Please write clearly in block capitals.

Centre number						Candidate number				

Surname ______________________________

Forename(s) ______________________________

Candidate signature ______________________________

A-level
PHYSICS
Paper 2

Friday 8 June 2018 Morning Time allowed: 2 hours

Materials
For this paper you must have:
- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet.

Instructions
- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 85.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
6	
7	
8–32	
TOTAL	

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Section A

Answer **all** questions in this section.

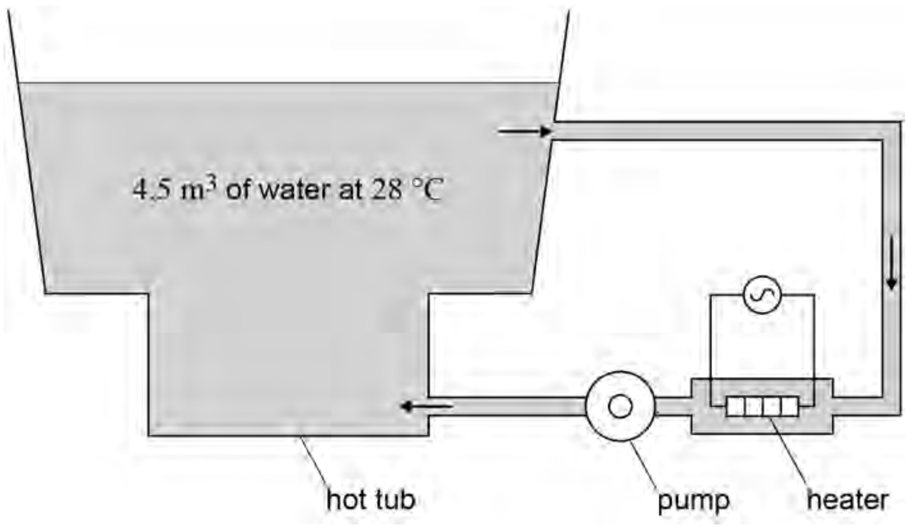
0 1 . 1 Explain what is meant by specific latent heat of fusion. → Solid to liquid

[2 marks]

The energy required to change the state of 1Kg of a substance from solid to liquid without changing its temperature

0 1 . 2 **Figure 1** shows how the temperature of the water is maintained in a hot tub.

Figure 1



The hot tub system has a volume of $4.5\ m^3$ and is filled with water at a temperature of $28\ °C$

The heater transfers thermal energy to the water at a rate of $2.7\ kW$ while a pump circulates the water.

Assume that no heat is transferred to the surroundings.

Volume = $4 \cdot 5\,m^3$ V, temperature = $28\,^{\circ}C$, Heater power = $2.7\,kW$ = P

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Calculate the rise in water temperature that the heater could produce in 1.0 hour. t

density of water = 1000 kg m^{-3} ρ
specific heat capacity of water = 4200 J kg^{-1} K^{-1} c

[3 marks]

Conservation of energy

$P = \frac{E}{t} \rightsquigarrow E = Pt$ energy transferred

$E = mc\Delta\theta \rightsquigarrow Pt = mc\Delta\theta$

don't know mass yet. Have volume

$\rho = \frac{m}{V} \rightsquigarrow m = \rho V = 1000 \times 4.5 = 4500$

kW → W, hr → s

$\Delta\theta = \frac{Pt}{mc} = \frac{2.7 \times 10^3 \times 1 \times 60^2}{4500 \times 4200} = 0.5142857\ldots\,K \approx 0.51\,K$

temperature rise = 0.51 K (2s.f.)

0 1 . 3 The pump can circulate the water at different speeds.
When working at higher speeds the rise in temperature is greater.

Explain why.
Again assume that no heat is transferred to the surroundings.

[2 marks]

The pump circulating the water causes work to be done upon the water. This work is converted to thermal energy of the water by raising the mean kinetic energy of water molecules. A higher pump speed means more work is done per unit time.

(✓)

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Pump is doing work on water.

Water

Force

Work dissipated as thermal energy

Turn over ►

Do not write outside the box

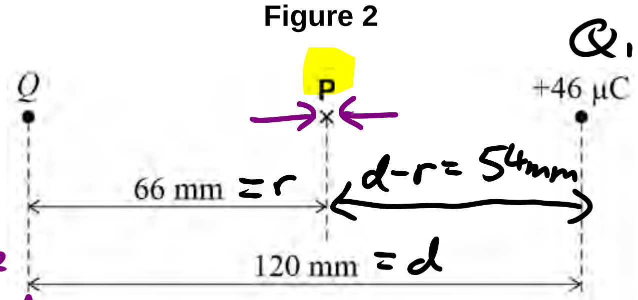
0 2 . 1 Define the electric field strength at a point in an electric field.

[2 marks]

Electric field strength is the force per unit charge acting on a small, positive test charge at a point.

0 2 . 2 **Figure 2** shows a point charge of +46 μC placed 120 mm from a point charge Q.

Figure 2



Q is a positive charge as at P a positive test charge must be repelled in both directions.

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}$$

r ← distance from Q.

Position **P** is on the line joining the charges at a distance 66 mm from charge Q.
The resultant electric field strength at position **P** is zero.

Calculate the charge Q.

[3 marks]

$$\frac{Q}{\cancel{4\pi\varepsilon_0} r^2} - \frac{Q_1}{\cancel{4\pi\varepsilon_0}(d-r)^2} = 0$$

$$\frac{Q}{r^2} = \frac{Q_1}{(d-r)^2}$$

$$Q = Q_1\left(\frac{r}{d-r}\right)^2$$

$$Q = 46\times10^{-6} \times \left(\frac{66\ \cancel{mm}}{54\ \cancel{mm}}\right)^2 = 68.716049\ldots \times 10^{-6}\ C$$

μC → C

$Q =$ 6.9×10^{-5} C (2s.f.)

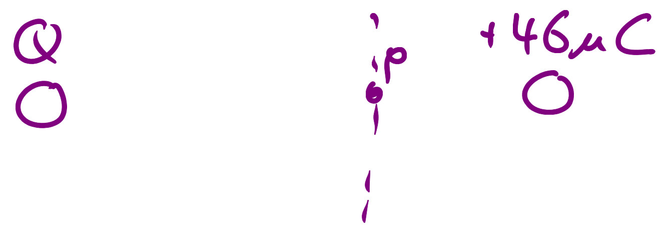
Do not write outside the box

0 2 . 3 Explain, without calculation, whether net work must be done in moving a proton from infinity to position **P** in **Figure 2**.

[2 marks]

The potential at P is positive, so work is done on the proton moving it from zero potential at infinity to a positive potential at P.

E field strength zero.



Electric potential: scalar, $\frac{Q}{4\pi\varepsilon_0 r}$

add potentials together, > 0.

Work done on any charge = potential × size of charge (W = QV) (general: W = QΔV), | here: ΔV = V − V_∞ and V_∞ = 0.

NB: Can also think of this like work is done moving the proton towards the positive charges against their repulsion.

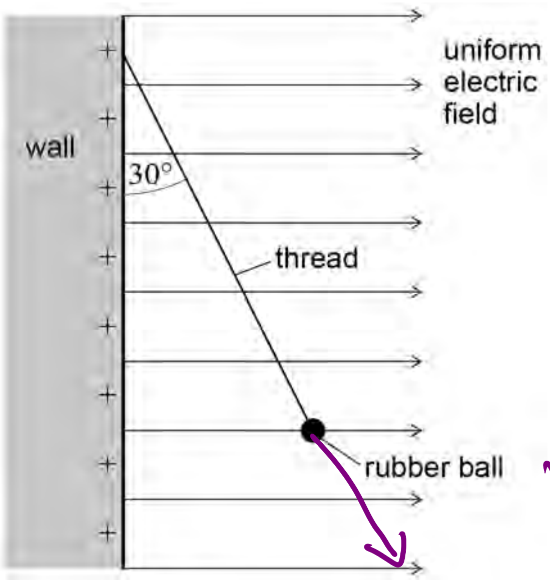
Turn over ▶

Do not write outside the box

0 2 . 4 A small rubber ball coated with a conducting paint carries a positive charge. The ball is suspended in equilibrium from a vertical wall by an uncharged non-conducting thread of negligible mass. The wall is positively charged and produces a horizontal uniform electric field perpendicular to the wall along the whole of its length.

Figure 3 shows that the thread makes an angle of 30° to the wall.

Figure 3



F_E

weight (W)

Vector sum

Resultant Force F

W

F

F_E

The thread breaks.

motion ⇒ $F = ma$

$a = \frac{F}{m}$

Explain the motion of the ball.

[2 marks]

The ball experiences both horizontal and vertical forces, which give it a constant acceleration and cause it to move in a straight line. or

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Alternate mark:

NB: Since the ball is in equilibrium before the thread breaks, and tension balances the weight and electric forces which are unchanged after thread broken, the tension force is equal to the negative of the resultant force that acts on the ball with no thread. Therefore it is accelerated away at 30° to the vertical, downwards.

30°

volt (unit of potential difference).

Capacitance = charge stored per unit potential difference

Do not write outside the box

$F = CV$

coulomb (unit of charge)

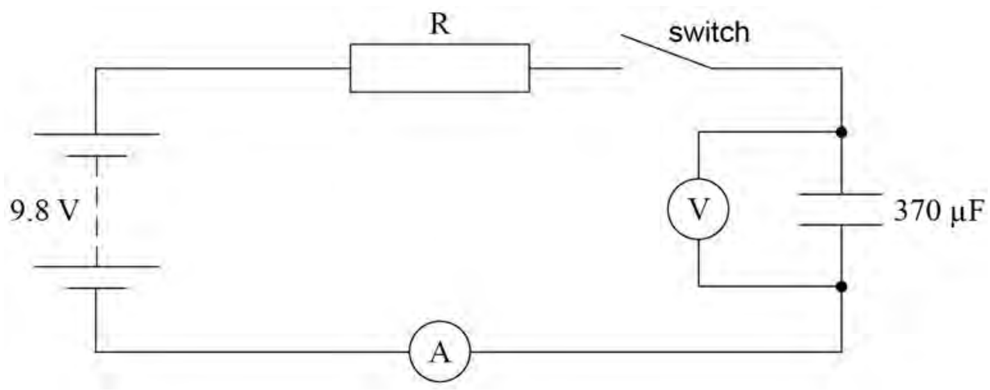
0 3 . 1 State what is meant by a capacitance of 370 μF

[2 marks]

370 μC of charge can be stored per unit volt of potential difference across the capacitor's plates.

0 3 . 2 The charging of a 370 μF capacitor is investigated using the circuit shown in **Figure 4**. Both meters in the circuit are ideal.

Figure 4



The power supply of emf 9.8 V has a negligible internal resistance. The capacitor is initially uncharged. When the switch is closed at time $t = 0$ charge begins to flow through resistor R. The time constant of the charging circuit is 1.0 s

Calculate the resistance of R.

[1 mark]

$\tau = RC$

$\mu F \rightarrow F$

$$R = \frac{\tau}{C} = \frac{1.0}{370 \times 10^{-6}} = 2702.702\ldots$$

$$\simeq 2.7 \times 10^{3}$$

resistance of R = 2.7×10^{3} Ω (2 s.f.)

Turn over ►

Do not write outside the box

0 3 . 3 Identify, with the symbol X on **Figure 5**, the potential difference (pd) across the capacitor when the switch has been closed for 2.0 s

Sketch the graph that shows how the pd varies from $t = 0$ to $t = 2.0$ s

[2 marks]

$V = V_0\left(1 - e^{-\frac{t}{RC}}\right)$, $V_0 = 9.8\,V$, $\tau = 1\,s$

$RC = \tau$, $V = V_0\left(1 - e^{-\frac{t}{\tau}}\right)$, at $t = 2.0\,s$

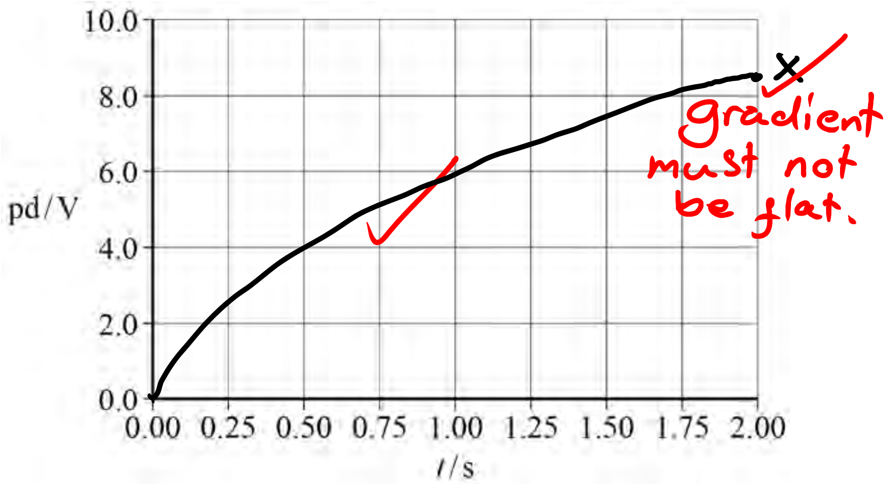
$V = 9.8 \times \left(1 - e^{-\frac{2}{1}}\right) \approx 8.47\,V$

$e \simeq 2.718$

for resistor: $V = IR$
no current
$\Rightarrow$ no p.d.
So as the capacitor becomes fully charged (as time gets very large compared to the time constant), no charge flows so all p.d. from battery across capacitor)

$Q = CV$

Figure 5



0 3 . 4 Calculate the time taken for the charging current to fall to half its initial value.

[1 mark]

current I, initial current I_0

$I = I_0 e^{-\frac{t}{\tau}}$

$\frac{I}{I_0} = e^{-\frac{t}{\tau}}$

$\frac{1}{2} = e^{-\frac{T_{\frac{1}{2}}}{\tau}}$

$\ln\frac{1}{2} = \ln\left(e^{-\frac{T_{\frac{1}{2}}}{\tau}}\right) = \ln(2^{-1})$

$-\frac{T_{\frac{1}{2}}}{\tau} \ln e = -\ln 2$, $\ln e = 1$

$\frac{T_{\frac{1}{2}}}{\tau} = \ln 2$, $T_{\frac{1}{2}} = \tau \times \ln 2$

$T_{\frac{1}{2}} = \tau \times \ln 2$

$T_{\frac{1}{2}} = 1.0 \times \ln 2 \approx 0.69\,s$

time = 0.69 s (2 s.f.)

Do not write outside the box

0 3 . 5 Calculate the time taken for the charge on the capacitor to reach 3.0 mC

[3 marks]

$Q = Q_0(1 - e^{-\frac{t}{\tau}})$ $Q = CV$

Final charge on capacitor

$Q_0 = CV_0 = 370 \times 10^{-6} \times 9.8$

$= 3.626 \times 10^{-3}$ C

$Q = Q_0(1 - e^{-\frac{t}{\tau}})$, $\tau = 1.0$ s

$\ln e = 1$

$\frac{Q}{Q_0} = 1 - e^{-\frac{t}{\tau}}$

$\ln(e^{-\frac{t}{\tau}}) = \ln(1 - \frac{Q}{Q_0})$

$-\frac{t}{\tau} = \ln(1 - \frac{Q}{Q_0})$

$e^{-\frac{t}{\tau}} = 1 - \frac{Q}{Q_0}$

time = 1.8 s (2 s.f.)

$t = -\tau \ln(1 - \frac{Q}{Q_0})$

$t = -1.0 \times \ln(1 - \frac{3 \times \cancel{10^{-3}}}{3.626 \times \cancel{10^{-3}}})$

$t = 1.756535...$ s

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Turn over ►

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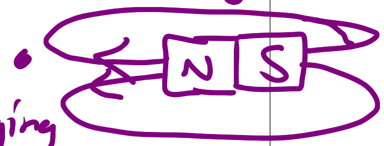
0 4 . 1 State Lenz's law.

[1 mark]

In electromagnetic induction, the direction of the induced emf is such that it opposes the change in magnetic flux that produced it.

0 4 . 2 Lenz's law can be demonstrated using a bar magnet and a coil of wire connected to a sensitive ammeter as shown in **Figure 6**.

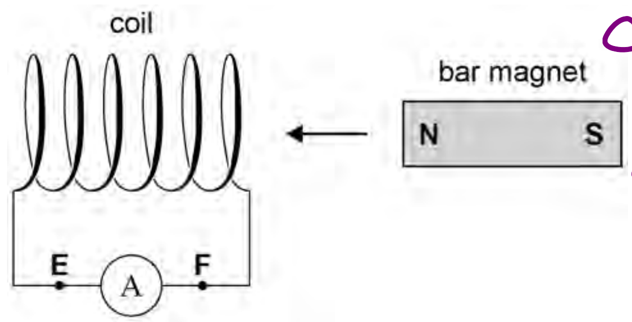
Far away:



Changing B in coil

Closer:

Figure 6



$\mathcal{E} = N \frac{\Delta\phi}{\Delta t}$

$\phi = BA\cos\theta$

Complete circuit

emf ⇒ current

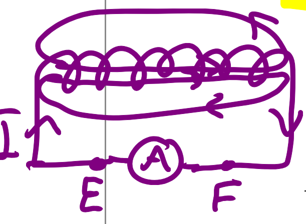
The bar magnet is moved towards the coil and is then brought to a halt.

State how the reading on the ammeter changes during this process.

[1 mark]

Ammeter reading increases (is non-zero) before becoming zero

0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.



Explain how this demonstrates Lenz's law.

[2 marks]

The current produces a magnetic field in the coil, which has a north pole on the coil's right ~~hand~~ side. This opposes the motion of the bar magnet, or since the two north poles repel. or

Like Coil is a bar magnet

coil

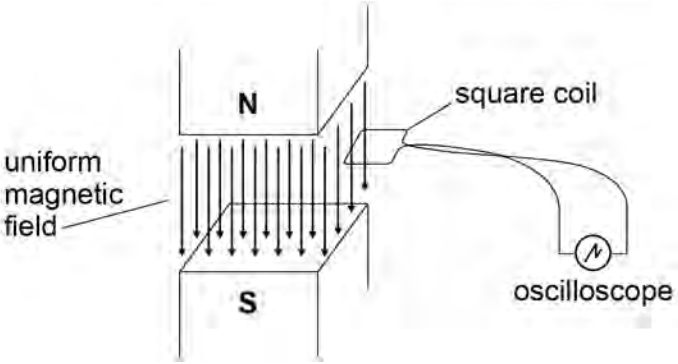
motion of the bar magnet repelled.

North poles repel actual bar magnet

Do not write outside the box

0 4 . 4 **Figure 7** shows an arrangement for investigating induced emf.

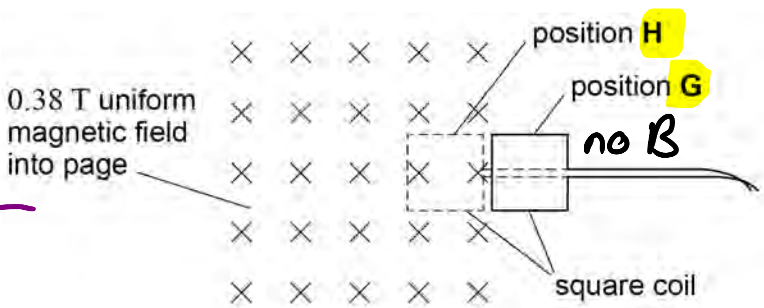
Figure 7

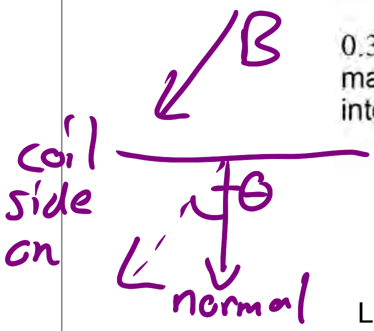


As shown, the uniform vertical magnetic field is confined to the gap between the poles of the magnet. The plane of the square coil is horizontal and is made of conducting wire. The coil consists of a single turn and is attached by flexible wire to an oscilloscope.

The oscilloscope gives a reading of 2.9×10^{-4} V when the coil is moved at uniform speed from position **G** outside the field to position **H** inside the field, as shown in **Figure 8**.

Figure 8





$\mathcal{E} = N\frac{\Delta\phi}{\Delta t}$

$\phi = BA\cos\theta$

uniform speed

$\frac{\Delta\phi}{\Delta t} = cst = \frac{\phi_{end} - \phi_{start}}{t}$

Length of side of square coil = 32 mm

Magnetic flux density of uniform magnetic field = 0.38 T

Calculate the time taken to move the coil from position **G** to position **H**.

[2 marks]

$\phi_{start} = 0 \times A$

Area of coil

$A = (32\times10^{-3})^2$

$\phi_{end} = B \times A \times \cos(0°) = BA$

$N = 1$

$\mathcal{E} = \frac{\phi_{end}}{t} N \rightarrow t = \frac{\phi_{end}}{\mathcal{E}} = \frac{0.38 \times (32\times10^{-3})^2}{2.9\times10^{-4}}$

$t = 1.34179103...$

time = 1.3 s (2s.f.)

Question 4 continues on the next page

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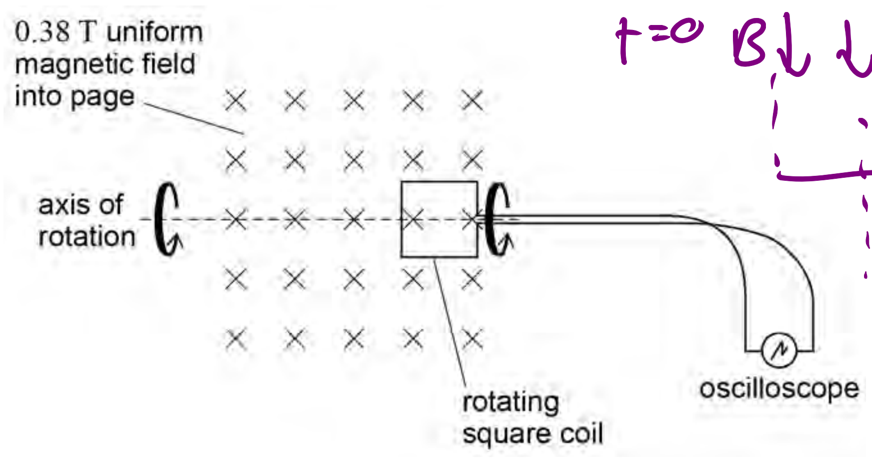
0 4 . 5 The square coil is rotated through 360° at a constant angular speed about the horizontal axis shown in **Figure 9**.

Figure 9



t=0 B↓ ↓↓ B ↓↓↓ coil 45° B ↓↓↓ 90°

Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

$N=1$, $A=(32\times10^{-3})^2$

[2 marks]

$\mathcal{E}=\omega BAN\sin(\omega t)$ $B=0.38\,T$

we pick $\sin\omega t = \sin 90° = 1$

$\mathcal{E}=\omega BA$ mV → V

$\omega = \dfrac{\mathcal{E}}{BA} = \dfrac{5.1\times10^{-3}}{0.38\times(32\times10^{-3})^2}$

$\omega = 13.10649671\ldots$
$\simeq 13\ \text{rad s}^{-1}$

angular speed = 13 rad s^{-1}

(2s.f.)

8

Do not write outside the box

0 5 . 1 Suggest, with a reason, which type of radiation is likely to be the most appropriate for the sterilisation of metallic surgical instruments.

[1 mark]

α, β, γ

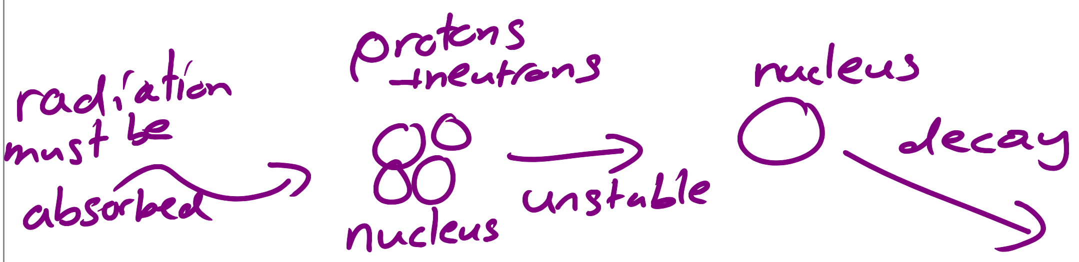
γ is the most penetrating will definitely reach all surfaces of the instruments and kill pathogens.

Gamma, because it is the most penetrating.

0 5 . 2 Explain why the public need not worry that irradiated surgical instruments become radioactive once sterilised.

[1 mark]

Ionising radiation does not ~~affect~~ the nucleus, which means that the atoms/ions in the instruments do not become radioactive.



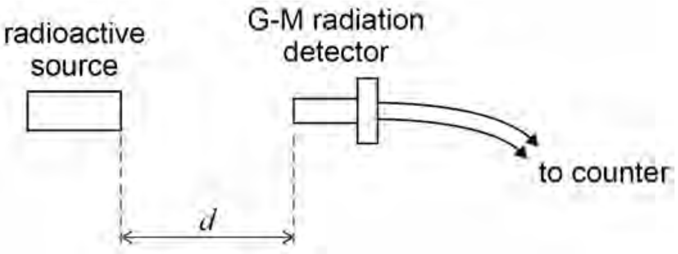
Ionising: outer e^- in atom (rather than nucleus)

Turn over ▶

Do not write outside the box

0 5 . 3 A student detects the counts from a radioactive source using a G-M radiation detector as shown in **Figure 10**.

Figure 10



The student measures the count rate for three different distances *d*. **Table 1** shows the count rate, in counts per minute, corrected for background for each of these distances.

Table 1

d/m	Corrected count rate / counts per minute C	$C \times d^2 = k$ / counts min^{-1} $\times$ m^2	k / counts min^{-1} m^2	
0.20	9013	9013×0.2^2	360.52	
0.50	1395	1395×0.5^2	348.75	
1.00	242	242×1^2	242	

Explain, with the aid of suitable calculations, why the data in **Table 1** are **not** consistent with an inverse-square law. You may use the blank columns for your working.

[2 marks]

$I = \frac{k}{d^2} \propto \frac{1}{d^2}$, follows an inverse square law $\Rightarrow Id^2 = k$

Intensity $I \propto$ Count rate C

For an inverse square law, count rate $C \times d^2$ should be constant. However, it's not constant here, so the data does not obey this law.

Do not write outside the box

0 5 . 4 State **two** possible reasons why the results do **not** follow the expected inverse-square law.

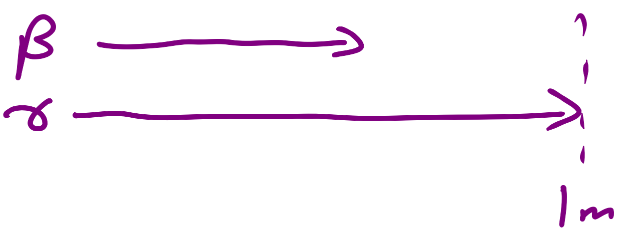
[2 marks]

Reason 1 Source is not a pure gamma emitter.

Reason 2 If the emitter has a short half life, then the activity of the sample decreases during the experiment, lowering count rate of later measurements.

6

Different types of radiation:



β attenuated before reaching detector for largest d measurement, γ is not. This will affect the inverse square law.

Activity → number of radioactive nuclei

$A = \lambda N$

Short half-life source will have many nuclei decaying rapidly so activity decreases during experiment ⇒ count rate is lower.

NB: Another reason is "dead time" in the GM detector. This refers to the time taken for the detector to reset itself after it detects something (in which it cannot detect anything else). Therefore this would mostly affect the high count rate measurements and reduce their value of $k = Cd^2$.

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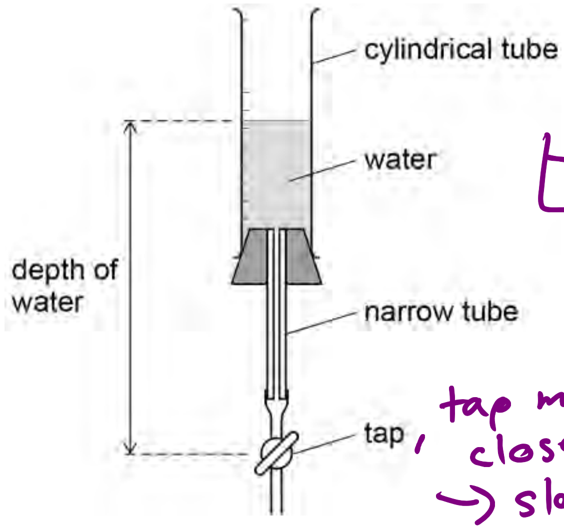
0 6 **Figure 11** shows how radioactive decay of one nuclide can be modelled by draining water through a tap from a cylindrical tube.

Figure 11



wider tube → more water leaves tube at each height

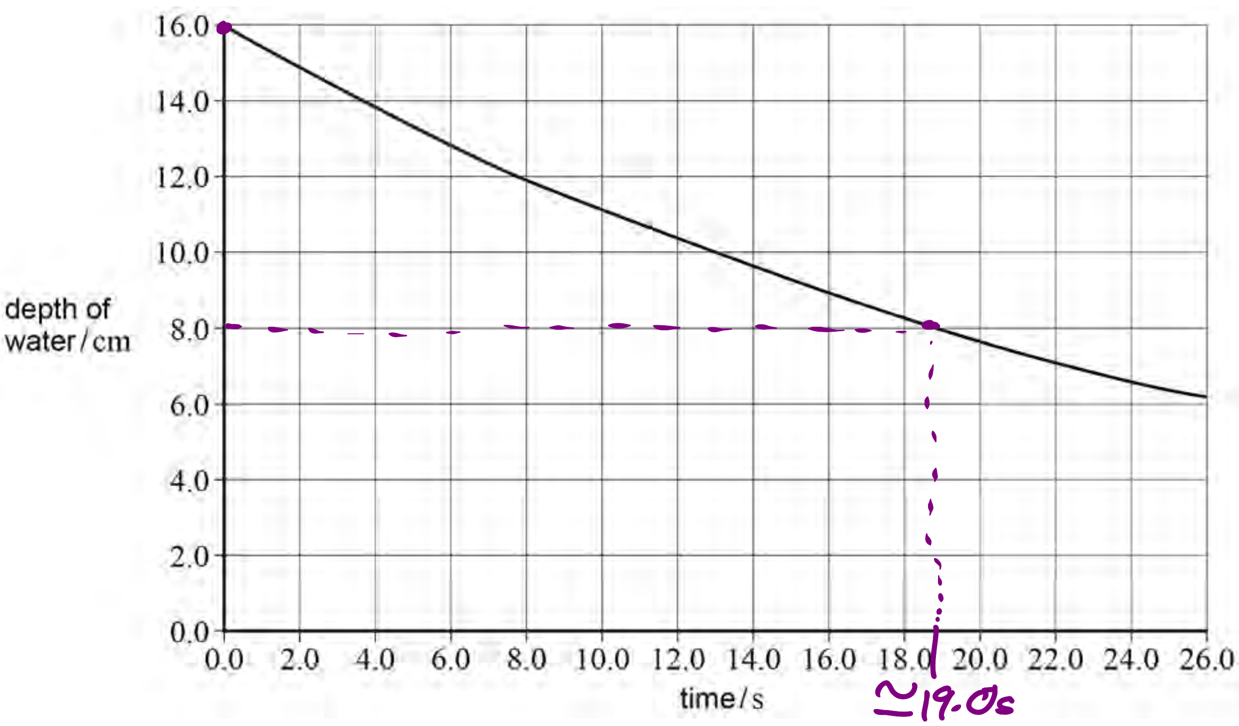
tap more closed → slower rate

The water flow-rate is proportional to the pressure of the water. The pressure of the water is proportional to the depth of the water. Therefore the rate at which the depth decreases is proportional to the depth of the water.

Before the tap is opened the depth is 16.0 cm

The tap is opened and the depth is measured at regular intervals. These data are plotted on the graph in **Figure 12**.

Figure 12



$T_{\frac{1}{2}} \simeq 19s$

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d: depth of water $\propto \frac{\Delta d}{\Delta t}$ (exponential decay) $N = N_0 e^{-\lambda t}$

$d = d_0 e^{-\lambda t} = d_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{\frac{1}{2}}}}$

Do not write outside the box

0 6 . 1 Determine the predicted depth of water when the time is 57 s

[1 mark]

$T_{\frac{1}{2}} = 19.0\,s$

$\frac{57}{19}$

$d = d_0 \times \left(\frac{1}{2}\right)^3$ ($d_0 \to 16.0\,cm$)

$d = 16.0 \times \left(\frac{1}{2}\right)^3 = 2.0\,cm$

depth = 2.0 cm

0 6 . 2 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of the same nuclide with a greater number of nuclei.

[1 mark]

$d = d_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{\frac{1}{2}}}}$

(Nuclei $N = N_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{\frac{1}{2}}}}$)

Increase the depth of the water.

0 6 . 3 Suggest how the apparatus in **Figure 11** may be changed to represent a radioactive sample of a nuclide with a smaller decay constant.

[1 mark]

$\frac{\Delta d}{\Delta t} = -\lambda d$

$(A = \lambda d)$

Use a wider cylindrical tube.

λ affects decay rate $\to$ any factor that slows rate of depth decrease.

0 6 . 4 The age of the Moon has been estimated from rock samples containing rubidium (Rb) and strontium (Sr), brought back from Moon landings.

${}^{87}_{37}Rb$ decays to ${}^{87}_{38}Sr$ with a radioactive decay constant of 1.42×10^{-11} year^{-1}

Calculate, in years, the half-life of ${}^{87}_{37}Rb$.

[1 mark]

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

$T_{\frac{1}{2}} = \frac{1}{1.42 \times 10^{-11}} \times \ln 2 = 4.88131873\ldots \times 10^{10}$

$\simeq 4.88 \times 10^{10}$ yr

half-life = 4.88×10^{10} years

(3 s.f.)

Question 6 continues on the next page

Turn over ▶

Do not write outside the box

0 6 . 5 A sample of Moon rock contains 1.23 mg of $^{87}_{37}\mathrm{Rb}$.

Calculate the mass, in g, of $^{87}_{37}\mathrm{Rb}$ that the rock sample contained when it was formed 4.47 × 10^9 years ago.

$\lambda = 1.42\times10^{-11}\ \text{year}^{-1}$

Give your answer to an appropriate number of significant figures.

[3 marks]

NB: Longer way around is to convert N to moles, n (ie. $\frac{N}{N_A} = n$) then do mass $m = nM_r$ ← relative atomic mass.

$N = N_0 e^{-\lambda t}$

$N = \frac{m}{\text{mass of one nuclide}}$, $N \propto m$

$m = m_0 e^{-\lambda t}$

$m = m_0 e^{-\lambda t}$

$m_0 = m e^{+\lambda t}$

current mass of radioactive nuclides; initial mass of radioactive nuclides

mg → g

$m_0 = 1.23\times10^{-3} \times e^{1.42\times10^{-11}\times4.47\times10^9}$

$= 1.3106024091\ldots \times10^{-3}$

mass = 1.31×10^{-3} g (3s.f.)

0 6 . 6 Calculate the activity of a sample of $^{87}_{37}\mathrm{Rb}$ of mass 1.23 mg

Give an appropriate unit for your answer.

[3 marks]

$A = \lambda N$ $\quad \lambda = 1.42\times10^{-11}\ \text{year}^{-1}$

$N = \frac{\text{mass of sample}}{\text{mass of one nuclei}}$

mg → kg

$N = \frac{1.23\times10^{-6}}{1.673\times10^{-27}\times37 + 1.675\times10^{-27}\times(87-37)}$

proton mass × number of protons; neutron mass × number of neutrons

$N = 8.44348\ldots\times10^{18}$

λ is per year, so need to convert to per second

activity = 3.80 (3s.f.) unit s^{-1} (Bq)

$\lambda = \frac{1.42\times10^{-11}}{365\times24\times60\times60} = 4.50279\ldots\times10^{-19}$

year → s

$A = 8.44348\ldots\times10^{18}\times4.50279\ldots\times10^{-19} = 3.801922121\ldots\ s^{-1}$

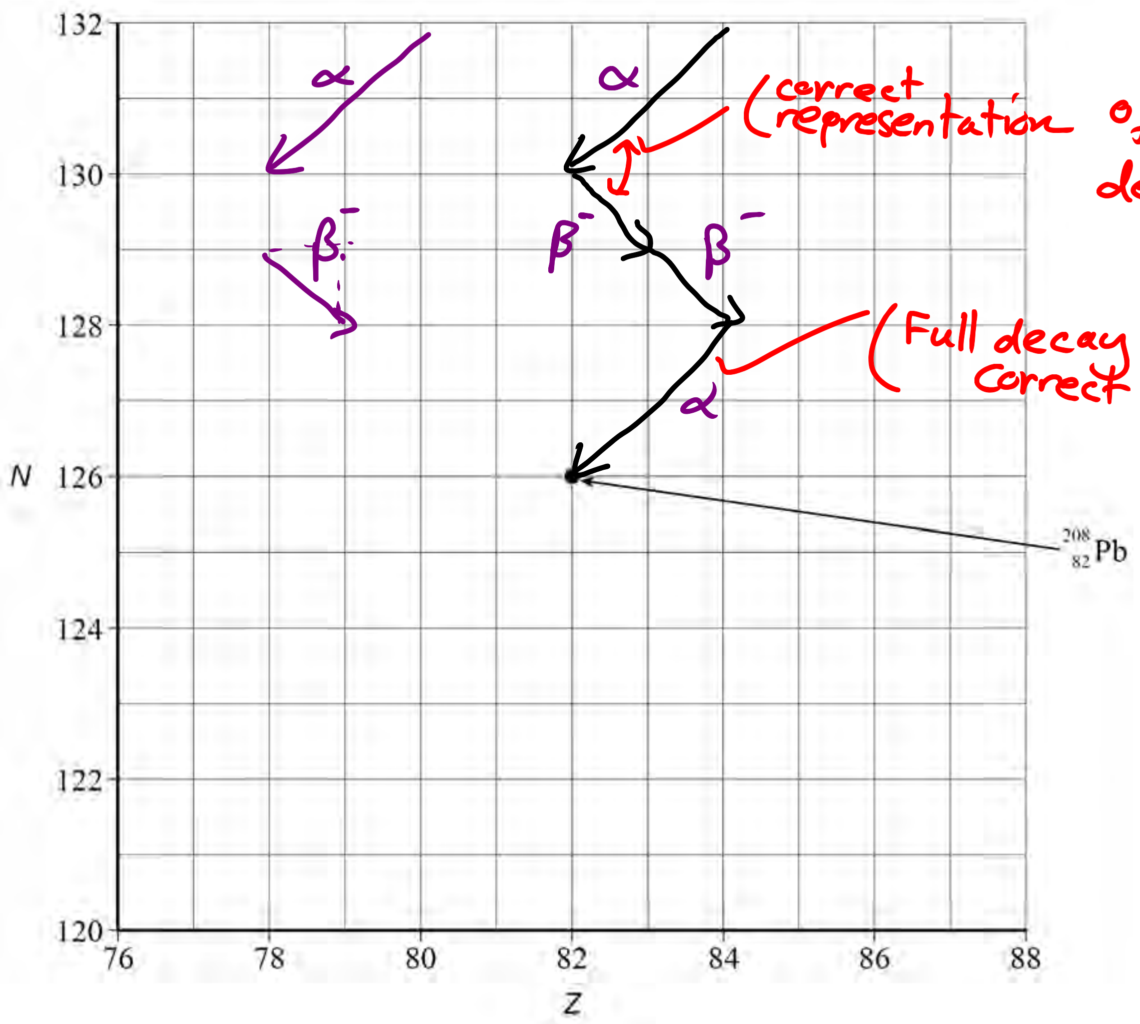
Do not write outside the box

0 7 A nucleus of polonium Po may decay to the stable isotope of lead $^{208}_{82}\mathrm{Pb}$ through a chain of emissions following the sequence $\alpha\ \beta^-\ \beta^-\ \alpha$.

Figure 13 shows the position of the isotope $^{208}_{82}\mathrm{Pb}$ on a grid of neutron number *N* against proton number *Z*. (α particle given out) α: −2 neutrons, −2 protons

β^-: +1 proton, −1 neutron

Figure 13



0 7 . 1 Draw **four arrows** on **Figure 13** to show the sequence of changes to *N* and *Z* that occur as the polonium nucleus is transformed into $^{208}_{82}\mathrm{Pb}$.

[2 marks]

Turn over ►

Do not write outside the box

0 7 . 2 A nucleus of the stable isotope $^{208}_{82}\mathrm{Pb}$ has more neutrons than protons.

Explain why there is this imbalance between proton and neutron numbers by referring to the forces that operate within the nucleus. Your explanation should include the range of the forces and which particles are affected by the forces.

[4 marks]

In the nucleus the main forces that act are the electromagnetic and strong nuclear forces. The electromagnetic force only affects the charged protons, and is a long-ranged force. The strong nuclear force affects all the nucleons, is repulsive up to about 0.8 fm, and is attractive from 0.8 fm – 3 fm above which it does not act. Therefore, in order to reduce the electromagnetic repulsion between the positively charged protons, the number of protons is smaller.

3 from 5 for explaining the nature of the forces.

1 for explaining the imbalance

0 7 . 3 Many, but not all, isotopes of lead are stable. For example, $^{205}_{82}\mathrm{Pb}$ decays by electron capture to become an isotope of thallium, Tl.

Write the equation to represent this decay, including the isotope of thallium produced.

[1 mark]

e^- capture

mass is conserved

mass	$^{0}_{-1}e^-$ +	$^{205}_{82}\mathrm{Pb}$ $\rightarrow$	$^{205}_{81}\mathrm{Tl}$ +	$^{0}_{0}\nu_e$
charge				
lepton	(+1)	(0)	(0)	(+1)

Lepton number is conserved

Charge is conserved

Do not write outside the box

0 7 . 4 The thallium nucleus is formed in an excited state. Electromagnetic radiation is emitted from the thallium atom following its formation.

Explain the origin and location of **two** sources of this radiation.

[2 marks]

Excited

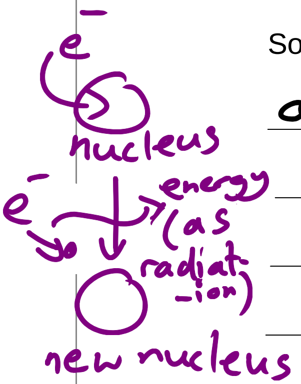
γ

Ground

Source 1 The nucleus de-excites from an excited state to its ground state, releasing energy as a gamma ray.

Electron capture

Source 2 An outer electron in the thallium atom falls down to fill the gap in the inner energy level due to electron capture. This electron loses energy as radiation.



0 7 . 5 Other nuclides also emit electromagnetic radiation.

Explain why the metastable form of the isotope of technetium $^{99}_{43}\mathrm{Tc}$ is a radioactive source suitable for use in medical diagnosis.

Any two valid points.

[2 marks]

Technetium has a long enough lifetime for the diagnosis to be performed, but short enough that it does not stay in the body for a long time. The metastable form of technetium is also a pure gamma emitter and so is weakly ionising, and also means that the position where the gamma rays were emitted from can be determined, since gamma is the most penetrating form of radiation.

11

END OF SECTION A

Turn over ►

Do not write outside the box

Section B

Each of Questions **08** to **32** is followed by four responses, **A**, **B**, **C** and **D**.

For each question select the best response.

Only **one** answer per question is allowed.
For each answer completely fill in the circle alongside the appropriate answer.

CORRECT METHOD ⬬ WRONG METHODS

If you want to change your answer you must cross out your original answer as shown.

If you wish to return to an answer previously crossed out, ring the answer you now wish to select as shown.

You may do your working in the blank space around each question but this will not be marked.
Do **not** use additional sheets for this working.

0 8 The graph shows the variation of pressure p with temperature θ for a fixed mass of an ideal gas at constant volume.

What is the gradient of the graph?

[1 mark]

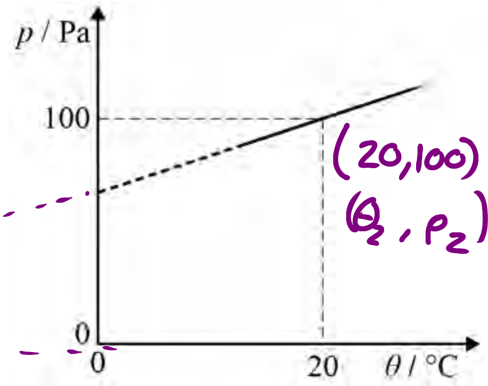
Ideal gas: $pV = Nk_B\theta$

absolute 0 (0 in K)

$(-273, 0)$

(θ_1, p_1)

$-273°C$



$(20,100)$

(θ_2, p_2)

$\frac{\Delta p}{\Delta \theta} = \frac{p_2 - p_1}{\theta_2 - \theta_1}$

V is cst.

fixed mass → N cst.

$pV = Nk_B\theta$, p and θ.

A 0.341

B 0.395

C 2.93

D 5.00

$\frac{\Delta p}{\Delta \theta} = \frac{100 - 0}{20 - (-273)} = \frac{100}{293}$

$= 0.3412969...$

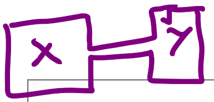
$\simeq 0.341$

deduce a second point

$p = 0$

$p \propto \theta$

$p = 0, \theta = 0$



pressure is the same in X and Y

Ideal gas : X: $pV_x = N_x k_B T_x$

Y: $pV_y = N_y k_B T_y$

0 9 Two flasks **X** and **Y** are filled with an ideal gas and are connected by a tube of negligible volume compared to that of the flasks. The volume of **X** is twice the volume of **Y**.
X is held at a temperature of 150 K and **Y** is held at a temperature of 300 K

$V_x = 2V_y$

$T_y = 2T_x$

What is the ratio $\dfrac{\text{mass of gas in } \mathbf{X}}{\text{mass of gas in } \mathbf{Y}}$?

[1 mark]

A 0.125 ○

B 0.25 ○

C 4 ●

D 8 ○

$$\frac{\cancel{p}V_x}{\cancel{p}V_y} = \frac{N_x \cancel{k_B} T_x}{N_y \cancel{k_B} T_y} = \frac{N_x T_x}{N_y T_y}$$

$N = \dfrac{\text{mass of all}}{\text{mass of one}}$

$N = \dfrac{m}{m_{one}}$

X and Y have the same gas ⇒ m_{one} is the same

$$\frac{N_x}{N_y} = \frac{V_x}{V_y} \times \frac{T_y}{T_x} = \frac{2\cancel{V_y}}{\cancel{V_y}} \times \frac{2\cancel{T_x}}{\cancel{T_x}} = 4$$

$$\frac{m_{one} N_x}{m_{one} N_y} = \frac{m_x}{m_y} = 4$$

1 0 The average mass of an air molecule is 4.8×10^{-26} kg

What is the mean square speed of an air molecule at 750 K?

[1 mark]

A $3.3 \times 10^5\ \text{m}^2\ \text{s}^{-2}$ ○

B $4.3 \times 10^5\ \text{m}^2\ \text{s}^{-2}$ ○

C $6.5 \times 10^5\ \text{m}^2\ \text{s}^{-2}$ ●

D $8.7 \times 10^5\ \text{m}^2\ \text{s}^{-2}$ ○

$$\frac{1}{2} m \overline{c^2} = \frac{3}{2} k_B T$$

$$\overline{c^2} = \frac{3 k_B T}{m}$$

$$\overline{c^2} = \frac{3 \times 1.38 \times 10^{-23} \times 750}{4.8 \times 10^{-26}}$$

$\overline{c^2} = 646875$

$\simeq 6.5 \times 10^5\ m^2 s^{-2}$

1 1 A transparent illuminated box contains small smoke particles and air.
The smoke particles are observed to move randomly when viewed through a microscope.

What is the cause of this observation of Brownian motion?

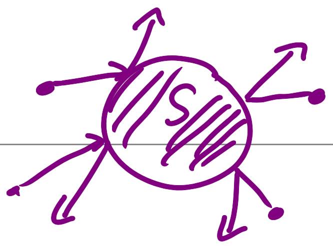
[1 mark]

A Smoke particles gaining kinetic energy by the absorption of light ○

B Collisions between smoke particles and air molecules ●

C Smoke particles moving in convection currents caused by the air being heated by the light ○

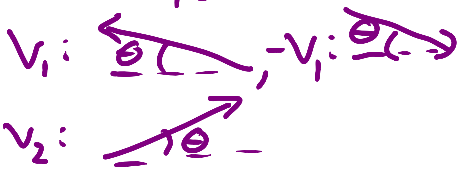
D The smoke particles moving randomly due to their temperature ○

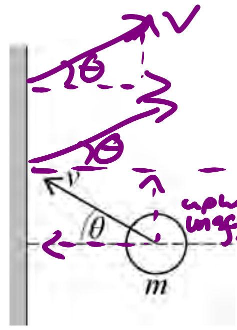


Smoke particle moves randomly

1 2 The diagram shows a gas particle about to collide elastically with a wall.

* $V_2 + (-V_1)$
add tip to tail.





elastic collision
E_k conserved. ($=\frac{1}{2}mv^2$)
mass the same.
only component ⊥ to wall of velocity is affected

Which diagram shows the correct change in momentum Δmv that occurs during the collision?

$\Delta p = (\Delta v)\, m = m(V_2 - V_1)$

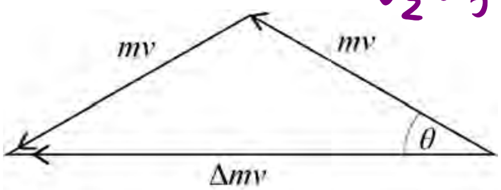
[1 mark]

$v^2 = V_{up,2}^2 + V_{side,2}^2$

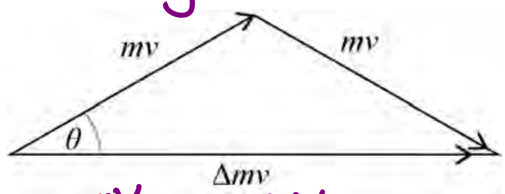
V_1: initial velocity
V_2: final velocity

subtract as vectors. *

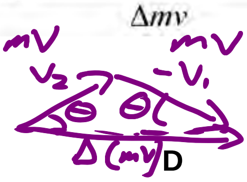
A



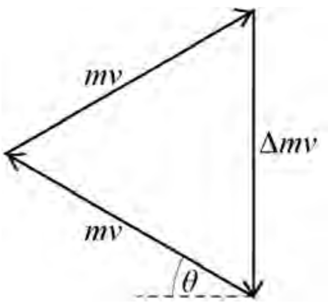
B



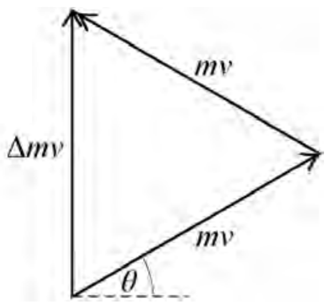
$\Delta p = m(v_2 + (-v_1))$



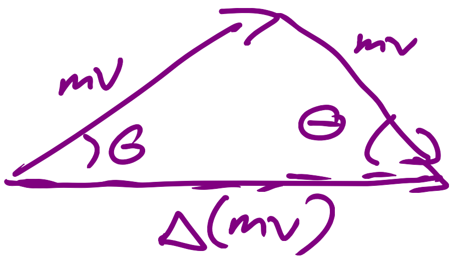
C



D



A ○
B ●
C ○
D ○



m_1 (sun) $= 1.99 \times 10^{30}$ kg

m_2 (earth) $= 5.97 \times 10^{24}$ kg

$F = \frac{G m_1 m_2}{r^2}$

Do not write outside the box

1 3 The distance between the Sun and the Earth is 1.5×10^{11} m

What is the gravitational force exerted on the Sun by the Earth?

[1 mark]

A 3.5×10^{22} N

B 1.7×10^{26} N

C 5.3×10^{33} N

D 8.9×10^{50} N

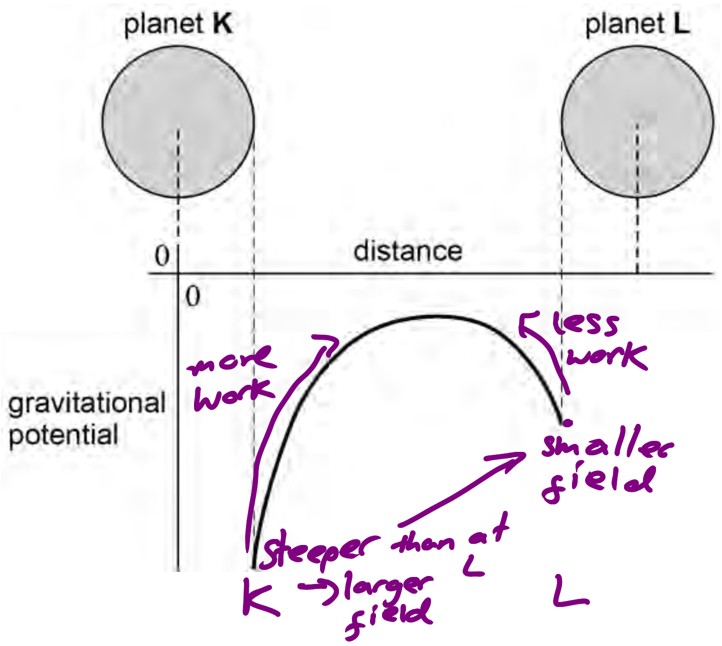
$F = \frac{6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 5.97 \times 10^{24}}{(1.5 \times 10^{11})^2}$

$F = 3.521848933 \times 10^{22}$

$\approx 3.5 \times 10^{22}$ N (2s.f.)

1 4 The graph shows how the gravitational potential varies with distance between two planets, **K** and **L**, that have the same radius.

$V = -\frac{GM}{r}$



$V = -\frac{GM}{R}$

Steeper gradient ⇒ larger magnitude of field

Which statement is correct?

[1 mark]

~~**A**~~ The mass of **L** is greater than the mass of **K**.

~~**B**~~ The gravitational field strength at the surface of **L** is greater than that at the surface of **K**.

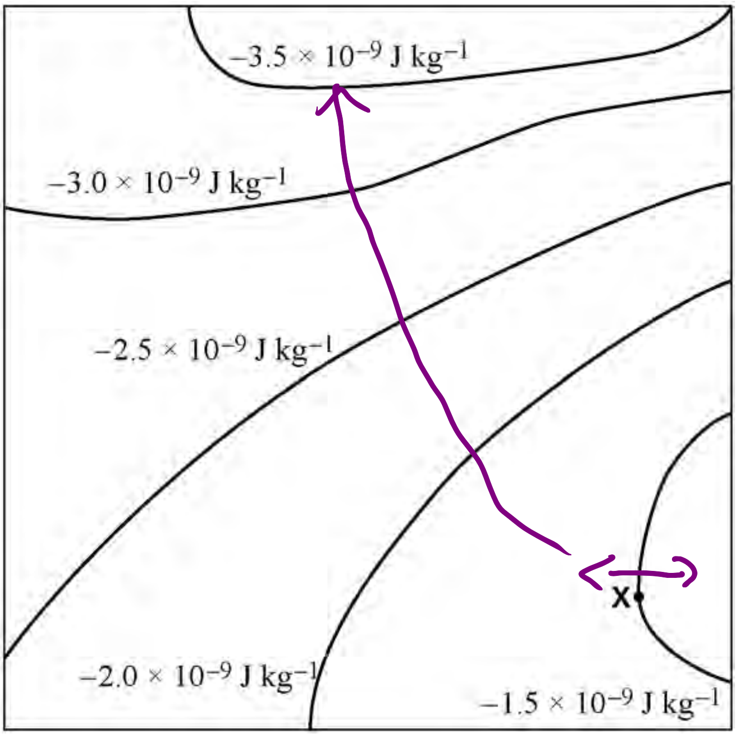
~~**C**~~ The escape velocity from planet **L** is greater than that from planet **K**.

D More work must be done to move a mass of 1 kg from the surface of **K** to a distant point, than 1 kg from the surface of **L**.

Turn over ►

Do not write outside the box

1 5 The diagram shows equipotential lines near a group of asteroids.



Field is perpendicular to an equipotential at every point.

Gravitational potential energy of a mass at X will be lowered as the field moves it.

Which arrow shows the direction of the gravitational field at **X**?

[1 mark]

A ↑ ☐

B ↓ ☐

C ← ■

D → ☐

$\rho = \frac{M}{V}$; sphere $M = \rho V$, $V = \frac{4}{3}\pi R^3 \rightarrow M = \rho \times \frac{4}{3}\pi R^3$

Do not write outside the box

1 6 Planet **N** has a gravitational potential $-V$ at its surface. Planet **M** has double the density and double the radius of planet **N**. Both planets are spherical and have uniform density.

$N: R, \rho$. $M: 2\rho, 2R$

What is the gravitational potential at the surface of planet **M**?

[1 mark]

N: potential $= -\frac{GM}{R} = -\frac{G}{R}\frac{4}{3}\pi R^3 \rho = -\frac{4}{3}\pi G R^2 \rho = -V$

A $-16V$ ○

B $-8V$ ●

C $-4V$ ○

D $-0.2V$ ○

$M: -\frac{4}{3}\pi G (2R)^2 (2\rho)$

$= -\frac{4}{3}\pi G R^2 \rho \times 8$

$= -8V$

1 7 A spacecraft of mass 1.0×10^6 kg is in orbit around the Sun at a radius of 1.1×10^{11} m
The spacecraft moves into a new orbit of radius 2.5×10^{11} m around the Sun.

m_2, m_1, r_1, r_2

What is the total change in gravitational potential energy of the spacecraft?

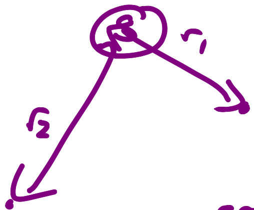
[1 mark]

A -6.76×10^{14} J ○

B -3.38×10^{14} J ○

C 3.38×10^{14} J ○

D 6.76×10^{14} J ●



mass of sun

mass of spacecraft.

$E_p = -\frac{G m_1 m_2}{r}$

$E_{p_1} = \frac{-G m_1 m_2}{r_1}$, $E_{p_2} = \frac{-G m_1 m_2}{r_2}$

$\Delta E_p = E_{p_2} - E_{p_1} = -\frac{G m_1 m_2}{r_2} - \left(-\frac{G m_1 m_2}{r_1}\right) = -G m_1 m_2 \left(\frac{1}{r_2} - \frac{1}{r_1}\right)$

$\Delta E_p = -6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times \left(\frac{1}{2.5 \times 10^{11}} - \frac{1}{1.1 \times 10^{11}}\right)$

$= +6.757316 \ldots \times 10^{14}$

$\approx 6.76 \times 10^{14}$ J (3s.f.)

Do not write outside the box

1 8 Which graph shows the relationship between the time period T and the orbital radius r of a planet in orbit around the Sun?

[1 mark]

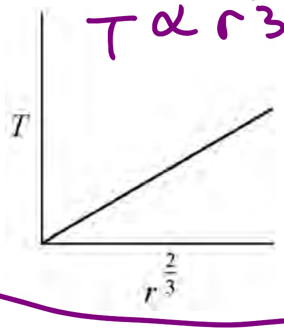
Circular orbit $F = \frac{mv^2}{r}$ m mass of planet

Gravitational Force $F = \frac{mMG}{r^2}$ M mass of Sun

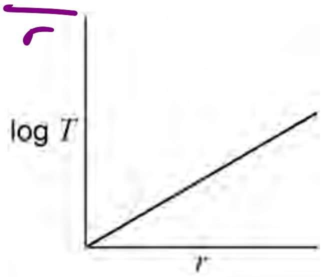
Circular motion $\frac{\cancel{m}v^2}{\cancel{r}} = \frac{\cancel{m}MG}{r^{\cancel{2}}}$

$v = \frac{2\pi r}{T}$ $v^2 = \frac{MG}{r}$

~~A~~ $T \propto r^{\frac{2}{3}}$

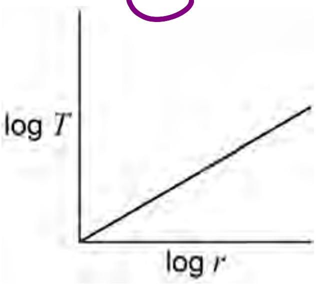


~~B~~

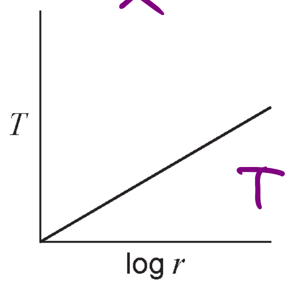


$\frac{(2\pi)^2 r^2}{T^2} = \frac{MG}{r} \Rightarrow T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$

C



~~D~~



$T \propto \log r$

$T = \sqrt{\frac{(4\pi^2)}{GM}}\, r^{\frac{3}{2}} \Rightarrow$ A, D are out

$\log T = \log\left(\sqrt{\frac{4\pi^2}{GM}}\, r^{\frac{3}{2}}\right)$

$\log T = \log\left(\sqrt{\frac{4\pi^2}{GM}}\right) + \log\left(r^{\frac{3}{2}}\right)$

$\log T = \frac{3}{2}\log(r) + \log\left(\sqrt{\frac{4\pi^2}{GM}}\right)$

$\log T \propto \log(r)$

A ○

B ○

C ●

D ○

Do not write outside the box

1 9 The Earth can be assumed to be a uniform sphere of radius R.

What is the mean density of the Earth?

[1 mark]

size of $g = \frac{GM}{R^2}$, $\rho = \frac{M}{V}$

$M = \rho V$

$V = \frac{4}{3}\pi R^3$

$M = \rho \frac{4}{3}\pi R^3$

$g = \frac{G}{\cancel{R^2}} \rho \times \frac{4}{3}\pi R^{\cancel{3}}$

$g = \rho G \times \frac{4}{3}\pi R \rightarrow \rho = \frac{3g}{4G\pi R}$

A $\frac{3g}{4\pi RG}$ ●

B $\frac{3RG}{4\pi g}$ ○

C $\frac{3G}{4\pi Rg}$ ○

D $\frac{3Rg}{4\pi G}$ ○

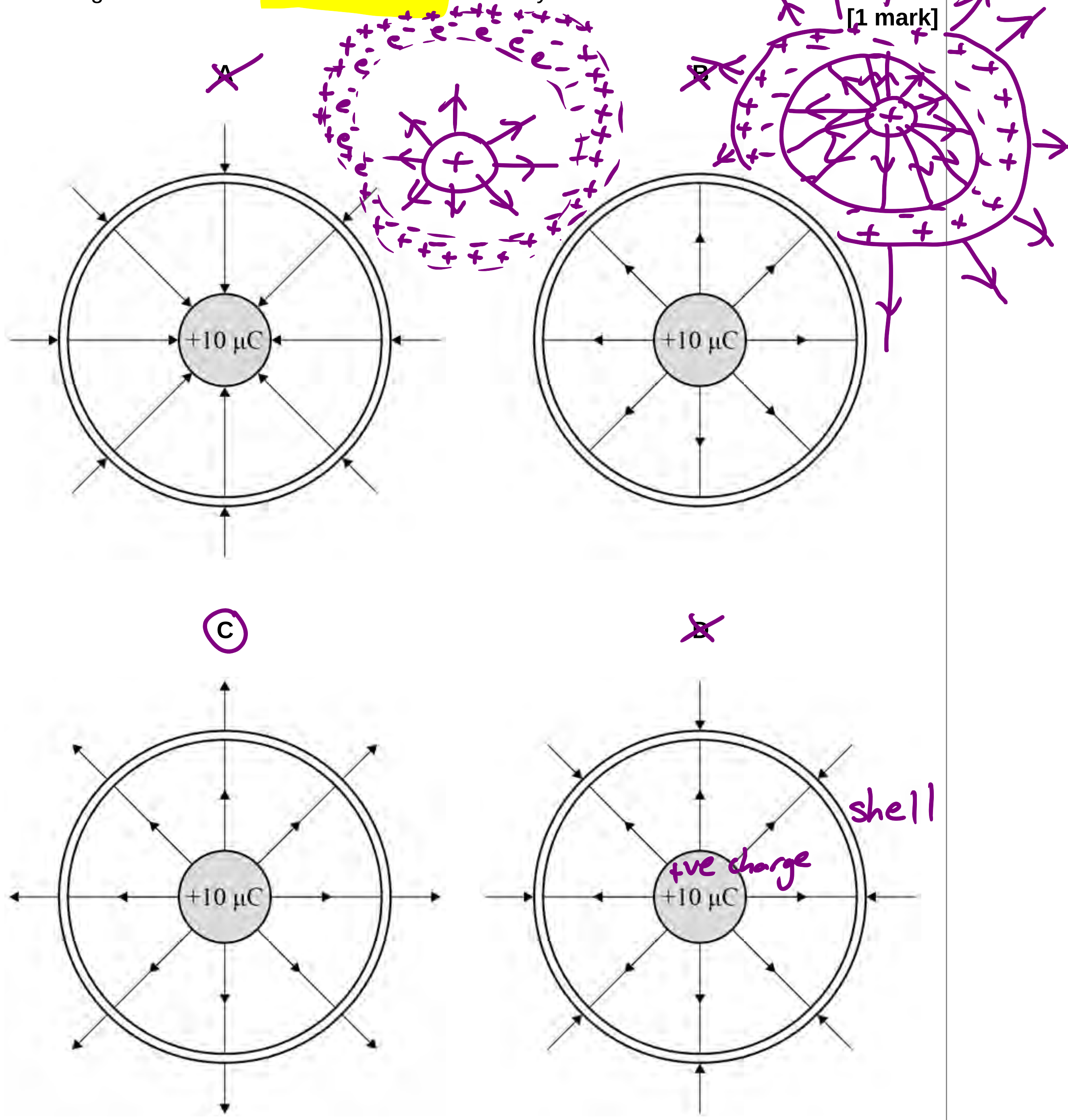
Turn over ▶

Do not write outside the box

2 0 A conducting sphere holding a charge of +10 μC is placed centrally inside a second uncharged conducting sphere.

Which diagram shows the electric field lines for the system?

[1 mark]



A ☐

B ☐

C ■

D ☐

+ve charge attracts free electrons in the metal to the inner surface of the shell. This causes the inner surface to have more e⁻ than ions, but leaves more ions than e⁻ on the outer surface. Hence there is a net positive charge on that surface so generates an electric field like the first charged sphere.

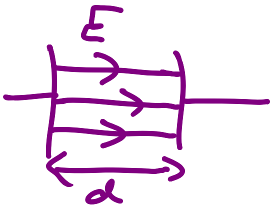
Do not write outside the box

2 1 A charged spherical conductor has a radius r. An electric field of strength E exists at the surface due to the charge.

What is the potential of the spherical conductor?

[1 mark]

Similar case:



~~A~~ r^2E

~~B~~ $r\,E^2$

~~C~~ $\dfrac{E}{r}$

D $r\,E$ ●

$V = Ed$

$\left(E = \dfrac{V}{d}\right)$

Units of potential = units of E field × units of distance

also distance multiplied by E field units

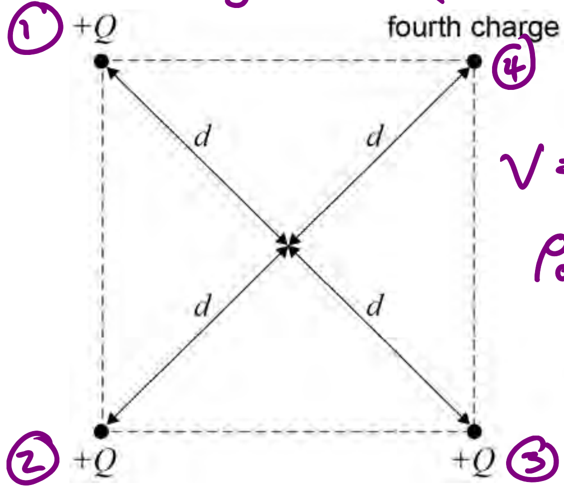
$[E] = NC^{-1}$ $(= kg\,m\,s^{-3}A^{-1})$

(contain kg, A, s)

Do not write outside the box

2 2 Four positive charges are fixed at the corners of a square as shown.

Let unknown charge be Q'



Potential of point charge
$V = \frac{Q}{4\pi\varepsilon_0 r}$ (r is distance from charge)
Potentials add

The total potential at the centre of the square, a distance d from each charge, is $\frac{5Q}{4\pi\varepsilon_0 d}$.
Three of the charges have a charge of $+Q$.

What is the magnitude of the fourth charge?

[1 mark]

A $-\frac{7Q}{4}$

B Q

C $\sqrt{2}Q$

D $2Q$ ■

Sum of potentials

$$\underset{1}{\frac{Q}{4\pi\varepsilon_0 d}} + \underset{2}{\frac{Q}{4\pi\varepsilon_0 d}} + \underset{3}{\frac{Q}{4\pi\varepsilon_0 d}} + \underset{4}{\frac{Q'}{4\pi\varepsilon_0 d}} = \frac{5Q}{4\pi\varepsilon_0 d}$$

$$\frac{3Q}{4\pi\varepsilon_0 d} + \frac{Q'}{4\pi\varepsilon_0 d} = \frac{5Q}{4\pi\varepsilon_0 d}$$

$3Q + Q' = 5Q \Rightarrow Q' = 2Q$

Disconnecting: Charge on the plates is the same

Capacitor: $Q = CV$ → $Q = CEd$

parallel plate: $E = \frac{V}{d}$ → $\hookrightarrow C = \frac{\varepsilon_0 \varepsilon_r A}{d}$ (parallel plate), $\varepsilon_r = 1$

Do not write outside the box

2 3 An air-filled parallel-plate capacitor is charged from a source of emf. The electric field has a strength E between the plates. The capacitor is disconnected from the source of emf and the separation between the isolated plates is doubled.

What is the final electric field between the plates?

[1 mark]

A $2E$

B E

C $\frac{E}{2}$

D $\frac{E}{4}$

$$Q = \frac{\varepsilon_0 A}{\cancel{d}} E \cancel{d} = \varepsilon_0 A E$$

$$E = \frac{Q}{\varepsilon_0 A}$$

Field is independent of separation of plates ⇒ unaffected

2 4 A parallel-plate capacitor has square plates of length l separated by distance d and is filled with a dielectric.

A second capacitor has square plates of length $2l$ separated by distance $2d$ and has air as its dielectric.

Both capacitors have the same capacitance.

What is the relative permittivity of the dielectric in the first capacitor?

[1 mark]

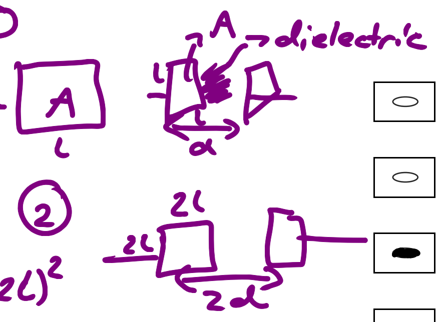
A $\frac{1}{2}$

B 1

C 2

D 8

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$



1: $C_1 = \frac{\varepsilon_0 \varepsilon_r l^2}{d}$

2: $C_2 = \frac{\varepsilon_0 \times 1 \times (2l)^2}{2d}$ (air)

$$\frac{\cancel{\varepsilon_0} \varepsilon_r \cancel{l^2}}{\cancel{d}} = \frac{\cancel{\varepsilon_0} (2\cancel{l})^2}{2\cancel{d}} \Rightarrow \varepsilon_r = \frac{4}{2} = 2$$

Do not write outside the box

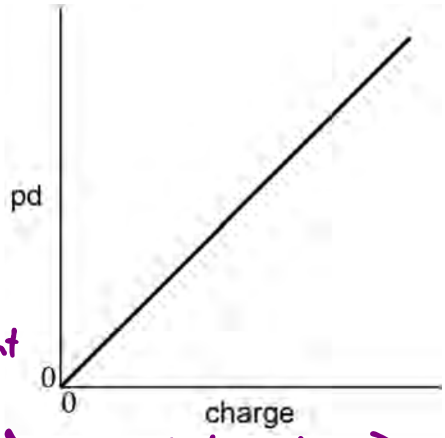
2 5 The graph shows the variation of potential difference (pd) with charge for a capacitor while it is charging.

This graph says nothing about time

Only tells us about p.d. across Capacitor not terminal.

$C = \frac{Q}{V}$

$V = \frac{Q}{C}$



$V \propto Q$ (gradient $= \frac{1}{C}$ $\Rightarrow$ gradient cst $\Rightarrow$ C is cst)

Which statement can be deduced from the graph?

[1 mark]

explicit reference to time.

~~**A**~~ The charging current is constant. $I = \frac{Q}{t}$ ○

~~**B**~~ The energy stored in the capacitor increases uniformly with time. ○

C The capacitance of the capacitor is constant. ●

~~**D**~~ The power supply used to charge the capacitor had a constant terminal pd. ○

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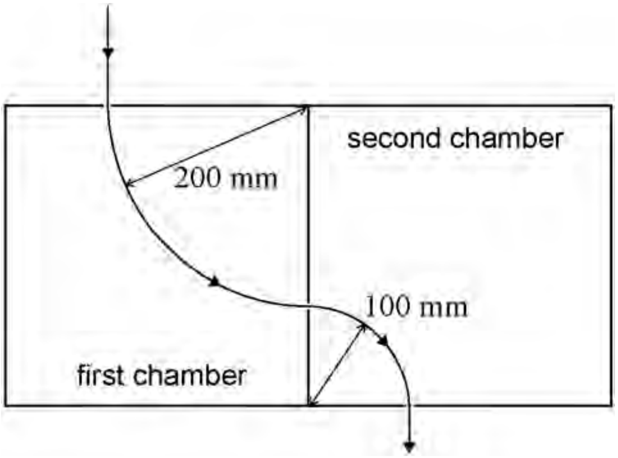
2 6 Different magnetic fields are present in the two chambers shown. A particle enters the first chamber at a velocity of 80 m s^{-1} and is deflected into a circular path of radius 200 mm
In the second chamber it follows a circular path of radius 100 mm



Magnetic force does no work
Energy of particle is unchanged
$\Rightarrow E_K = \frac{1}{2}mv^2$ unchanged
$\Rightarrow$ v the same since particle mass unchanged.

The particle leaves the second chamber at a speed of

[1 mark]

A 20 m s^{-1} ⬭

B 40 m s^{-1} ⬭

C 80 m s^{-1} ⬬

D 160 m s^{-1} ⬭

Turn over ▶

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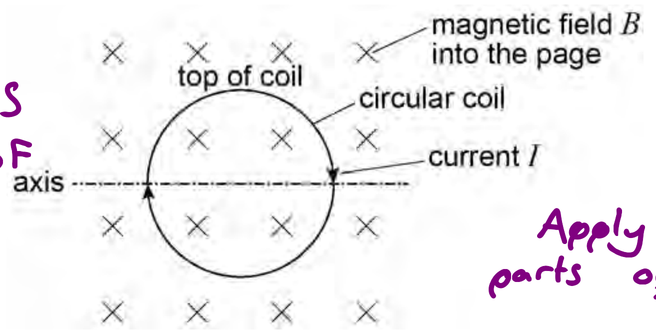
2 7 The diagram shows a clockwise current I in a circular coil placed in a uniform magnetic field B with the plane of the coil perpendicular to the magnetic field.

Top F I B

LHS I B F

RHS B F I

Bottom I B F



Left hand
Thumb - Force
Index - Field
Second - current

Apply this to various parts of coil

What is the effect on the coil of the interaction between the current and the magnetic field?

[1 mark]

~~**A**~~	It rotates about the axis with the top moving out of the page.	⬭
~~**B**~~	It rotates about the axis with the top moving into the page.	⬭
C	It causes an increase in the diameter of the coil.	●
~~**D**~~	It causes a decrease in the diameter of the coil.	⬭

2 8 A transformer has an efficiency of 80%
It has 7000 turns on its primary coil and 175 turns on its secondary coil. When the primary of the transformer is connected to a 240 V ac supply, the secondary current is 8.0 A

What are the primary current and secondary voltage?

mA → A

[1 mark]

	Primary current / mA	Secondary voltage / V		$\frac{V_s}{I_p}$	= 24
A	250	6.0	●	$\frac{6}{250\times10^{-3}}$	24 ✓
B	160	6.0	⬭	37.5	✗
C	250	9600	⬭	38400	✗
D	160	9600	⬭	60000	✗

Ex Power in = power out

$0.8 \times P_{in} = P_{out}$

$P_{in} = I_p V_p$, $P_{out} = I_s V_s$

$0.8 I_p V_p = I_s V_s$

$\frac{V_s}{I_p} = 0.8 \frac{V_p}{I_s} = 0.8 \times \frac{240}{8} = 24$

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2 9 Which graph shows how intensity I varies with angle θ when electrons are diffracted by a nucleus?

[1 mark]

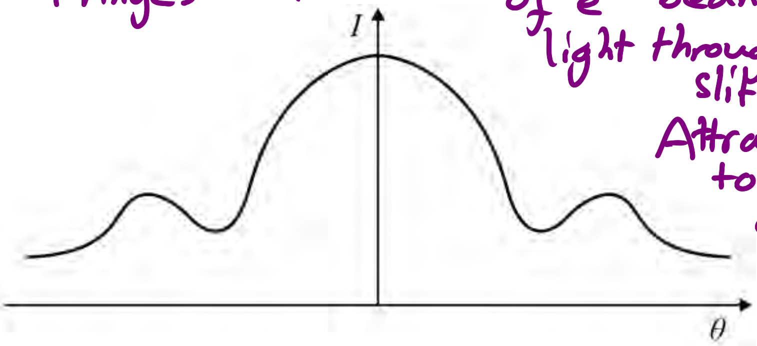
Fringes ←

Diffraction of e^- beam like light through single slit (1)

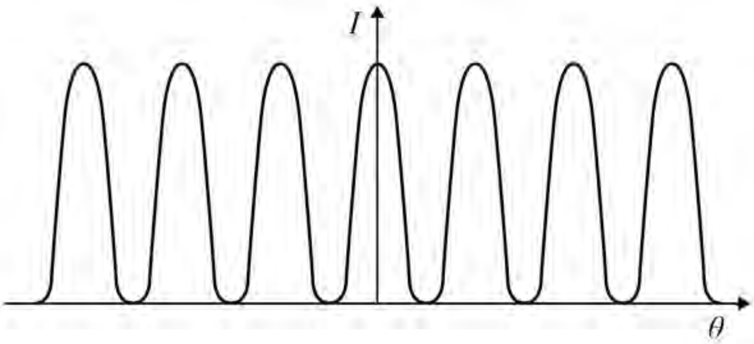
Attraction of e^- to nucleus due to electric force (2)

↳ decreasing intensity with angle θ.

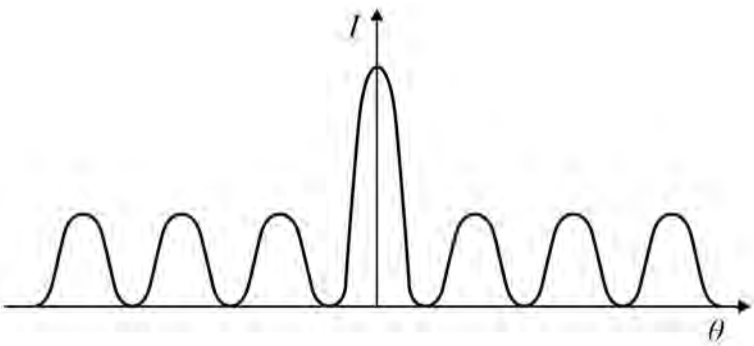
A



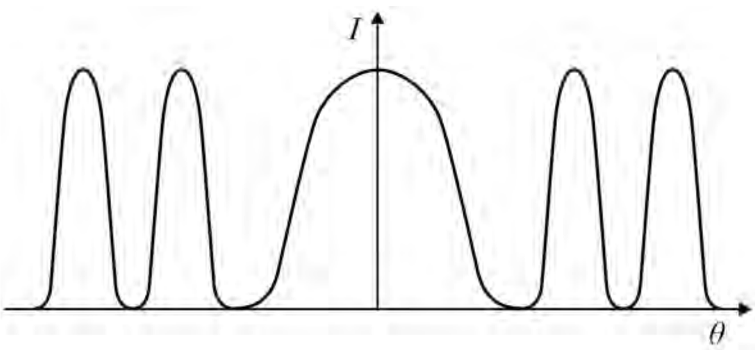
B



C



D



Turn over ▶

$^{A}_{Z}X$ A → nucleon #

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3 0 The radius of a uranium $^{238}_{92}\text{U}$ nucleus is 7.75×10^{-15} m

What is the radius of a $^{12}_{6}\text{C}$ nucleus?

$R = R_0 A^{\frac{1}{3}}$ → nucleon #

↪ reference radius ≈ 1.2 fm

[1 mark]

$R_u = R_0 A_u^{\frac{1}{3}}$

$R_c = R_0 A_c^{\frac{1}{3}}$

$\dfrac{R_c}{R_u} = \dfrac{\cancel{R_0} A_c^{\frac{1}{3}}}{\cancel{R_0} A_u^{\frac{1}{3}}} = \left(\dfrac{A_c}{A_u}\right)^{\frac{1}{3}}$

$R_c = R_u \left(\dfrac{A_c}{A_u}\right)^{\frac{1}{3}} = 7.75\times10^{-15} \times \left(\dfrac{12}{238}\right)^{\frac{1}{3}}$

$R_c = 2.863\ldots\times10^{-15}$ m

$\simeq 2.86\times10^{-15}$ m (3s.f.)

A 1.10×10^{-18} m

B 3.91×10^{-16} m

C 2.86×10^{-15} m

D 3.12×10^{-15} m

3 1 During a single fission event of uranium-235 in a nuclear reactor the total mass lost is 0.23 u. The reactor is 25% efficient.

m

How many events per second are required to generate 900 MW of power?

[1 mark]

$E = mc^2$ (energy released from mass loss)

$E = 0.23 \times u \times c^2$

useful energy: $0.25E$

number of events n (per second)

$0.25nE = 900\,\text{MW}$ ($\text{M} \to 10^6$)

$n = \dfrac{900\times10^6}{0.25\times0.23\times u\times c^2} = \dfrac{9\times10^8}{0.25\times0.23\times1.661\times10^{-27}\times(3\times10^8)^2}$

$n = 1.04703\ldots\times10^{20}$

$\simeq 1.1\times10^{20}$

A 1.1×10^{14}

B 6.6×10^{18}

C 1.1×10^{20}

D 4.4×10^{20}

3 2 Which of the following substances can be used as a moderator in a nuclear reactor?

[1 mark]

A Boron → absorbs neutron

B Concrete → containment

C Uranium-238 → alternative isotope of Uranium

D Water → moderator

25

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