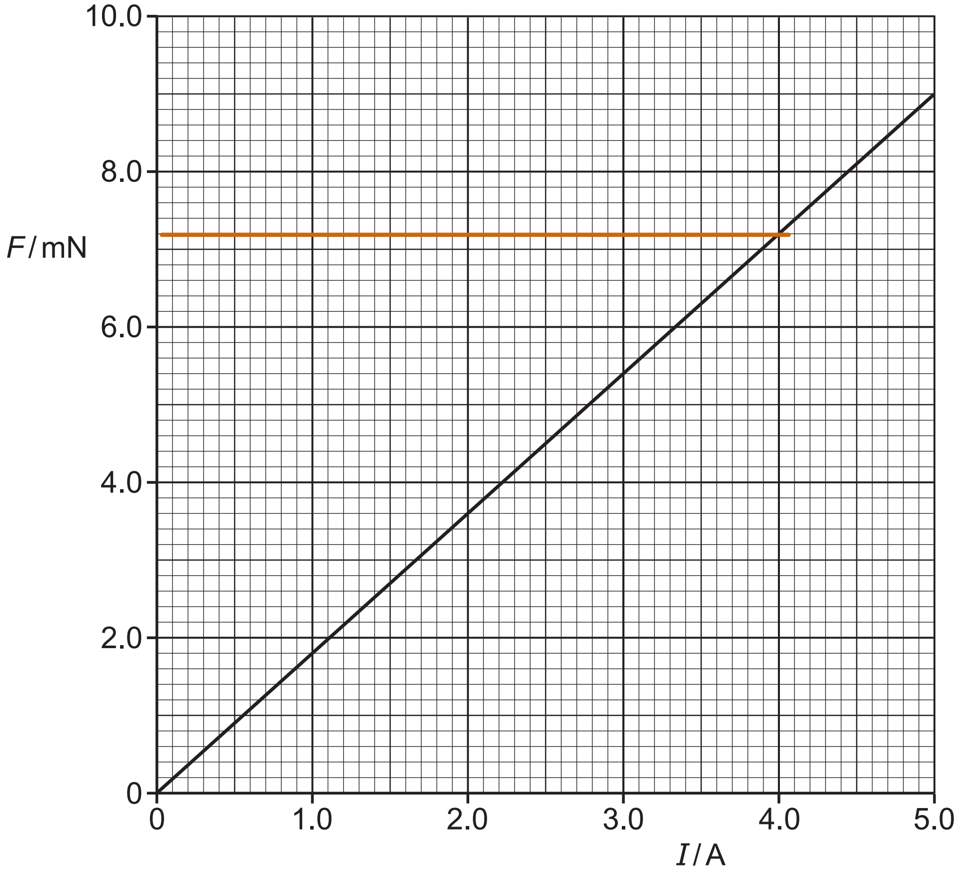


Fig. 8.2

Calculate the magnetic flux density B.

$F = BIL \sin 90$

$B = \frac{F}{IL} = \frac{7.2 \times 10^{-3}}{4 \times 4.5 \times 10^{-2}}$

$= 4 \times 10^{-2}$

$B =$ ....4×10^{-2}.... T [2]

(c) In a different experiment, electrons are accelerated through a potential difference and then enter a region of magnetic field. The magnetic field is into the plane of the paper and is perpendicular to the direction of travel of the electrons, as illustrated in Fig. 8.3.

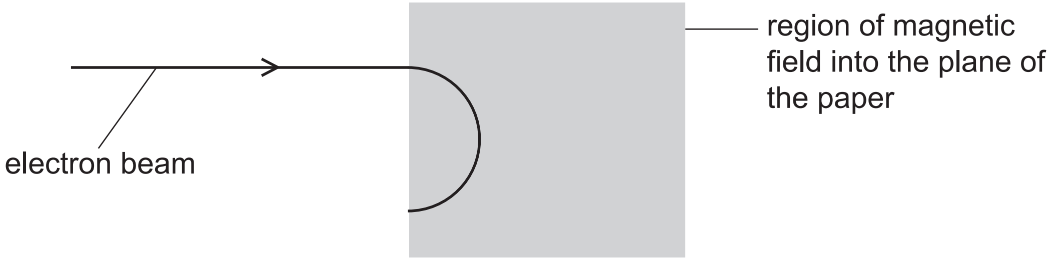


Fig. 8.3

(i) Explain why the electrons follow a circular path when inside the region of the magnetic field.

Because the force on the particles is perpendicular to the direction of the velocity and so that force provides the centripetal force so the electron follows circular motion, magnitude of force is constant [3] 2

(ii) State the measurements needed in order to determine the charge to mass ratio, e/m_e, of an electron.

· The velocity of the electrons.

· The magnetic field strength.

· The radius of the circular path. [2]

$$Bq = \frac{mv}{r}$$

$$\frac{q}{m} = \frac{v}{Br}$$

[Total: 8]

7/8

9 **(a)** The output of a power supply is represented by:

$$V = 9.0\sin 20t$$

where V is the potential difference in volts and t is the time in seconds.

Determine, for the output of the supply:

(i) the root-mean-square (r.m.s.) voltage, $V_{r.m.s.}$

$\frac{9}{\sqrt{2}} = 6.36$

$V_{r.m.s} =$ ......6.4...... V [1]

(ii) the period T.

$\omega = \frac{2\pi}{T} = 20$

$T = \frac{2\pi}{20} = 0.314$

$T =$ ......0.31...... s [2]

! **(b)** The variations with time t of the output potential difference V from two different power supplies are shown in Fig. 9.1 and Fig. 9.2.

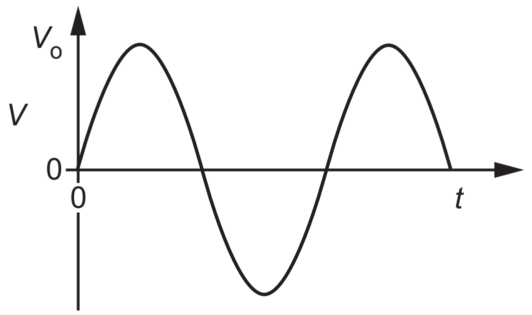


Fig. 9.1

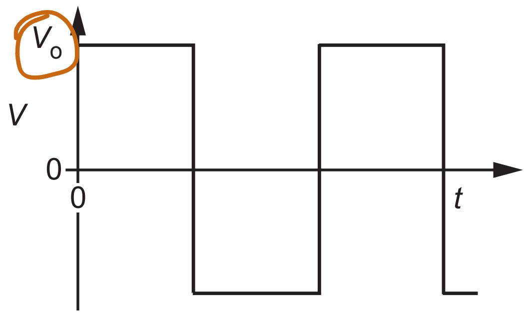


Fig. 9.2

The graphs are drawn to the same scale.

State and explain whether the same power would be dissipated in a 1.0 Ω resistor connected to each power supply.

The r.m.s voltages are different, so no

....

.... [1]

(c) **(i)** The power supply in **(a)** is connected to a transformer. The input power to the transformer is 80 W.

The secondary coil is connected to a resistor. The r.m.s. voltage across the resistor is 120 V. The r.m.s. current in the secondary coil is 0.64 A.

Calculate the efficiency of the transformer.

$P = IV = 120 \times 0.64$
$= 76.8$

$\frac{76.8}{80} \times 100 = 96\%$

efficiency = ...96%.. [3]

(ii) State **one** reason why the transformer is not 100% efficient.

heat losses due to eddy currents.

.... [1]

[Total: 8]

1
2

10 **(a)** By reference to the photoelectric effect, explain what is meant by *work function energy*.

It is the minimum energy required for a photon that is hitting a metal, for ~~photoelectric emission to occur~~: it to remove from surface [2] 1

(b) In an experiment, electromagnetic radiation of frequency f is incident on a metal surface.

The results in Fig. 10.1 show the variation with frequency f of the maximum kinetic energy E_{MAX} of electrons emitted from the surface.

$E = hf - hf_0$

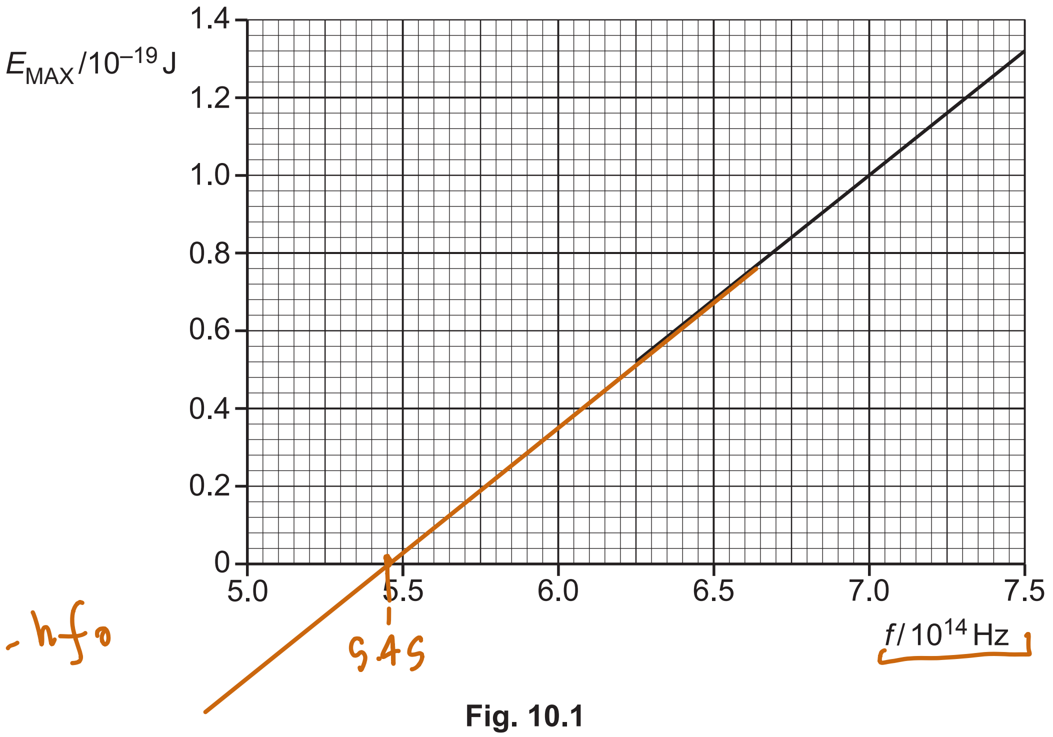


Fig. 10.1

(i) Determine the work function energy in J of the metal used in the experiment.

1

$5.45 \times 10^{14} h = hf_0$

$= 3.61 \times 10^{-19}$

work function energy = 3.6×10^{-19} J [2]

(ii) The work function energy in eV for some metals is given in Table 10.1.

Table 10.1

metal	work function / eV
tungsten	4.49
magnesium	3.68
potassium	2.26

Determine the metal used in the experiment. Show your working.

$$\frac{3.61 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.257 \approx 2.26$$

Potassium

[1]

(c) The intensity of the electromagnetic radiation for one particular frequency in **(b)** is increased.

State and explain the change, if any, in:

(i) the maximum kinetic energy of the emitted electrons

vs

no change, each photon has same energy

[1]

(ii) the rate of emission of photoelectrons.

increases as more electrons would be emmited per unit time because of greater photons

[1]

[Total: 7]

6
7

100kV

11 Electrons are accelerated through a potential difference of 100 kV. They are then incident on a metal target, they decelerate, and X-ray photons are emitted.

(a) Calculate the maximum possible frequency of the emitted X-ray photons.

$E = hf$

$f = \frac{E}{h} = \frac{1.6\times10^{-19}\times 100000}{h} = 2.4147\times10^{19}$

frequency = ...2.4 × 10^19.... Hz [2]

(b) Explain why an aluminium filter may be placed in the X-ray beam when producing an X-ray image of a patient.

?

....

....

....

....

....

.... [3]

(c) The linear attenuation (absorption) coefficients μ for X-rays in bone, blood and muscle are given in Table 11.1.

Table 11.1

	μ / cm^{-1}
bone	3.0
blood	0.23
muscle	0.22

(i) A beam of these X-rays is incident on a person.

Calculate the percentage of the intensity of the X-ray beam that has been absorbed after passing through 0.80 cm of blood.

$I = I_0 e^{-\mu x}$

$\frac{I}{I_0} = e^{-0.23\times0.8}$

$= 0.8319$

$1 - 0.8319 = 0.16806$

$= 17\%$

percentage of intensity absorbed = ...17%.... % [2]

(ii) In an X-ray image, white regions show greater absorption of X-rays than dark regions.

State and explain the difference between the X-ray image of bone compared to that of muscle.

As μ of bone is high it absorbs more, and thus bone is seen lighter. 0

.... ~~[2]~~ 0

[Total: 9]

6/9

12 **(a)** Explain what is meant by the *binding energy* of a nucleus.

It is the energy required to separate the nucleons to the infinity

[2]

(b) The following nuclear reaction takes place:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{144}_{55}Cs + ^{90}_{x}Rb + y^{1}_{0}n$$

236 235 92

(i) Determine the values of *x* and *y*.

$x =$ 37

$y =$ 2

[1]

(ii) State the name of this type of nuclear reaction.

fission

[1]

(iii) Compare the binding energy per nucleon of uranium-235 with the binding energy per nucleon of caesium-144.

caesium is higher

[1]

* **(c)** Yttrium-90 decays into zirconium-90, a stable isotope.

A sample initially consists of pure yttrium-90.

Calculate the time, in days, when the ratio of the number of yttrium-90 nuclei to the number of zirconium-90 nuclei would be 2.0.

The half-life of yttrium-90 is 2.7 days.

$\lambda = \frac{\ln 2}{T_{\frac{1}{2}}}$

$\lambda = \frac{\ln 2}{2.7} = 0.257$

$n = n_0 e^{-0.257t}$

$\frac{1}{e^{-0.257t}} = 2$

$2e^{-0.257t} = 1$

$e^{-0.257t} = 0.5$

$t = \frac{\ln 0.5}{0.257}$

2.697

time = 2.7 days [3]

1

[Total: 8]

6/8

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