



Oxford Cambridge and RSA

Friday 24 May 2019 – Morning

A Level Physics A

H556/02 Exploring physics

Time allowed: 2 hours 15 minutes



You must have:

- the Data, Formulae and Relationships Booklet (sent with general stationery)

You may use:

- a scientific or graphical calculator
- a ruler (cm/mm)



Please write clearly in black ink. **Do not write in the barcodes.**

Centre number

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Candidate number

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First name(s)

Last name

StemUp Model Solution

INSTRUCTIONS

- Use black ink. You may use an HB pencil for graphs and diagrams.
- Answer **all** the questions.
- Where appropriate, your answers should be supported with working. Marks may be given for a correct method even if the answer is incorrect.
- Write your answer to each question in the space provided. If additional space is required, use the lined page(s) at the end of this booklet. The question number(s) must be clearly shown.

INFORMATION

- The total mark for this paper is **100**.
- The marks for each question are shown in brackets [].
- Quality of extended responses will be assessed in questions marked with an asterisk (*).
- This document consists of **32** pages.

2
SECTION A

You should spend a maximum of 30 minutes on this section.

Write your answer to each question in the box provided.

Answer **all** the questions.

1 Which law indicates that charge is conserved?

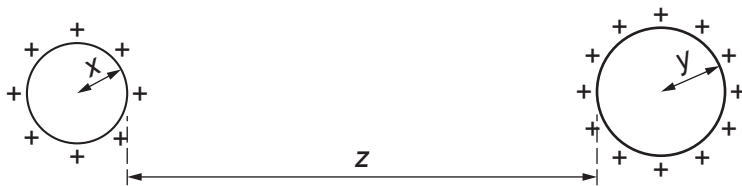
- A** Lenz's law
- B** Coulomb's law
- C** Kirchhoff's first law
- D** Faraday's law of electromagnetic induction

Your answer

C

[1]

2 The diagram below shows two uniformly charged spheres separated by a large distance z .



The radius of the small sphere is x and the radius of the large sphere is y .

Which is the correct distance to use when determining the electric force between the charged spheres?

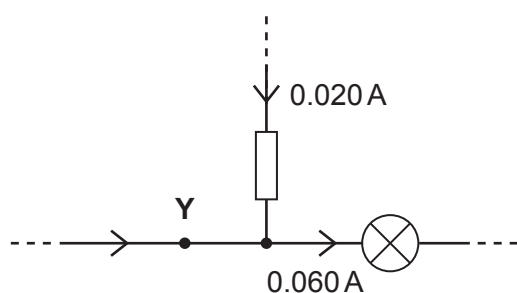
- A** z
- B** $x + z$
- C** $y + z$
- D** $x + y + z$

Your answer

D

[1]

3 Part of an electric circuit is shown below.



The direction of all the currents and the magnitude of two currents are shown.

How many electrons pass through the point **Y** in 10 s?

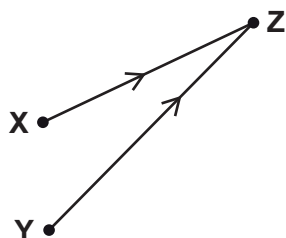
- A 1.25×10^{18}
- B 2.50×10^{18}
- C 3.75×10^{18}
- D 5.00×10^{18}

Your answer

B

[1]

4 Coherent radio waves from transmitters **X** and **Y** are emitted in phase. The waves interfere **constructively** at point **Z**.



The distance **XZ** is 16.0 m and the distance **YZ** is 20.0 m.
The radio waves have wavelength λ .

Which value of λ is **not** possible?

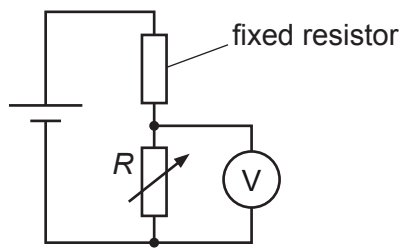
- A 1.0 m
- B 2.0 m
- C 3.0 m
- D 4.0 m

Your answer

C

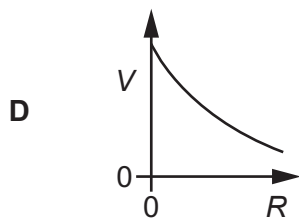
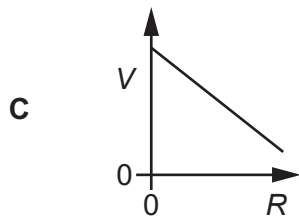
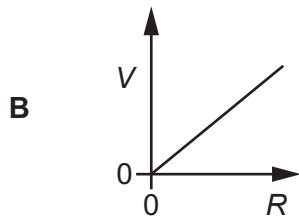
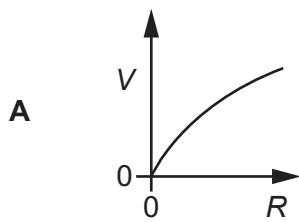
[1]

- 5 A potential divider circuit is shown below.



The resistance of the variable resistor is R . The potential difference across the variable resistor is V .

Which graph shows the correct variation with R of V ?



Your answer

A

[1]

- 6 Wires **P** and **Q**, made from the same metal, are connected in **parallel** across a cell of negligible internal resistance.

The table shows some data.

Wire	Length of wire	Diameter of wire	Mean drift velocity of electrons in the wire / mm s^{-1}
P	L	d	0.60
Q	$3L$	$2d$	v

What is the mean drift velocity v of the electrons in wire **Q**?

- A** 0.15 mm s^{-1}
- B** 0.20 mm s^{-1}
- C** 0.30 mm s^{-1}
- D** 0.60 mm s^{-1}

Your answer

B

[1]

- 7 Which of the following statements is/are correct about electromagnetic waves?

- 1 They can be plane polarised.
- 2 They can be refracted and diffracted.
- 3 They have the same speed in a vacuum and in glass.

- A** Only 1
- B** Only 3
- C** Only 1 and 2
- D** 1, 2 and 3

Your answer

C

[1]

- 8 The electric field strength at a distance of $2.0 \times 10^{-8} \text{ m}$ from a nucleus is $3.3 \times 10^8 \text{ NC}^{-1}$.

What is the charge on the nucleus?

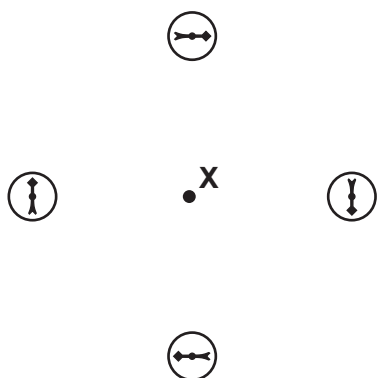
- A $1.6 \times 10^{-19} \text{ C}$
- B $1.5 \times 10^{-17} \text{ C}$
- C $7.3 \times 10^{-10} \text{ C}$
- D $3.8 \times 10^{-9} \text{ C}$

Your answer

B

[1]

- 9 The diagram shows four magnetic compasses placed at the same distance from point X.



Which of the following is most likely to be at point X?

- A permanent magnet
- B current-carrying solenoid
- C current-carrying flat coil
- D straight current-carrying wire

Your answer

D

[1]

- 10** A coil with 500 turns is placed in a uniform magnetic field.
The average cross-sectional area of the coil is $3.0 \times 10^{-4} \text{ m}^2$.
The magnetic flux through the plane of the coil is reduced from $1.8 \times 10^{-4} \text{ Wb}$ to zero in a time t .
The average electromotive force (e.m.f.) induced across the ends of the coil is 0.75 V.

What is the value of t ?

- A** $3.6 \times 10^{-5} \text{ s}$
B $2.4 \times 10^{-4} \text{ s}$
C 0.12 s
D 8.3 s

Your answer

C

[1]

- 11** The radius of a gold nucleus with 197 nucleons is $7.3 \times 10^{-15} \text{ m}$.

What is the best estimate for the volume of a uranium nucleus with 235 nucleons?

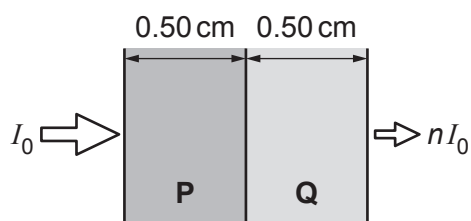
- A** $1.6 \times 10^{-42} \text{ m}^3$
B $1.9 \times 10^{-42} \text{ m}^3$
C $2.1 \times 10^{-42} \text{ m}^3$
D $2.8 \times 10^{-42} \text{ m}^3$

Your answer

B

[1]

- 12 The intensity of a beam of X-rays incident on material **P** is I_0 .
The beam passes through 0.50 cm of material **P** and 0.50 cm of material **Q**.



The absorption (attenuation) coefficients of **P** and **Q** are 0.60 cm^{-1} and 0.20 cm^{-1} respectively.
The intensity of the beam after passing through both **P** and **Q** is nI_0 .

What is the value of n ?

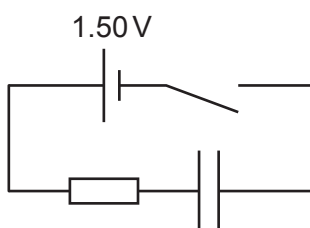
- A 0.67
- B 0.74
- C 0.82
- D 0.90

Your answer

A

[1]

- 13 A capacitor is charged through a resistor.



The cell has electromotive force (e.m.f.) 1.50 V and negligible internal resistance.
The time constant of the circuit is 10 s. The switch is closed at time $t = 0$. At time t , the potential difference across the resistor is 0.60 V.

Which expression is correct?

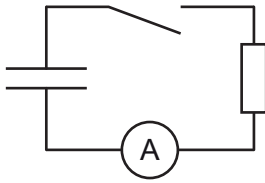
- A $0.60 = 1.50e^{-0.10t}$
- B $0.90 = 1.50e^{-0.10t}$
- C $0.60 = 1.50e^{-10t}$
- D $0.60 = 1.50(1 - e^{-10t})$

Your answer

A

[1]

- 14 A capacitor is discharged through a resistor.



The capacitor is fully charged at time $t = 0$. The time constant of the circuit is 10 s. The switch is closed at time $t = 0$. The current in the resistor is I .

Which row is correct?

	Current I at $t = 0$	Current I at $t = 10$ s
A	maximum	0
B	maximum	37% of the current at $t = 0$
C	0	63% of the current at $t = \infty$
D	0	37% of the current at $t = \infty$

Your answer

B

[1]

- 15 The number of turns on the coils of four ideal iron-cored transformers **A**, **B**, **C** and **D** are shown in the table below.

Transformer	Number of turns on the secondary coil	Number of turns on the primary coil
A	100	100
B	50	200
C	200	50
D	500	100

Each transformer is connected in turn to an alternating 240 V supply.

Which transformer will give the largest output current?

Your answer

B

[1]

SECTION B

Answer **all** the questions.

16 This question is about waves.

- (a) The **period** of a progressive wave can be determined from Fig. 16.1. Add a correct label to the horizontal axis so that the period can be found. [1]

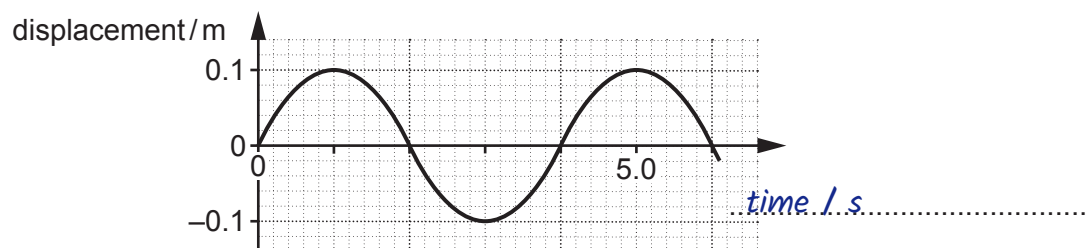


Fig. 16.1

- (b) A progressive wave has wavelength λ , frequency f and period T .

Show that the speed v of the wave is given by the equation $v = f\lambda$.

In one period T the wave travels a distance of one wavelength λ .

speed = distance / time, so $v = \lambda / T$

The frequency is $f = 1 / T$ (number of waves per second)

so $v = \lambda \times (1 / T) = f\lambda$

[2]

- (c) A scientist is investigating the interference of light using very thin transparent material. A sample of the transparent material is placed in a vacuum. Fig. 16.2 shows the path of two identical rays of light **L** and **M** from a laser.

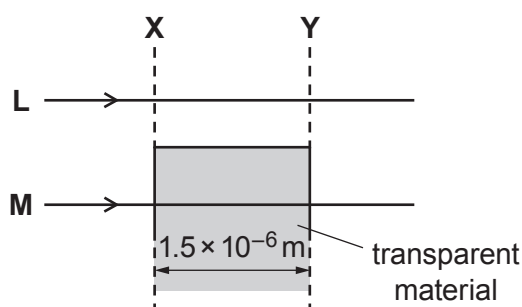


Fig. 16.2

The refractive index of the material is 1.20. The thickness of the material is 1.5×10^{-6} m. The wavelength of the light in vacuum is 6.0×10^{-7} m.

- (i) Show that the difference in time t for the two rays to travel between the dashed lines **X** and **Y** is 1.0×10^{-15} s.

$$\text{speed in material} = c / n = 3.0 \times 10^8 / 1.20 = 2.5 \times 10^8 \text{ m s}^{-1}$$

$$\text{time for L (vacuum)}: 1.5 \times 10^{-6} / 3.0 \times 10^8 = 5.0 \times 10^{-15} \text{ s}$$

$$\text{time for M (material)}: 1.5 \times 10^{-6} / 2.5 \times 10^8 = 6.0 \times 10^{-15} \text{ s}$$

$$t = 6.0 \times 10^{-15} - 5.0 \times 10^{-15} = 1.0 \times 10^{-15} \text{ s}$$

$$t = \underline{1.0 \times 10^{-15}} \dots \text{ s [3]}$$

- (ii) Calculate the period T of the light wave.

$$f = c / \lambda = 3.0 \times 10^8 / 6.0 \times 10^{-7} = 5.0 \times 10^{14} \text{ Hz}$$

$$T = 1 / f = 1 / 5.0 \times 10^{14} = 2.0 \times 10^{-15} \text{ s}$$

$$T = \underline{2.0 \times 10^{-15}} \dots \text{ s [2]}$$

- (iii) The rays of light are in phase at the dashed line **X**.

Use your two answers above to state the phase difference ϕ in degrees between the light rays at **Y**.

$$\phi = (t / T) \times 360^\circ = (1.0 \times 10^{-15} / 2.0 \times 10^{-15}) \times 360^\circ$$

$$\phi = \underline{180} \dots^\circ \text{ [1]}$$

Question 16 continues on page 12

- (d)* The speed v of surface water waves in shallow water of depth d is given by the equation $v = \sqrt{gd}$, where g is the acceleration of free fall.

The speed v is about 1 m s^{-1} for a depth of about 10 cm.

You are provided with a rectangular plastic tray, supply of water and other equipment available in the laboratory.

Describe how an experiment can be conducted in the laboratory to test the validity of the equation above and how the data can be analysed to determine a value for g . [6]

Fill the tray with water on a level bench to a depth d and measure d with a ruler at several points, taking the mean (start at about 1 cm).

Make a single wave pulse by lifting one end of the tray slightly and releasing it (or by dropping a small ball into the water at one end).

Measure the length x of the tray (the distance the pulse travels) with a metre rule. Time how long, t , the pulse takes to travel along the tray with a stopwatch, or film it with a phone/video camera and a timer in view and step through the frames. Timing several lengths (reflections) reduces the percentage uncertainty in t .

Calculate the speed using $v = x / t$. Repeat three times for each depth and find the average v .

Add water to change d (e.g. 1, 2, 3, 4, 5 and 6 cm) and determine v for each depth, making the pulse in the same way each time.

Analysis: $v = \sqrt{gd}$, so $v^2 = gd$. Record d , v and v^2 in a table and plot a graph of v^2 against d .

Additional answer space if required.

If the equation is valid the graph is a straight line through the origin, and $g = \text{gradient}$. (Or plot v against $\sqrt{d}$, gradient $= \sqrt{g}$ so $g = \text{gradient}^2$; or $\lg v$ against $\lg d$ should give a gradient of 0.5.)

Compare the value of g from the gradient with 9.81 m s^{-2} ; a straight line through the origin and close agreement confirm the equation.

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- 17 (a) Fig. 17.1 shows the variation with distance of the displacement of a **stationary** wave at time $t = 0$.

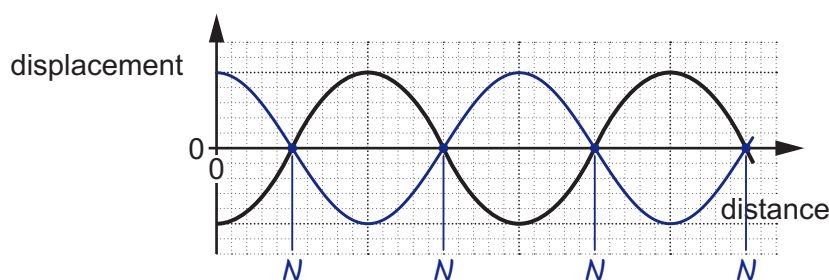


Fig. 17.1

The period of the wave is T .

- (i) On Fig. 17.1, sketch a graph to show the variation of the displacement at time $t = \frac{T}{2}$. [1]
- (ii) On Fig. 17.1, show the positions of **all** the nodes. Label each node **N**. [1]
- (b) Stationary sound waves are formed in a tube closed at one end.
Fig. 17.2 shows three stationary wave patterns formed in the air column of the tube.

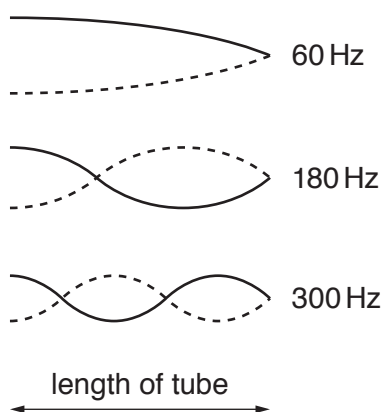


Fig. 17.2

The frequency f of the oscillations for each stationary wave is shown in Fig. 17.2.

Use Fig. 17.2 to explain how the frequency f of the sound wave depends on the wavelength λ .

Closed end is a node, open end an antinode: $L = \lambda/4$ at 60 Hz, $L = 3\lambda/4$ at 180 Hz and $L = 5\lambda/4$ at 300 Hz.

So $\lambda = 4L$, $4L/3$ and $4L/5$: from 60 Hz to 180 Hz f increases by a factor of 3 and λ decreases by a factor of 3; from 60 to 300 Hz both change by a factor of 5.

$f\lambda = 60 \times 4L = 180 \times 4L/3 = 300 \times 4L/5 = 240L = \text{constant}$, so $f \propto 1/\lambda$ (speed $v = f\lambda$ is constant). [3]

- 18 (a) State Kirchhoff's second law **and** the physical quantity that is conserved according to this law.

In any closed loop of a circuit, the sum of the e.m.f.s is equal to the sum of the p.d.s.

Energy is conserved.

[2]

- (b) The S.I. base units for the ohm (Ω) are $\text{kg m}^2 \text{s}^{-3} \text{A}^{-2}$.

Use the equation $R = \frac{\rho L}{A}$ to determine the S.I. base units for resistivity ρ .

$$\rho = RA / L, \text{ so the unit of } \rho \text{ is } \Omega \times \text{m}^2 / \text{m} = \Omega \text{ m}$$

$$\text{base units of } \rho = (\text{kg m}^2 \text{s}^{-3} \text{A}^{-2}) \times \text{m}$$

base units for ρ *$\text{kg m}^3 \text{s}^{-3} \text{A}^{-2}$* [2]

Question 18 continues on page 16

- (c) Fig. 18.1 shows a circuit used by a student to determine the resistivity of the material of a wire.

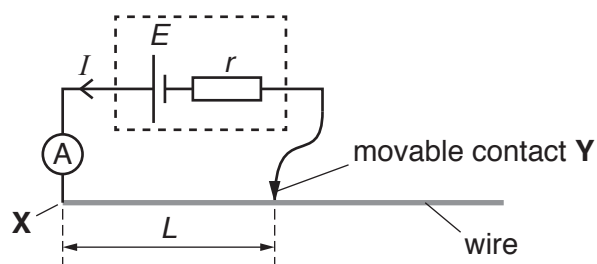


Fig. 18.1

The wire is uniform and has diameter 0.38 mm. The cell has electromotive force (e.m.f.) E and internal resistance r . The length of the wire between **X** and **Y** is L .

The student varies the length L and measures the current I in the circuit for each length.

Fig. 18.2 shows the data points plotted by the student.

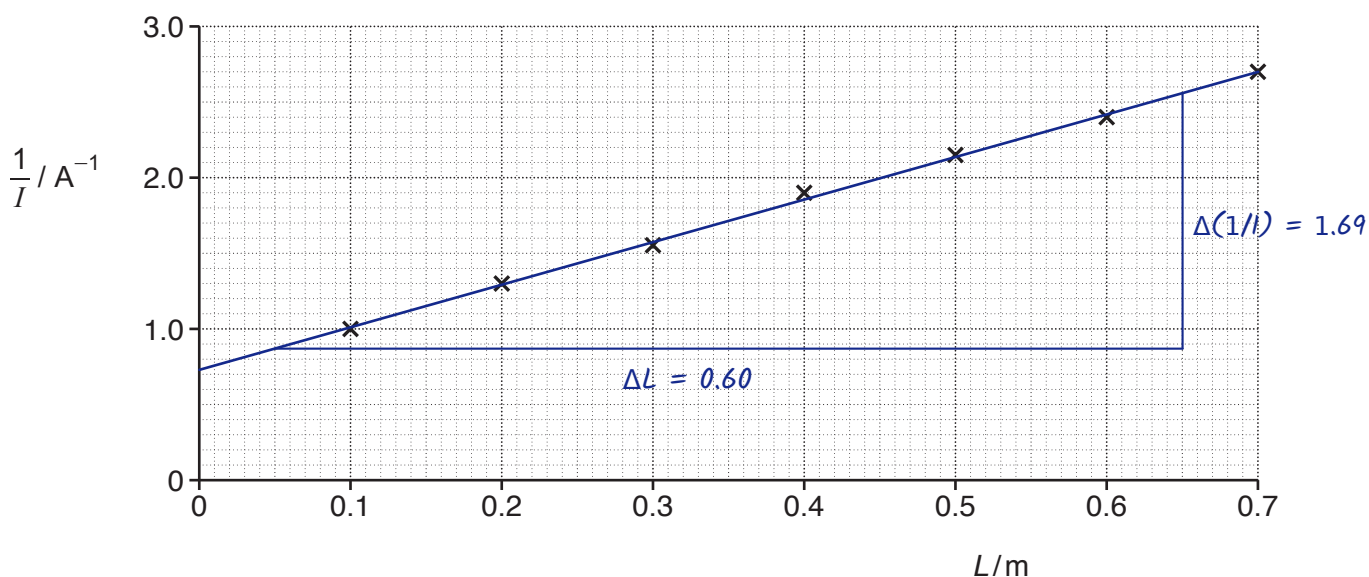


Fig. 18.2

- (i) On Fig. 18.2 draw the straight line of best fit. Determine the gradient of this line.

$$\begin{aligned} \text{gradient} &= (2.56 - 0.87) / (0.65 - 0.05) \\ &= 1.69 / 0.60 = 2.8 \end{aligned}$$

gradient = 2.8..... $A^{-1}m^{-1}$ [2]

- (ii) Show that the gradient of the line is $\frac{\rho}{AE}$, where ρ is the resistivity of the material of the wire, A is the area of cross-section of the wire and E is the e.m.f. of the cell.

$$E = I(R + r) \text{ and } R = \rho L / A$$

$$\text{so } 1/I = (R + r)/E = (\rho / AE) L + r / E$$

Compare with $y = mx + c$: a graph of $1/I$ against L is a straight line with gradient $= \rho / AE$

[2]

- (iii) The e.m.f. E of the cell is 1.5V. The diameter of the wire is 0.38 mm.

Use your answer to (i) and the equation given in (ii) to determine ρ .

$$\rho = \text{gradient} \times A \times E, A = \pi r^2 = \pi \times (0.19 \times 10^{-3})^2 = 1.13 \times 10^{-7} \text{ m}^2$$

$$\rho = 2.8 \times 1.13 \times 10^{-7} \times 1.5$$

$$\rho = 4.8 \times 10^{-7} \Omega \text{ m}$$

$$\rho = 4.8 \times 10^{-7} \dots \dots \dots \Omega \text{ m} \quad [2]$$

- (iv) Fig. 18.3 illustrates how the student had incorrectly measured all the lengths L of the wire.

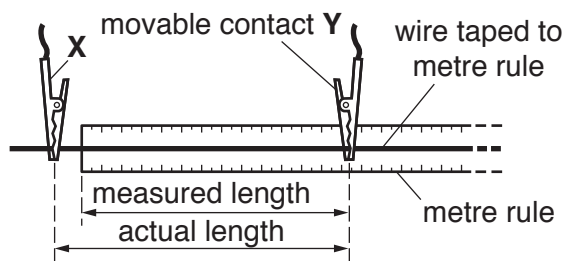


Fig. 18.3

According to the student, re-plotting the data points using the **actual** lengths of the wire will not affect the value of the resistivity obtained in (iii).

Explain why the student is correct.

Every length is wrong by the same amount (a systematic/zero error), so
all the points just shift horizontally by the same distance.
The gradient of the line is unchanged, so ρ ($= \text{gradient} \times AE$) is the
same. [2]

19 Fig. 19.1 shows an electric circuit.

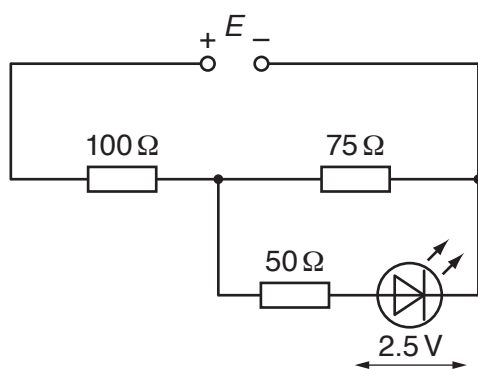


Fig. 19.1

The power supply has electromotive force (e.m.f.) E and negligible internal resistance.

The resistance values of the resistors are shown in Fig. 19.1. The I – V characteristic of the light-emitting diode (LED) is shown in Fig. 19.2.

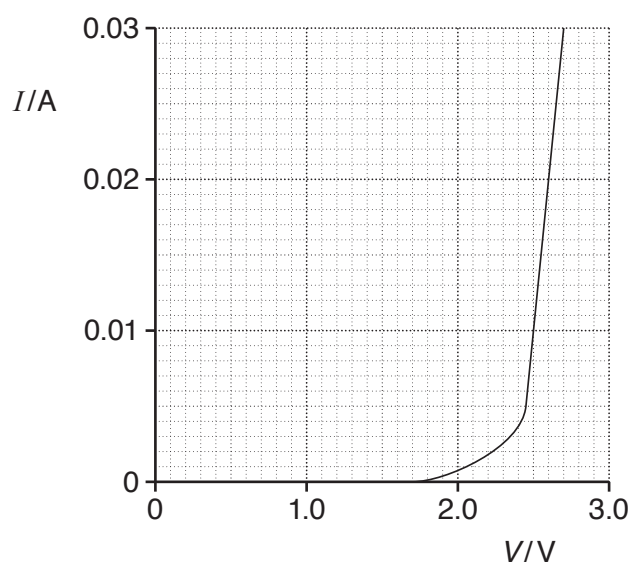


Fig. 19.2

The potential difference (p.d.) across the LED is 2.5 V.

(a) Use Fig. 19.2 to show that the p.d. across the $50\ \Omega$ resistor is 0.50 V.

From Fig. 19.2, at 2.5 V the current in the LED is 0.010 A.

The $50\ \Omega$ resistor is in series with the LED, so it has the same current:

$$p.d. = IR = 0.010 \times 50 = 0.50\text{ V}$$

- (b) Calculate the e.m.f. E of the power supply.

$$p.d. \text{ across } 75 \, \Omega = 0.50 + 2.5 = 3.0 \, \text{V (in parallel with the LED branch)}$$

$$\text{current in } 75 \, \Omega = 3.0 / 75 = 0.040 \, \text{A}$$

$$\text{current in } 100 \, \Omega = 0.040 + 0.010 = 0.050 \, \text{A, } p.d. = 0.050 \times 100 = 5.0 \, \text{V}$$

$$E = 5.0 + 3.0 = 8.0 \, \text{V}$$

$$E = \underline{8.0} \dots\dots\dots \text{V [3]}$$

- (c) The LED emits blue light of wavelength $4.7 \times 10^{-7} \text{m}$.

- (i) Estimate the number of blue light photons emitted from the LED per second.

$$\text{power of LED} = VI = 2.5 \times 0.010 = 0.025 \, \text{W}$$

$$\text{photon energy} = hc / \lambda = (6.63 \times 10^{-34} \times 3.00 \times 10^8) / 4.7 \times 10^{-7}$$

$$= 4.23 \times 10^{-19} \, \text{J}$$

$$\text{number per second} = 0.025 / 4.23 \times 10^{-19} = 5.9 \times 10^{16}$$

$$\text{number of photons per second} = \underline{5.9 \times 10^{16}} \dots\dots\dots \text{s}^{-1} \text{ [3]}$$

- (ii) The light from the LED is incident on a metal of work function 2.3 eV.

Explain, with the help of a calculation, whether or not photoelectrons will be emitted from the surface of the metal.

$$\text{photon energy} = 4.23 \times 10^{-19} / 1.60 \times 10^{-19} = 2.64 \, \text{eV}$$

$$(\text{work function} = 2.3 \times 1.60 \times 10^{-19} = 3.68 \times 10^{-19} \, \text{J})$$

The photon energy (2.64 eV) is greater than the work function (2.3 eV),

$hf > \phi$, so photoelectrons will be emitted (maximum KE = 0.34 eV).

..... [2]

20 Fig. 20 illustrates a device used to determine the relative abundance of charged rubidium ions.

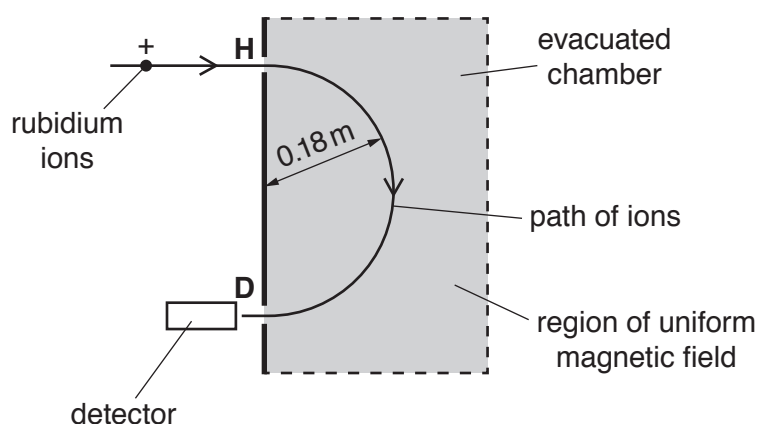


Fig. 20

A uniform magnetic field is applied to an evacuated chamber. The direction of the magnetic field is perpendicular to the plane of the paper.

A beam of positive rubidium ions enters the chamber through a hole at **H**. The ions travel in a semi-circular path in the magnetic field. The ions are detected at point **D**.

- (a) Each rubidium ion has charge $+1.6 \times 10^{-19} \text{ C}$ and speed $4.8 \times 10^4 \text{ ms}^{-1}$.
The radius of the semi-circular path of the ions is 0.18 m.
The mass of a rubidium ion is $1.4 \times 10^{-25} \text{ kg}$.

Calculate the magnitude of the magnetic flux density B of the magnetic field.

The magnetic force provides the centripetal force: $BQv = mv^2 / r$

$$\text{so } B = mv / Qr = (1.4 \times 10^{-25} \times 4.8 \times 10^4) / (1.6 \times 10^{-19} \times 0.18)$$

$$B = 0.233 \text{ T}$$

$$B = \underline{0.23} \dots \text{ T [3]}$$

- (b) The chemical composition of ancient rocks found on the Earth can be used to estimate the age of the Earth.

Nuclei of rubidium-87 ($^{87}_{37}\text{Rb}$) decay spontaneously into nuclei of strontium-87 ($^{87}_{38}\text{Sr}$).
The half-life of rubidium-87 is 49 billion years.

- (i) Name the two leptons emitted in the decay of a rubidium-87 nucleus.

1. *electron (beta-minus particle)*
2. *(electron) antineutrino*

[1]

- (ii) The percentage of rubidium **left** in a sample of an ancient rock is 95%.

Estimate the age of the Earth in billion years.

$$\text{decay constant } \lambda = \ln 2 / t_{1/2} = 0.693 / 49 = 0.0141 \text{ per billion years}$$

$$N / N_0 = e^{-\lambda t}; 0.95 = e^{-0.0141t}$$

$$t = -\ln(0.95) / 0.0141 = 0.0513 / 0.0141$$

$$t = 3.6 \text{ billion years}$$

age = *3.6* billion years [3]

- 21 (a) Fig. 21 shows stable and unstable nuclei of some light elements plotted on a grid. This grid has number of neutrons N on the vertical axis and number of protons Z on the horizontal axis.

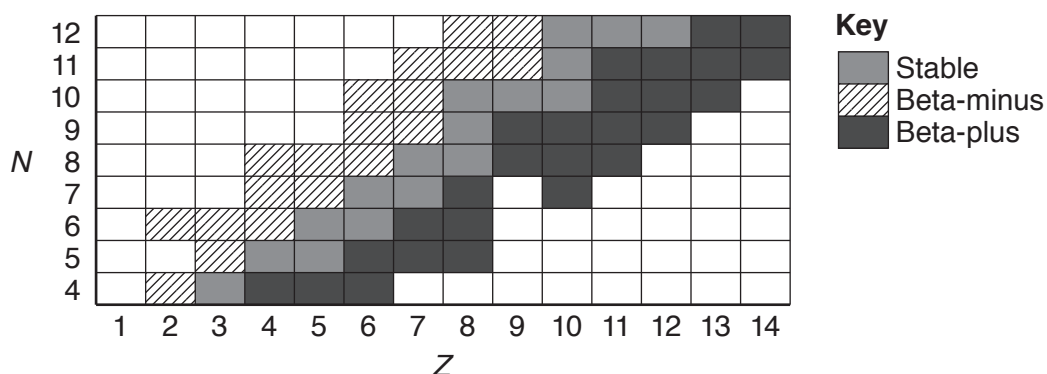


Fig. 21

The key on Fig. 21 shows whether a nucleus is stable, emits a beta-plus particle or emits a beta-minus particle to become stable.

For $Z = 7$, suggest in terms of N why an isotope may emit

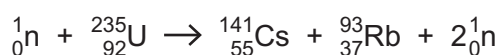
- (i) a beta-minus particle

It has too many neutrons for stability (neutron-rich), so a neutron changes into a proton (Z becomes 8). [1]

- (ii) a beta-plus particle.

It has too few neutrons for stability (proton-rich), so a proton changes into a neutron (Z becomes 6). [1]

- (b) Inside a nuclear reactor, fission reactions are controlled and **chain reactions** are prevented. A typical fission reaction of the uranium-235 nucleus ($^{235}_{92}\text{U}$) is illustrated below.



The neutron triggering the fission reaction moves slowly. The neutrons produced in the fission reaction move fast.

- (i) Describe what is meant by **chain reaction**.

Each fission reaction produces more neutrons (here 2) than the one neutron that caused it. These neutrons go on to cause further fission reactions (splitting more uranium-235 nuclei), so the reactions continue and multiply. [2]

- (ii) Explain how chain reactions are prevented inside a nuclear reactor.

Control rods (e.g. boron or cadmium) are inserted into the reactor.

They absorb neutrons (without fission), so on average only one neutron

from each fission causes another fission. [2]

- (iii) The energy released in each fission reaction is equivalent to a decrease in mass of 0.19 u.

A fuel rod in a nuclear reactor contains 3.0% of uranium-235 by mass.

Estimate the total energy produced from 1.0 kg of fuel rod.

molar mass of uranium-235 = 0.235 kg mol⁻¹

1 u = 1.66 × 10⁻²⁷ kg

$$\Delta m = 0.19 \times 1.66 \times 10^{-27} = 3.15 \times 10^{-28} \text{ kg}$$

$$\text{energy per fission} = \Delta mc^2 = 3.15 \times 10^{-28} \times (3.0 \times 10^8)^2 = 2.84 \times 10^{-11} \text{ J}$$

$$\text{mass of uranium-235} = 0.030 \times 1.0 = 0.030 \text{ kg}$$

$$\text{number of U-235 nuclei} = (0.030 / 0.235) \times 6.02 \times 10^{23} = 7.69 \times 10^{22}$$

$$\text{energy} = 7.69 \times 10^{22} \times 2.84 \times 10^{-11} = 2.2 \times 10^{12} \text{ J}$$

$$\text{energy} = 2.2 \times 10^{12} \text{ J [4]}$$

- 22 (a) Fig. 22.1 shows two horizontal metal plates in a vacuum.

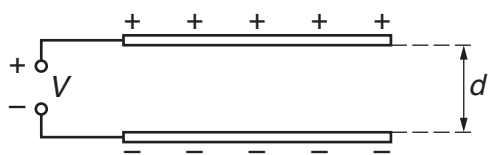


Fig. 22.1

The plates are connected to a power supply. The potential difference V between the plates is constant. The magnitude of the charge on each plate is Q . The separation between the plates is d .

Fig. 22.2 shows the variation with d of the charge Q on the positive plate.

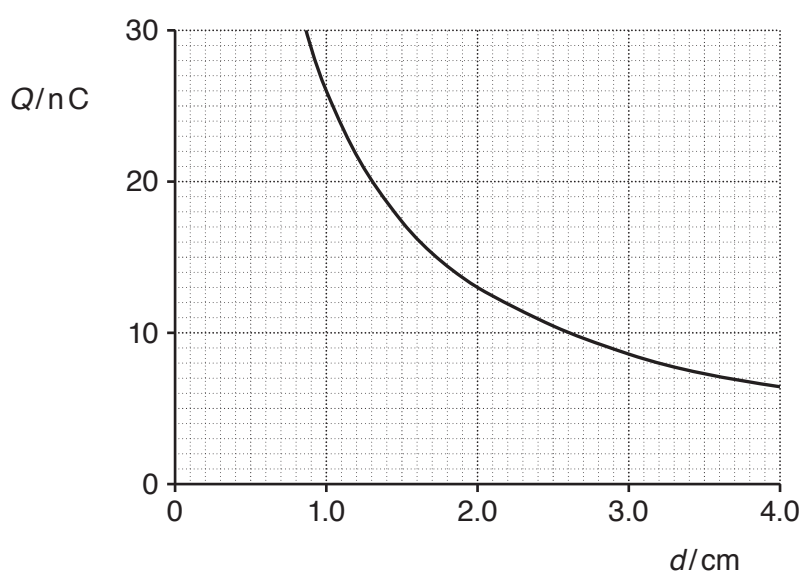


Fig. 22.2

- (i) Use Fig. 22.2 to propose and carry out a test to show that Q is inversely proportional to d .

Test proposed:

Check whether $Q \times d$ is constant for several pairs of values read from the graph.

Working:

$$d = 1.0 \text{ cm}, Q = 26 \text{ nC}: Qd = 26 \times 1.0 = 26 \text{ nC cm}$$

$$d = 2.0 \text{ cm}, Q = 13 \text{ nC}: Qd = 13 \times 2.0 = 26 \text{ nC cm}$$

$$d = 4.0 \text{ cm}, Q = 6.5 \text{ nC}: Qd = 6.5 \times 4.0 = 26 \text{ nC cm}$$

Qd is constant (d doubles, Q halves), so $Q \propto 1/d$

- (ii) Use capacitor equations to show that Q is inversely proportional to d .

$$Q = CV \text{ and } C = \epsilon_0 A / d$$

$$\text{so } Q = \epsilon_0 AV / d; \epsilon_0, A \text{ and } V \text{ are constant, so } Q \propto 1/d$$

[2]

- (b) Fig. 22.3 shows a negatively charged oil drop between two oppositely charged horizontal plates in a vacuum.

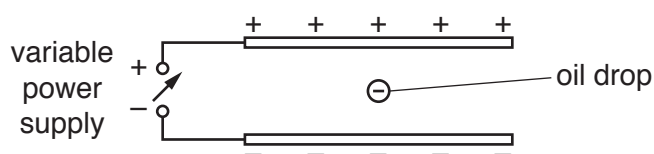


Fig. 22.3

The plates are fixed and connected to a variable power supply. The weight of the oil drop is $1.8 \times 10^{-14} \text{ N}$.

- (i) The power supply is adjusted so that the potential difference between the plates is 200 V when the oil drop becomes **stationary**.

State the magnitude of the vertical electric force F_E acting on the charged oil drop.

$$F_E = \underline{1.8 \times 10^{-14}} \dots \text{ N [1]}$$

- (ii) The potential difference between the plates is now increased to 600 V. The oil drop accelerates upwards.

Calculate the acceleration a of the oil drop.

$$F_E = qV/d \propto V, \text{ so at } 600 \text{ V: } F_E = 3 \times 1.8 \times 10^{-14} = 5.4 \times 10^{-14} \text{ N}$$

$$\text{resultant force} = 5.4 \times 10^{-14} - 1.8 \times 10^{-14} = 3.6 \times 10^{-14} \text{ N}$$

$$\text{mass} = W / g = 1.8 \times 10^{-14} / 9.81 = 1.83 \times 10^{-15} \text{ kg}$$

$$a = F / m = 3.6 \times 10^{-14} / 1.83 \times 10^{-15} = 19.6 \text{ m s}^{-2}$$

$$a = \underline{19.6} \dots \text{ ms}^{-2} \text{ [3]}$$

Question 22 continues on page 26

- (c)* Fig. 22.4 shows an arrangement used by a student to investigate the forces experienced by a small length of charged gold foil placed in a uniform electric field.

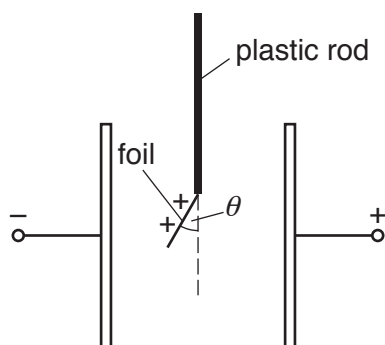


Fig. 22.4

The two vertical metal plates are connected to a high-voltage supply.

The foil is given a positive charge by briefly touching it to the positive plate.

The angle θ made with the vertical by the foil in the electric field is given by the expression

$$\tan \theta = \frac{qE}{W}$$

where q is the charge on the foil, E is the electric field strength between the plates and W is the weight of the foil.

The angle θ can be determined by taking photographs with the camera of a mobile phone.

Describe how the student can safely conduct an experiment to investigate the relationship between θ and E .

Identify any variables that must be controlled.

[6]

Connect the plates to the high-voltage supply, measure the p.d. V with a voltmeter (or the supply's meter) and the plate separation d with a ruler; then $E = V / d$.

Safety: use a supply with a current-limiting resistor, switch off before adjusting anything and do not touch the plates or terminals while the supply is on.

Hold the plastic rod in a clamp stand so the foil hangs midway between the plates, where the field is uniform. Charge the foil by briefly touching it to the positive plate.

Fix the phone on a stand in front of the foil, square on to it and in the same position each time, with a plumb line in view. Photograph the foil and

measure θ from the photo with a protractor (or software).

Vary E by changing V (keeping d constant), for about six values. For each E record θ and repeat to find a mean θ .

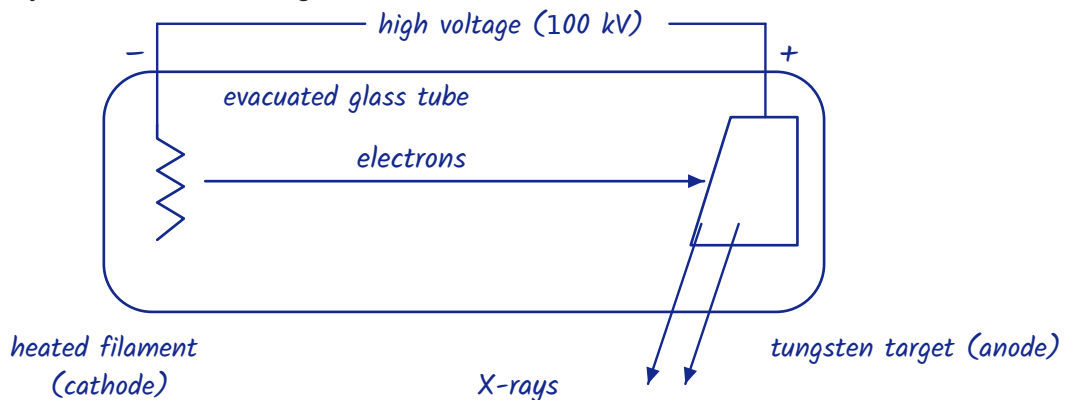
Control variables: keep the charge q on the foil constant (recharge it each

Additional answer space if required.

time from a separate supply at a fixed voltage and work quickly so the charge does not leak away); use the same foil so W is constant; keep d the same; work in a draught-free room.

Analysis: $\tan\theta = (q / W)E$, so plot a graph of $\tan\theta$ against E . A straight line through the origin shows $\tan\theta \propto E$, and the gradient = q / W .

- 23 (a) Describe the basic structure of an X-ray tube and explain how X-ray photons are produced. You may draw a labelled diagram.



An evacuated glass tube contains a heated filament (cathode) and a metal target such as tungsten (anode).

A high voltage (about 100 kV) between cathode and anode accelerates the electrons emitted by thermionic emission.

The electrons hit the target and decelerate rapidly; some of their kinetic energy is transformed into X-ray photons (most becomes heat).

[3]

- (b) A beam of X-rays is directed at tissues in a patient. The X-ray photons interact with the atoms of the tissues.

Simple scatter is one of the attenuation mechanisms.

Name and describe **two** other attenuation mechanisms.

1. *Photoelectric effect: the X-ray photon is absorbed by an (inner-shell) electron, which is removed from the atom.*

2. *Compton scattering: the photon interacts with an electron, which is removed from the atom; the photon is scattered (deflected) with lower energy (longer wavelength).*

[4]

- 24 (a) Explain how an ultrasound transducer can **emit** ultrasound.
You do **not** need to describe the design of the transducer.

The transducer uses the piezoelectric effect.

An alternating p.d. at ultrasound frequency (above 20 kHz, typically MHz) is applied across a piezoelectric crystal (e.g. quartz), making it expand and contract (vibrate) at resonance; these vibrations produce ultrasound waves.

[2]

- (b) Explain how the reflection of ultrasound at a boundary between two tissues depends on the physical properties of the tissues.

Reflection depends on the acoustic impedance Z of each tissue, $Z = \rho c$

(density of the tissue $\times$ speed of ultrasound in the tissue).

Fraction of intensity reflected: $I_r / I_0 = (Z_2 - Z_1)^2 / (Z_2 + Z_1)^2$.

If the two tissues have the same acoustic impedance there is no reflection

(all transmitted); the greater the difference in Z , the greater the fraction of the intensity reflected.

[3]

END OF QUESTION PAPER

[illegible]

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