

New
Specification



Rewarding Learning

ADVANCED
General Certificate of Education
2018

Centre Number

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Physics

StemUp Model Solution

Assessment Unit A2 2

assessing



Fields, Capacitors and Particle
Physics

[APH21]

APH21

FRIDAY 8 JUNE, MORNING

TIME

2 hours.

INSTRUCTIONS TO CANDIDATES

Write your Centre Number and Candidate Number in the spaces provided at the top of this page.

You must answer the questions in the spaces provided.

Do not write outside the boxed area on each page or on blank pages.

Complete in black ink only. **Do not write with a gel pen.**

Answer **all nine** questions.

INFORMATION FOR CANDIDATES

The total mark for this paper is 100.

Quality of written communication will be assessed in Question **5(a)(ii)**.

Figures in brackets printed down the right-hand side of pages indicate the marks awarded to each question or part question.

Your attention is drawn to the Data and Formulae Sheet which is inside this question paper.

You may use an electronic calculator.

11161.04R



24APH2101

- 1 The **time constant** of a resistor–capacitor (R–C) circuit can be determined using the circuit shown in **Fig. 1.1**.

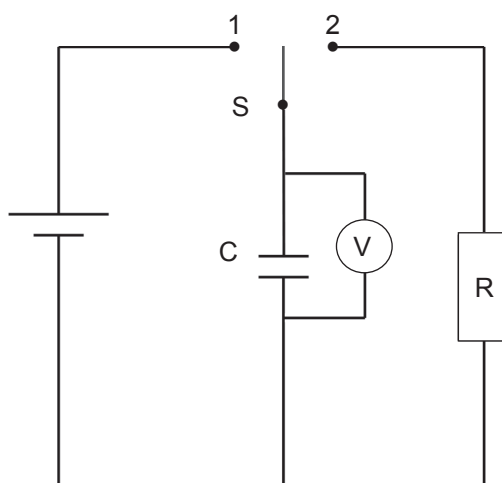


Fig. 1.1

- (a) (i) Define the term **time constant**.

The time taken for the p.d. (charge) across the capacitor to fall to $1/e$ (37%) of its initial value.

[1]

- (ii) Describe how the circuit in **Fig. 1.1** could be used to obtain results that would allow the time constant to be determined. The capacitor is initially uncharged.

Move switch S to position 1 so the capacitor charges fully from the battery; record the initial voltmeter reading V_0 .

Move S to position 2 so the capacitor discharges through R, starting a stopclock at the same instant.

Record the voltmeter reading V at regular time intervals (e.g. every 5 s) until V is close to zero.

[3]



- (b) (i) The results obtained in (a) (ii) can be used to plot a **non-linear** graph from which the time constant can be obtained. Label the axes on Fig. 1.2 and sketch the shape of the graph that you would expect to obtain.

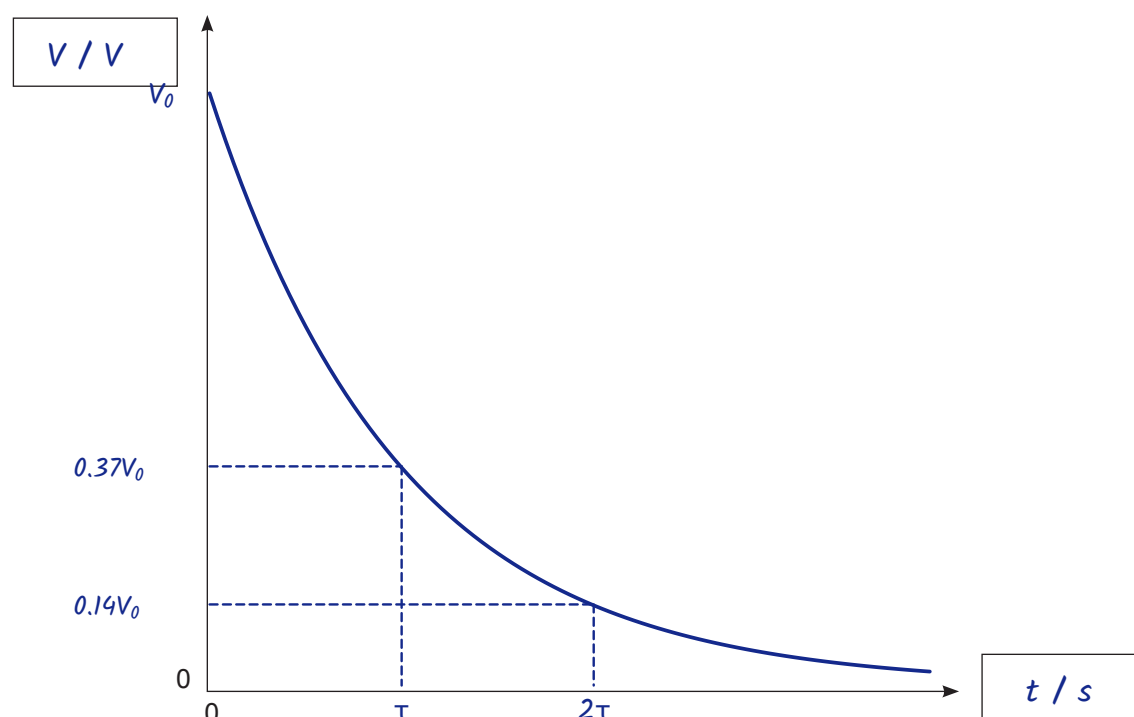


Fig. 1.2

[2]

- (ii) Explain fully how you would use your graph to obtain a **reliable** value for the time constant of the circuit.

From the graph, read the time taken for V to fall from V_0 to

$0.37V_0$; this time is the time constant τ .

Repeat for a second value, e.g. the time for V to fall from $0.37V_0$

to $0.14V_0$ ($0.37 \times 0.37V_0$), or 37% falls from other starting values

of V .

Calculate the average of these values of τ .

[3]

[Turn over]



- 2 (a) State Newton's law of universal gravitation in words.

Every point mass attracts every other point mass with a force that is proportional to the product of their masses and inversely proportional to the square of their separation.

[3]

- (b) (i) CloudSat is a satellite orbiting Earth. It was launched by NASA in April 2006 to study the vertical structure of clouds and quantify their ice and water content.

Use the information in **Table 2.1** to calculate the orbital height h of CloudSat above the Earth's surface.

Table 2.1

Mass of Earth / kg	5.98×10^{24}
Radius of Earth / km	6.37×10^3
Gravitational field strength at orbital height h / N kg^{-1}	7.97

$$g = GM_E / r^2 \quad \text{so} \quad r^2 = GM_E / g$$

$$r^2 = 6.67 \times 10^{-11} \times 5.98 \times 10^{24} / 7.97$$

$$r^2 = 5.00 \times 10^{13} \text{ m}^2$$

$$r = 7.07 \times 10^6 \text{ m}$$

$$h = r - R_E = 7.07 \times 10^6 - 6.37 \times 10^6$$

$$h = 7.04 \times 10^5 \text{ m}$$

Orbital height $h = 7.04 \times 10^5$ m

[4]



- (ii) Calculate the orbital period of CloudSat at this height.
Give your answer in hours.

$$GM_E m / r^2 = m \omega^2 r = m r (2\pi / T)^2$$

$$T^2 = 4\pi^2 r^3 / GM_E$$

$$T^2 = 4\pi^2 \times (7.07 \times 10^6)^3 / (6.67 \times 10^{-11} \times 5.98 \times 10^{24})$$

$$T^2 = 3.50 \times 10^7 \text{ s}^2 \quad \text{so} \quad T = 5920 \text{ s}$$

$$T = 5920 / 3600 = 1.64 \text{ hours}$$

Orbital period = 1.64 hours [6]

- (iii) State, giving a reason, if CloudSat is a geostationary satellite.

No: its period is 1.64 hours, but a geostationary satellite must have
a period of 24 hours. [1]

[Turn over]



- 3 The Standard Model of particle physics is a theory concerning the four fundamental forces in nature and is used to classify all known subatomic particles that exist.

- (a) (i) Complete **Table 3.1** by naming the four fundamental forces in nature and their corresponding exchange particles.

Table 3.1

Fundamental force	Exchange particle
<i>Strong nuclear</i>	<i>Gluon</i>
<i>Weak nuclear</i>	<i>W^+, W^-, Z^0</i>
<i>Electromagnetic</i>	<i>Photon</i>
<i>Gravitational</i>	<i>Graviton</i>

[4]

- (ii) Subatomic particles can be classified as hadrons or leptons. State two differences between hadrons and leptons.

Hadrons feel the strong force; leptons do not.

Hadrons are made of quarks; leptons are fundamental.

[2]

- (iii) State the quark structure of a neutron.

udd (one up quark and two down quarks)

[1]



- (iv) State the equations which describe β^- decay in terms of quarks. Include the virtual exchange particle emitted.

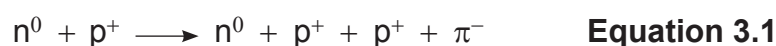
$$d \rightarrow u + W^-$$

$$W^- \rightarrow e^- + \bar{\nu}_e$$

(the W^- boson is the virtual exchange particle)

[2]

- (b) Consider two appropriate conservation laws to determine whether the hadron reaction described in **Equation 3.1**, which produces a pi-minus meson, can occur. Show your working clearly in the space below.



Charge: $LHS = 0 + (+1) = +1$; $RHS = 0 + 1 + 1 + (-1) = +1$

so charge is conserved.

Baryon number: $LHS = 1 + 1 = 2$; $RHS = 1 + 1 + 1 + 0 = 3$

so baryon number is not conserved.

Baryon number is not conserved, so the reaction cannot occur.

Can this reaction occur? No

[3]

[Turn over]



- 4 (a) A magnetic field exists around a conductor carrying an electric current. Sketch the shape of the field and indicate its direction due to the current carrying conductor shown in Fig. 4.1. The direction of the current is indicated by the arrow.

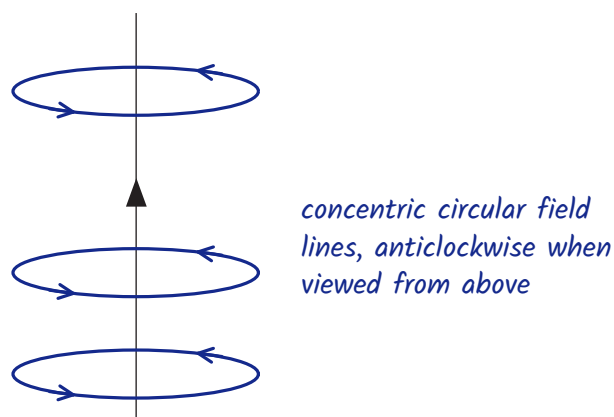


Fig. 4.1

[2]

- (b) Two identical magnets, with opposite poles facing, are placed on a top pan balance. A wire is fixed so that it is parallel to the magnets and connected to a circuit as shown in Fig. 4.2a.

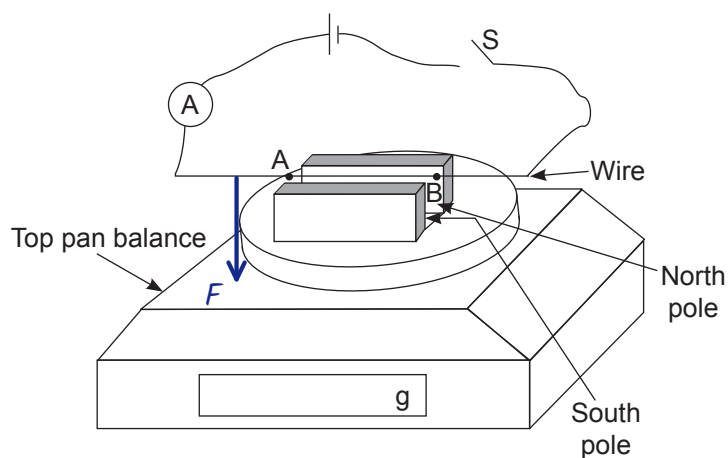


Fig. 4.2a

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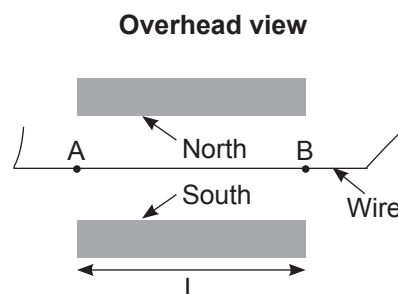


Fig. 4.2b

On Fig. 4.2a, draw an arrow to show the direction of the force on the wire when switch S is closed.

[1]



- (c) Before the switch was closed, an initial balance reading was taken. The switch was then closed and the readings on the ammeter and balance recorded. These readings are shown in **Table 4.1**.

Table 4.1

I / A	m / g	F / N
0	76.83	
4.24	76.30	0.0052

$$\Delta m = 76.83 - 76.30 = 0.53 \text{ g}; \quad F = 0.53 \times 10^{-3} \times 9.81 = 5.2 \times 10^{-3} \text{ N}$$

- (i) Complete the column headed **F / N** in **Table 4.1** to determine the magnitude of the force exerted on the wire for a current of 4.24 A. [2]

- (ii) Determine the flux density of the magnets. The length of the magnets **L**, as shown in **Fig. 4.2b**, is 5.00 cm.

$$F = BIL \quad \text{so} \quad B = F / IL$$

$$B = 0.0052 / (4.24 \times 5.00 \times 10^{-2})$$

$$B = 0.0245 \text{ T}$$

Flux density 0.0245 T [3]

- (iii) A voltmeter is placed in parallel across the wire between points A and B and reads 0.41 V when the current through the wire is 4.24 A. Calculate the resistivity of the wire if its diameter is 0.18 mm.

$$\rho = RA / L, \quad R = V / I = 0.41 / 4.24 = 0.0967 \, \Omega$$

$$A = \pi r^2 = \pi \times (0.09 \times 10^{-3})^2 = 2.54 \times 10^{-8} \text{ m}^2$$

$$\rho = 0.0967 \times 2.54 \times 10^{-8} / 5.00 \times 10^{-2}$$

$$\rho = 4.92 \times 10^{-8} \, \Omega \text{ m}$$

Resistivity = 4.92×10^{-8} $\Omega \text{ m}$ [4]

[Turn over]



5 Quality of written communication will be assessed in (a)(ii) of this question.

(a) Fig. 5.1 is a simplified diagram of the National Grid. T1 and T2 are transformers.

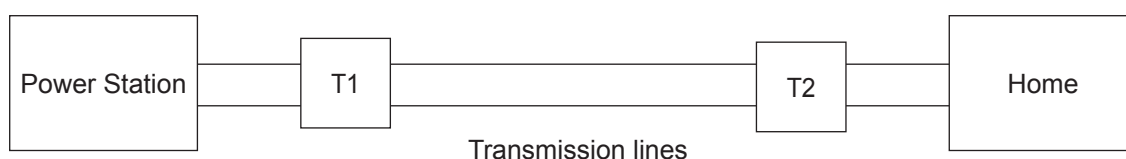


Fig. 5.1

(i) What type of transformers are T1 and T2?

Transformer T1: Step-up

Transformer T2: Step-down

[1]

Describe how a transformer is constructed.

A primary coil and a secondary coil of insulated wire, both wound
on (linked by) a laminated soft iron core.

[2]

(ii) Explain how transformer T2 works in order to produce an appropriate output voltage to our homes.

An alternating current (a.c.) supply at voltage V_p is connected to
the primary coil of T2.

The alternating current in the primary produces a continually
changing magnetic flux in the soft iron core.

The laminated soft iron core links this flux to the secondary coil,
so the flux through the secondary coil is also continually
changing.

By Faraday's law, this changing flux linkage induces an



alternating e.m.f. V_s across the secondary coil, giving an a.c.

output.

T2 is a step-down transformer: the secondary coil has fewer turns

than the primary coil, $N_s < N_p$.

Since $V_s / V_p = N_s / N_p$, the output voltage is smaller than the

input voltage ($V_s < V_p$), so the very high transmission voltage is

reduced to the safe 230 V supplied to our homes.

[6]

- (b) Explain why high voltage transmission lines are necessary for energy to be transmitted across the country efficiently.

For the same power transmitted ($P = IV$), a high voltage means a

much lower current flows in the cables.

Power lost as heat in the cables is $P = I^2R$, so a lower current means

far less energy is wasted as heat, and the energy is transmitted

efficiently.

[2]

[Turn over

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24APH2111

6 (a) Define **electric field strength**.

The force per unit charge experienced by a small positive test charge placed at that point ($E = F / Q$).

[2]

- (b) **Fig. 6.1** shows two point charges Q_1 and Q_2 of $+25\mu\text{C}$ and $+15\mu\text{C}$ placed a distance of 2 m apart in a vacuum.

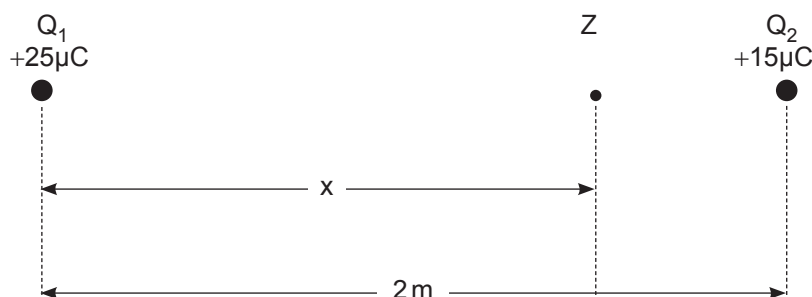


Fig. 6.1

- (i) Calculate the magnitude and direction of the force exerted on the $+25\mu\text{C}$ charge.

$$F = kQ_1Q_2 / r^2 = 8.99 \times 10^9 \times 25 \times 10^{-6} \times 15 \times 10^{-6} / 2^2$$

$$F = 0.84 \text{ N, repulsion (both positive), so away from } Q_2$$

$$\text{Force} = \underline{0.84} \text{ N}$$

$$\text{Direction} = \underline{\text{to the left}}$$

[3]



(ii) The resultant electric field strength is zero at point Z, a distance x from Q_1 .

Calculate the magnitude of x .

$E = kQ / r^2$; at Z the two field strengths are equal and opposite:

$$k(25 \times 10^{-6}) / x^2 = k(15 \times 10^{-6}) / (2 - x)^2$$

k cancels: $25 / x^2 = 15 / (2 - x)^2$

square root: $5 / x = \sqrt{15} / (2 - x) = 3.873 / (2 - x)$

$$5(2 - x) = 3.873x \quad \text{so} \quad 10 = 8.873x$$

$$x = 1.13 \text{ m}$$

$$x = \underline{1.13} \text{ m}$$

[4]

[Turn over]



- 7 **Fig. 7.1** shows the basic structure of a synchrotron. A synchrotron is an accelerator used to progressively increase the speed of particles as they travel in a circular path of fixed radius.

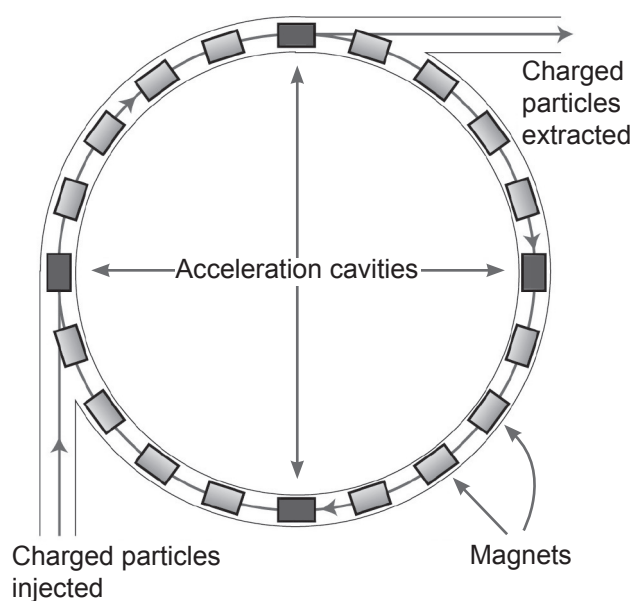


Fig. 7.1

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- (a) (i) Describe how the circular path of fixed radius is achieved.

The magnetic field provides the centripetal force, $Bqv = mv^2/r$.

B is increased as the particles speed up, so $r = mv/Bq$ is fixed.

[2]



- (ii) In this synchrotron the magnetic field is maintained using superconducting electromagnets.

Explain why superconductors are used to create the magnetic field and how the superconducting state is achieved.

Superconductors have zero resistance, so no energy is lost as heat in the coils.

So a very large current can flow, giving the very large magnetic field needed to bend the high energy particles.

This state is achieved by cooling the coils with liquid helium to below the critical (transition) temperature.

[4]

- (iii) The acceleration cavities are connected to a high frequency alternating voltage. The frequency of this voltage is increased as the speed of the particles increases. Why is this necessary?

To maintain synchronous acceleration: faster particles reach each cavity sooner, so the p.d. must reverse sooner.

[1]

- (iv) The particles can be accelerated until their speed approaches the speed of light. Explain how the particles can continue to gain kinetic energy but no longer increase their speed.

Near the speed of light, the energy supplied increases the particles' (relativistic) mass, not their speed.

[1]

[Turn over]



- (b) Protons are accelerated through the accelerator complex at CERN in various stages before being transferred to the synchrotron known as the Large Hadron Collider (LHC) with an initial energy of 0.45 TeV. The LHC has 8 cavities each with a potential difference of 2 MV which accelerate the protons.

How many orbits of the LHC must a proton complete to reach a final energy of 7 TeV?

$$\text{Energy gained per cavity: } E = qV$$

$$\text{Per orbit: } E = 1.6 \times 10^{-19} \times 8 \times 2 \times 10^6 = 2.56 \times 10^{-12} \text{ J}$$

$$\text{Per orbit} = 2.56 \times 10^{-12} / 1.6 \times 10^{-19} = 16 \times 10^6 \text{ eV (16 MeV)}$$

$$\text{Energy needed} = (7 - 0.45) \times 10^{12} = 6.55 \times 10^{12} \text{ eV}$$

$$\text{Number of orbits} = 6.55 \times 10^{12} / 16 \times 10^6$$

$$\text{Number of orbits} = 4.1 \times 10^5$$

$$\text{Number of orbits} = \underline{4.1 \times 10^5}$$

[5]





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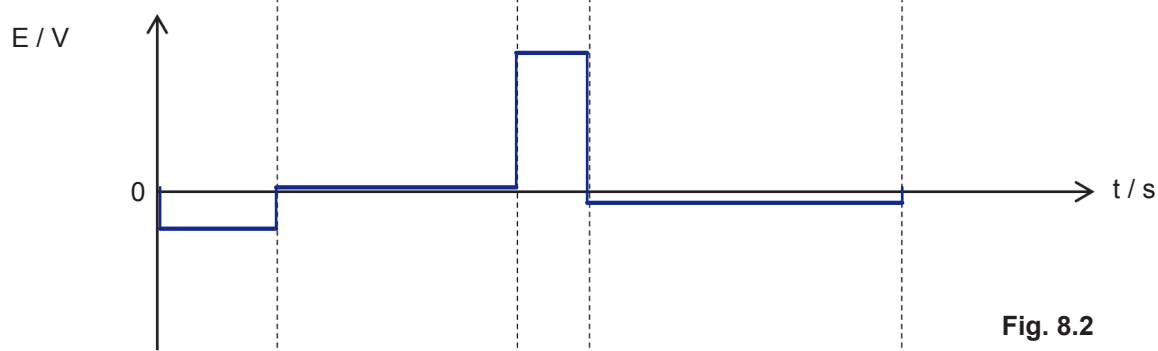
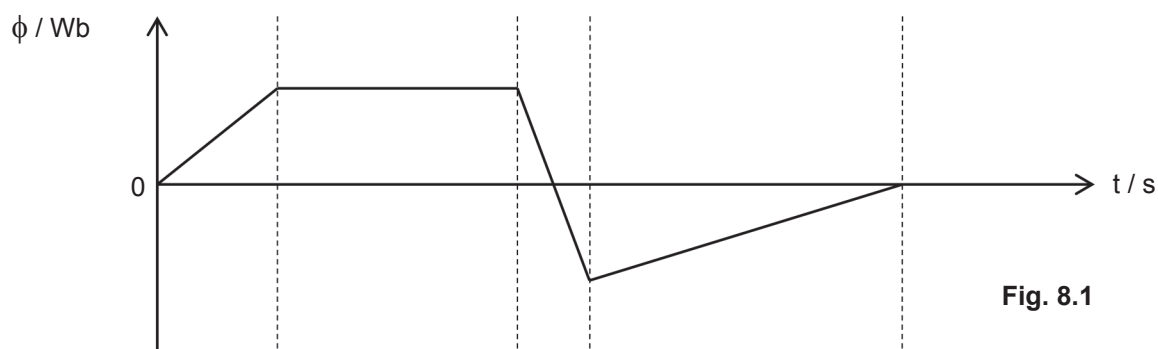
8 (a) (i) State Faraday's law of electromagnetic induction.

The magnitude of the induced e.m.f. is equal to the rate of change of magnetic flux linkage ($E = -N\Delta\phi/\Delta t$).

[1]

(ii) A circular coil of wire is placed with its plane perpendicular to a magnetic field. The magnetic flux ϕ through the coil changes with time t as shown in Fig. 8.1.

Draw a graph to show how the e.m.f. E induced in the coil changes with time on the blank set of axes in Fig. 8.2.



$E = -d\phi/dt$ (gradient of Fig. 8.1)

[4]





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24APH2119

- (b) A coil of wire with 340 turns, each of area 65 cm^2 , is placed within a uniform magnetic field of 55 mT . The coil is rotated through 500 revolutions per minute, inducing an alternating e.m.f. within the coils as shown in Fig. 8.3.

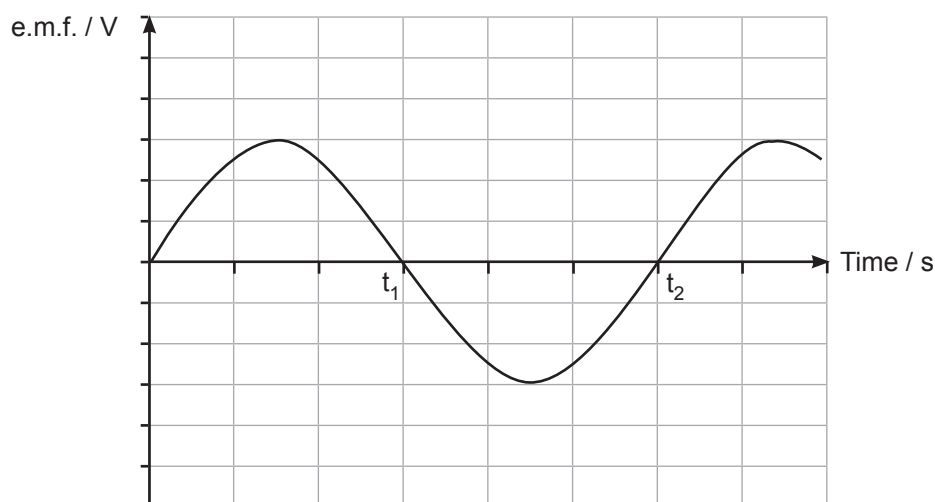


Fig. 8.3

- (i) The e.m.f. induced in the coil is 0 V at times t_1 and t_2 . By making reference to the position of the coil within the field explain why it is zero at these times.

At t_1 and t_2 the plane of the coil is perpendicular to the field.

The magnetic flux through the coil is then a maximum, but the rate of change of flux is zero (the coil sides move parallel to the field lines), so the induced e.m.f. is zero.

[3]



(ii) Calculate the frequency of the alternating output.

$$f = \text{revolutions per second} = 500 / 60$$

$$f = 8.33 \text{ Hz}$$

$$\text{Frequency} = \underline{8.33} \text{ Hz} \quad [1]$$

(iii) Calculate the maximum value of e.m.f.

$$E_{\max} = BAN\omega = BAN \times 2\pi f$$

$$E_{\max} = 55 \times 10^{-3} \times 65 \times 10^{-4} \times 340 \times 2\pi \times 8.33$$

$$E_{\max} = 6.36 \text{ V}$$

$$\text{Maximum e.m.f.} = \underline{6.36} \text{ V} \quad [2]$$

[Turn over



- 9 A beam of electrons travelling horizontally enters a uniform magnetic field midway between two horizontal metal plates, in a vacuum. The plates are 175 mm long and have a separation of 30 mm. The potential difference applied across the plates is increased to 1.5 kV so that the electron beam just emerges past the end of the lower plate as shown in Fig. 9.1.

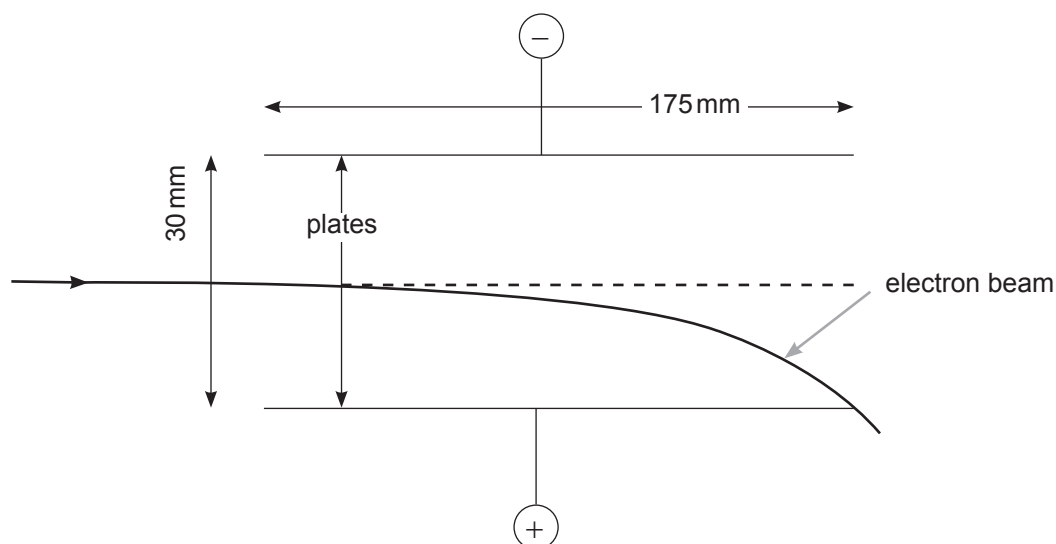


Fig. 9.1

- (a) (i) Determine the electric field strength between the plates.

$$E = V / d = 1500 / (30 \times 10^{-3})$$

$$E = 50\,000 \text{ V m}^{-1}$$

Electric field strength = 50 000 V m⁻¹

[2]

- (ii) Determine the force on the electron beam due to the electric field.

$$F = qE = 1.6 \times 10^{-19} \times 50\,000$$

$$F = 8.0 \times 10^{-15} \text{ N}$$

Force = 8.0×10^{-15} N

[2]



- (iii) Calculate the acceleration of an electron in the beam due to the electric field.

$$a = F / m_e = 8.0 \times 10^{-15} / 9.11 \times 10^{-31}$$

$$a = 8.78 \times 10^{15} \text{ m s}^{-2}$$

Acceleration = $\underline{8.78 \times 10^{15}}$ m s⁻² [1]

- (b) (i) For this electron beam that just emerges past the end of the lower plate, calculate the time spent by the beam in the electric field.

The beam enters midway, so its vertical deflection $s = 15 \times 10^{-3} \text{ m}$;

vertically $u = 0$: $s = ut + \frac{1}{2}at^2$

$$15 \times 10^{-3} = 0 + \frac{1}{2} \times 8.78 \times 10^{15} \times t^2$$

$$t^2 = 3.42 \times 10^{-18} \quad \text{so} \quad t = 1.85 \times 10^{-9} \text{ s}$$

Time = $\underline{1.85 \times 10^{-9}}$ s [3]

- (ii) Calculate the initial speed of the electrons as they enter the field.

Horizontal velocity is constant: $v = s / t$

$$v = 175 \times 10^{-3} / 1.85 \times 10^{-9} = 9.47 \times 10^7 \text{ m s}^{-1}$$

Initial speed = $\underline{9.47 \times 10^7}$ m s⁻¹ [1]

THIS IS THE END OF THE QUESTION PAPER



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Question Number	Marks
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Examiner Number

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Physics

Assessment Units A2 1 and A2 2

[APH11/APH21]

DATA AND FORMULAE SHEET

FOR USE FROM 2018 ONWARDS

Data and Formulae Sheet for A2 1 and A2 2

Values of constants

speed of light in a vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
permittivity of a vacuum	$\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ $\left(\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ F}^{-1} \text{ m} \right)$
elementary charge	$e = 1.60 \times 10^{-19} \text{ C}$
the Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$
(unified) atomic mass unit	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$
mass of electron	$m_e = 9.11 \times 10^{-31} \text{ kg}$
mass of proton	$m_p = 1.67 \times 10^{-27} \text{ kg}$
molar gas constant	$R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$
the Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
the Boltzmann constant	$k = 1.38 \times 10^{-23} \text{ J K}^{-1}$
gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
acceleration of free fall on the Earth's surface	$g = 9.81 \text{ m s}^{-2}$
electron volt	$1 \text{ eV} = 1.60 \times 10^{-19} \text{ J}$
the Hubble constant	$H_0 \approx 2.4 \times 10^{-18} \text{ s}^{-1}$

Useful formulae

The following equations may be useful in answering some of the questions in the examination:

Mechanics

conservation of energy $\frac{1}{2}mv^2 - \frac{1}{2}mu^2 = Fs$
for a constant force

Hooke's Law $F = kx$ (spring constant k)
strain energy $E = \frac{1}{2}Fx = \frac{1}{2}kx^2$

Uniform circular motion

centripetal Force $F = \frac{mv^2}{r}$

Simple harmonic motion

displacement $x = A \cos \omega t$
simple pendulum $T = 2\pi \sqrt{\frac{l}{g}}$
loaded spiral spring $T = 2\pi \sqrt{\frac{m}{k}}$

Waves

two-source interference $\lambda = \frac{ay}{d}$
diffraction grating $d \sin \theta = n \lambda$

Thermal physics

average kinetic energy of
a molecule

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

kinetic theory

$$pV = \frac{1}{3} Nm \langle c^2 \rangle$$

thermal energy

$$Q = mc\Delta\theta$$

Capacitors

capacitors in series

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

capacitors in parallel

$$C = C_1 + C_2 + C_3$$

time constant

$$\tau = RC$$

capacitor discharge

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

$$\text{or } V = V_0 e^{\frac{-t}{CR}}$$

$$\text{or } I = I_0 e^{\frac{-t}{CR}}$$

Light

lens formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Electricity

terminal potential difference

$$V = E - Ir$$

(e.m.f., E ; Internal Resistance, r)

potential divider

$$V_{\text{out}} = \frac{R_1 V_{\text{in}}}{R_1 + R_2}$$

a.c. generator

$$E = BAN\omega \sin\omega t$$

Nuclear Physics

nuclear radius

$$r = r_0 A^{\frac{1}{3}}$$

radioactive decay

$$A = -\lambda N, \quad A = A_0 e^{-\lambda t}$$

half-life

$$t_{\frac{1}{2}} = \frac{0.693}{\lambda}$$

Particles and photons

Einstein's equation

$$\frac{1}{2} m v_{\max}^2 = hf - hf_0$$

de Broglie equation

$$\lambda = \frac{h}{p}$$

Astronomy

red shift

$$z = \frac{\Delta \lambda}{\lambda}$$

recession speed

$$z = \frac{v}{c}$$

Hubble's law

$$v = H_0 d$$

