



A Level Physics B (Advancing Physics)

H557/03 Practical skills in physics

Time allowed: 1 hour 30 minutes

You must have:

- the Data, Formulae and Relationships Booklet

You can 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 can use an HB pencil, but only for graphs and diagrams.
- Write your answer to each question in the space provided. If you need extra space use the lined pages at the end of this booklet. The question numbers must be clearly shown.
- Answer **all** the questions.
- Where appropriate, your answer should be supported with working. Marks might be given for using a correct method, even if your answer is wrong.

INFORMATION

- The total mark for this paper is **60**.
- The marks for each question are shown in brackets [].
- Quality of extended response will be assessed in questions marked with an asterisk (*).
- This document has **20** pages.

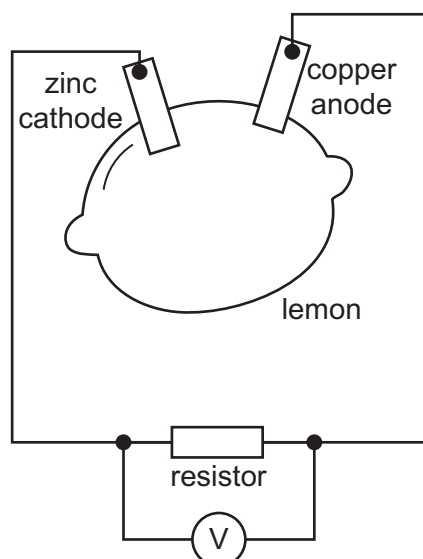
ADVICE

- Read each question carefully before you start your answer.

Section A

- 1 A cell can be made by inserting a zinc cathode and a copper anode into a lemon. A high resistance voltmeter is used in the circuit shown in **Fig. 1.1** to measure the p.d. across the lemon when different resistors are placed across the cell.

Fig. 1.1



- (a) **Table 1** below shows the data recorded.

Table 1

resistance /k Ω	potential difference /mV	current / μ A
3.3	540	164
6.6	666	101
10.0	738	73.8
13.3	765	57.5
16.6	784	47
20.0	812	41

- (i) Calculate the current and complete the missing rows in **Table 1**.

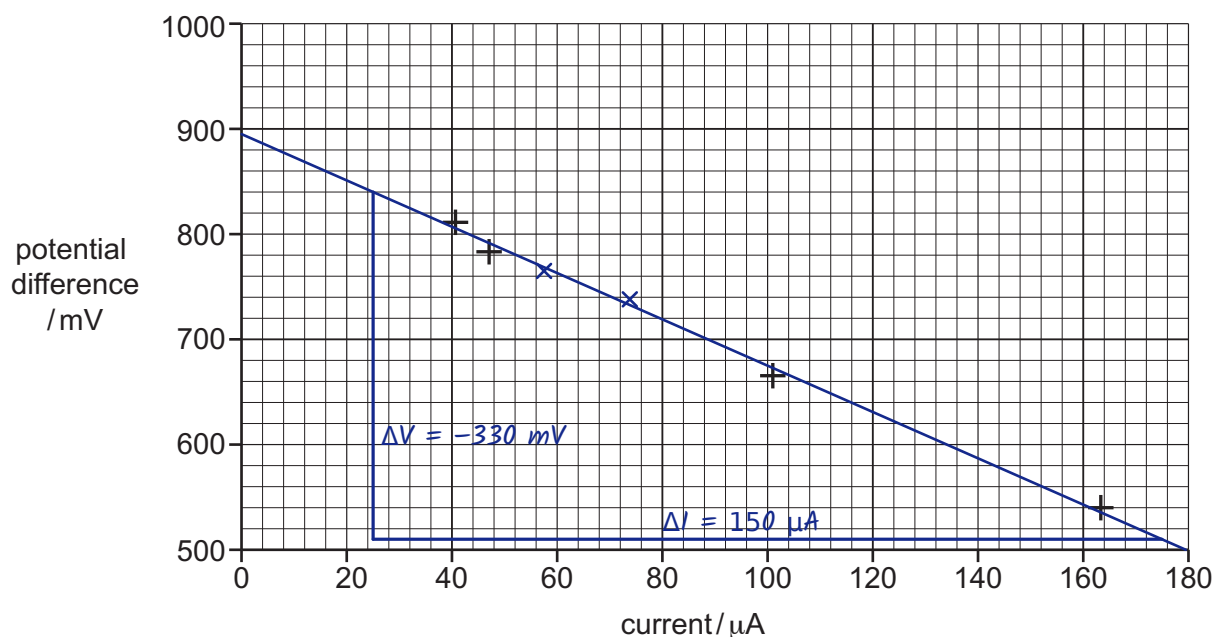
$$I = V/R = 738 \text{ mV} / 10.0 \text{ k}\Omega = 73.8 \text{ }\mu\text{A}$$

$$I = 765 \text{ mV} / 13.3 \text{ k}\Omega = 57.5 \text{ }\mu\text{A}$$

[1]

- (ii) Plot the missing points on the graph in **Fig. 1.2** and draw the line of best fit. [2]

Fig. 1.2



- (iii) Find the gradient of the line of best fit and hence calculate the lemon's internal resistance, in ohms, Ω . Show your working. [3]

$$\text{Gradient} = \Delta V / \Delta I = (510 - 840) \text{ mV} / (175 - 25) \mu\text{A}$$

$$= -330 \times 10^{-3} \text{ V} / 150 \times 10^{-6} \text{ A} = -2.2 \times 10^3 \Omega$$

$$\varepsilon = V + Ir, \text{ so } V = \varepsilon - Ir; \text{ gradient} = -r$$

$$r = -\text{gradient} = 2.2 \times 10^3 \Omega$$

Internal resistance = ...2200..... Ω [3]

- (iv) A student suggests that two lemon cells in series could be used to run a 1.5V, 0.45W filament lamp. Explain why this is not correct. [2]

Lamp needs $I = P/V = 0.45/1.5 = 0.3 \text{ A}$, but the current from the lemons is much too low, less than 1 mA ($\text{max } 0.9 \text{ V} / 2200 \Omega = 0.4 \text{ mA}$). Lamp resistance 5Ω is much smaller than the internal resistance, so most p.d. is across the lemon cells.

- (b)* The experiment is repeated with two lemon cells in series and with two lemon cells in parallel.

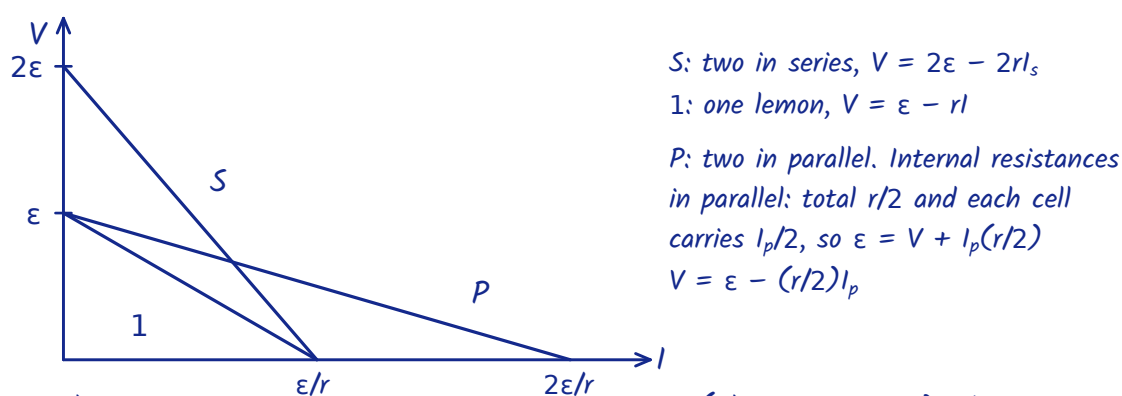
For two lemons in series, the emf expression is found to be

$$2\varepsilon = V + 2I_{\text{series}}r$$

where ε is the emf of one lemon cell and r is the internal resistance of a single lemon cell.

Describe the effects of these combinations on the relationship between current and potential difference. In your answer, you should:

- derive the emf expression for two lemon cells connected in parallel in terms of ε and r .
- compare the gradients and intercepts of all three experiments and sketch the V-I graphs to compare the two lemon V-I relationships to the graph for one lemon in **Fig. 1.2**.



One lemon: $V = \varepsilon - rI$, so the y-intercept is ε (about 895 mV), the gradient is $-r$ (about $-2.2 \text{ k}\Omega$) and the x-intercept (short-circuit current) is ε/r .

Two in series: $V = 2\varepsilon - 2rI_s$. The y-intercept doubles to 2ε and the gradient doubles to $-2r$, so the line is steeper, but the x-intercept $2\varepsilon/2r = \varepsilon/r$ is the same as for one lemon. The same current flows in both cells and the load, so a larger proportion of the emf is lost volts.

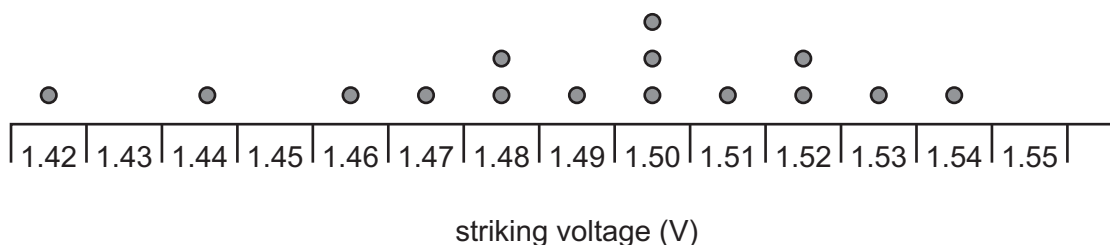
Two in parallel: $V = \varepsilon - (r/2)I_p$. The y-intercept is ε , the same as one lemon, the gradient is $-r/2$ so the line is less steep, and the x-intercept $2\varepsilon/r$ is twice that of one lemon. The current in each cell is half the load current, so for the same load current the lost volts are halved.

[6]

- 2 This question is about an experiment to determine the value of the Planck constant h .

A student increases the potential difference across a blue LED until it just starts to glow. The student measures the value of this pd using a multimeter. This is known as the 'striking voltage'. The measurement is repeated, and a dot-plot is drawn, as shown in **Fig. 2.1**.

Fig. 2.1



- (a) (i) Calculate the mean value of striking voltage and its absolute uncertainty.

$$\text{Mean} = (1.42 + 1.44 + 1.46 + 1.47 + 2(1.48) + 1.49 + 3(1.50) + 1.51 + 2(1.52) + 1.53 + 1.54) / 15 = 22.36 / 15 = 1.49 \text{ V}$$

$$\text{Uncertainty} = \frac{1}{2} \text{ range} = \frac{1}{2} (1.54 - 1.42) = 0.06 \text{ V}$$

Mean striking voltage = ...1.49..... $\pm$ 0.06..... V [2]

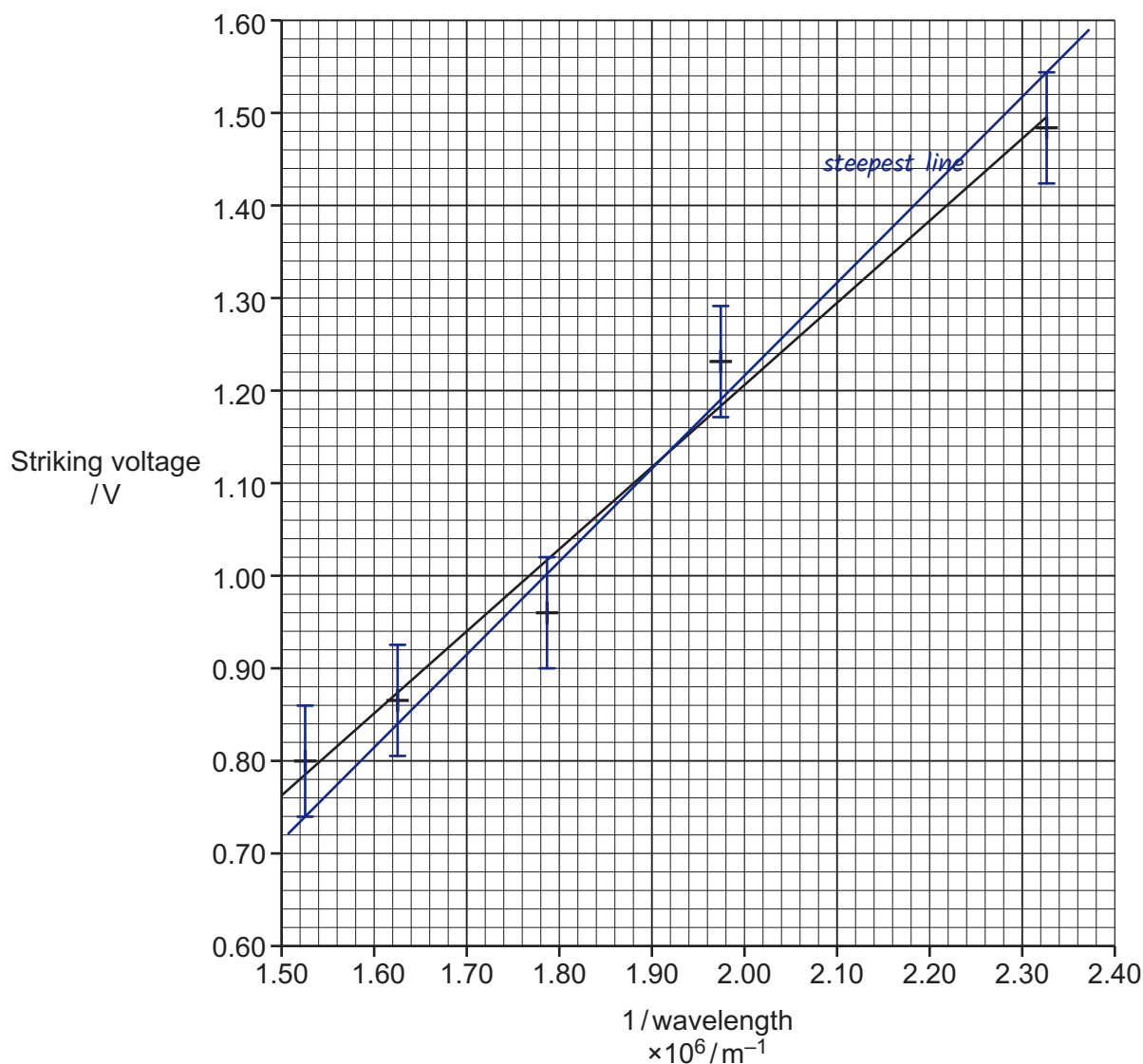
- (ii) Describe **one** significant cause of uncertainty in this measurement and suggest a method which would reduce the uncertainty.

..Ambient light makes it difficult to judge when the LED just starts to.....
 ..glow. Take readings in the dark, shielding the LED with a black tube.....
 ..from ambient light..... [2]

- (b) The student then repeats the measurement of striking voltage for LEDs of different colours. She refers to the manufacturer's data to find the value of wavelength for each LED and plots a graph of $1/\text{wavelength}$ (on the x-axis) against striking voltage (on the y-axis). The graph is shown in **Fig. 2.2**.

The gradient of this line of best fit = $8.90 \times 10^{-7} \text{ V m}$.

Fig. 2.2



- (i) Using the value for uncertainty found in (a)(i), add vertical error bars to all the plotted points and draw a steepest acceptable line through the error bars. [2]
- (ii) Hence calculate the absolute uncertainty of the gradient value.

Steepest line through (1.525, 0.740) and (2.326, 1.547):

$$\text{gradient} = (1.547 - 0.740) / ((2.326 - 1.525) \times 10^6) = 1.01 \times 10^{-6} \text{ V m}$$

$$\text{uncertainty} = 10.1 \times 10^{-7} - 8.90 \times 10^{-7} = 1.2 \times 10^{-7} \text{ V m}$$

Absolute uncertainty of gradient = $\pm 1.2 \times 10^{-7} \text{ V m}$ [2]

- (c) (i) Show that the Planck constant, $h = \text{gradient} \times \frac{e}{c}$.

Photon energy $E = hf = hc/\lambda$. Energy given to an electron = eV .

When the LED just strikes, $eV = hc/\lambda$, so $V = (hc/e) \times (1/\lambda)$

Gradient of V against $1/\lambda = V\lambda = hc/e$

so $h = \text{gradient} \times e/c$

[2]

- (ii) The gradient of the line of best fit is $8.90 \times 10^{-7} \text{ V m}$.
Use this value to calculate a value of the Planck constant.
Include a value for absolute uncertainty in your answer.

$$h = 8.90 \times 10^{-7} \times 1.60 \times 10^{-19} / 3.00 \times 10^8 = 4.75 \times 10^{-34} \text{ J s}$$

$$\text{Relative uncertainty in gradient} = 1.2 \times 10^{-7} / 8.90 \times 10^{-7} = 0.135$$

$$\text{Absolute uncertainty in } h = 0.135 \times 4.75 \times 10^{-34} = 0.6 \times 10^{-34} \text{ J s}$$

$$(\text{check: } h_{\text{max}} = 1.01 \times 10^{-6} \times e/c = 5.4 \times 10^{-34}, \text{ difference } 0.6 \times 10^{-34})$$

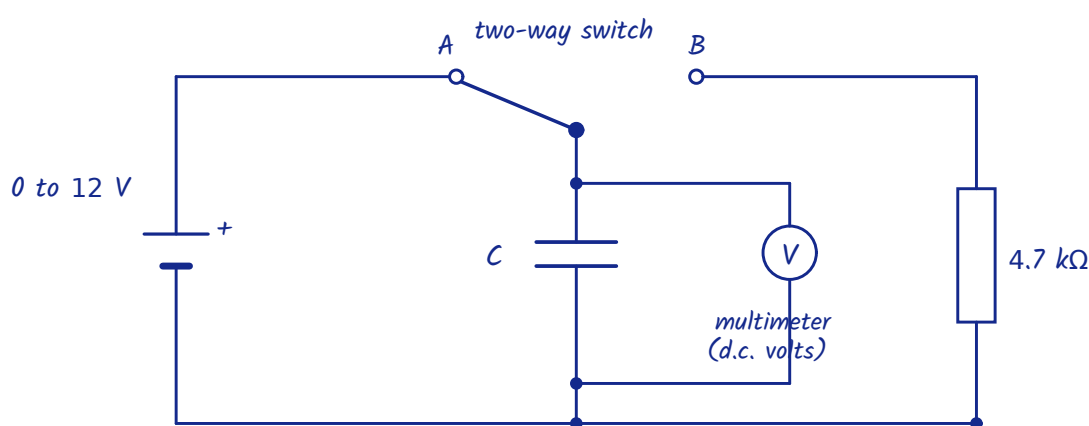
$$\text{Planck constant} = 4.7 \times 10^{-34} \pm 0.6 \times 10^{-34} \text{ Js [3]}$$

3 This question is about the discharge of a capacitor.

(a) You are provided with the following apparatus:

variable power supply (0 – 12 V)
 capacitor of unknown capacitance
 resistor of value $4.7\text{ k}\Omega$
 multimeter
 leads and switches
 stopwatch

Describe a method to record the potential difference, V , across the capacitor as it discharges, using the apparatus listed. Include a circuit diagram in your answer.



Switch to A and charge the capacitor fully from the supply (e.g. 8.0 V), with the multimeter set to d.c. volts across C.

Move the switch to B so the capacitor discharges through the $4.7\text{ k}\Omega$ resistor (supply not in this circuit) and start the stopwatch when V reaches a set value, e.g. 7.00 V .

Record V and t every 10 s as it discharges. Repeat the discharge and average V at each time.

[4]

- (b) Values of V as the capacitor discharges through the $4.7\text{ k}\Omega$ resistor are recorded at 10 s intervals in **Table 3**.

Table 3

time t/s	potential difference across capacitor V/V	$\ln V$	V_n/V_{n-1}
0	7.00	1.946	
10	4.54	1.513	0.649
20	2.97	1.089	0.654
30	1.98	0.683	0.667
40	1.35	0.300	0.682
50	0.94	-0.062	0.696

Ratios V_n/V_{n-1} for equal 10 s intervals are all about 0.67 (0.65 to 0.70):

- (i) Capacitor discharge is an example of exponential decay and follows the equation

$$V = V_0 e^{\frac{-t}{RC}}.$$

approximately constant, so V falls by the same fraction in equal times: exponential decay.

Complete the $\ln V$ column in **Table 3** and then perform a mathematical test on the data to show that it follows exponential decay.

You may use the extra column in the table for your working.

[3]

- (ii) Show that the value of the time constant, τ is approximately 25 s.

$$\ln V = \ln V_0 - t/RC, \text{ so gradient of } \ln V \text{ against } t = -1/RC$$

$$\text{gradient} = (-0.062 - 1.946) / (50 - 0) = -0.0402 \text{ s}^{-1}$$

$$\tau = RC = 1/0.0402 = 24.9 \text{ s} \approx 25 \text{ s}$$

$$\text{(or mean ratio 0.670 per 10 s: } \ln 0.670 = -10/RC, RC = 25 \text{ s)}$$

[1]

- (iii) Calculate the value of the capacitance.

$$C = \tau/R = 25 / 4.7 \times 10^3$$

$$\text{Capacitance} = \dots\dots\dots 5.3 \times 10^{-3} \dots\dots\dots \text{ F [1]}$$

(c) There is a general rule of thumb used by electronic engineers that the time taken for a capacitor to discharge completely is 5τ .

- (i) Starting from the equation given in (b)(i) and repeated below show that when $t = 5\tau$, the energy stored in the capacitor, $E = 4.5 \times 10^{-5} E_0$, where E_0 is the energy stored in the fully charged capacitor.

$$V = V_0 e^{\frac{-t}{RC}}$$

$$\text{At } t = 5\tau = 5RC: V = V_0 e^{-5RC/RC} = V_0 e^{-5} = 6.74 \times 10^{-3} V_0$$

Energy stored $E = \frac{1}{2} CV^2$, so E is proportional to V^2

$$E/E_0 = (V/V_0)^2 = (e^{-5})^2 = e^{-10}$$

$$E = (6.74 \times 10^{-3})^2 E_0 = 4.5 \times 10^{-5} E_0$$

[3]

- (ii) Justify why this rule of thumb is useful to engineers.

After 5τ there is negligible energy (charge, p.d.) left in the capacitor, so
it is safe to handle. [1]

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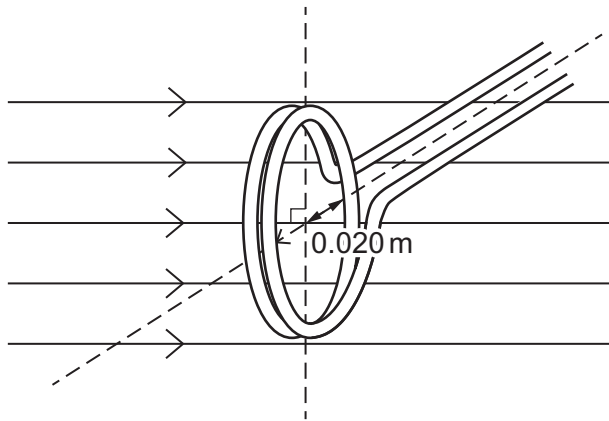
Section B begins on page 12

Section B

- 4 This question is about inducing an emf in a coil of wire.

Fig. 4.1 shows a coil of wire perpendicular to a uniform magnetic field.

Fig. 4.1



- (a) (i) The coil has 10 turns of radius 0.020 m. The field strength is 5.0 mT.

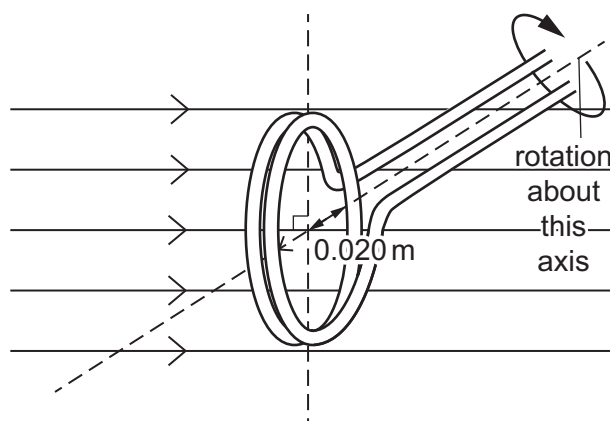
Show that the flux linkage of the coil is about 6.3×10^{-5} Wb.

$$\begin{aligned}
 \text{Flux linkage} &= N\Phi = BAN \\
 &= 5.0 \times 10^{-3} \times (\pi \times 0.020^2) \times 10 \\
 &= 6.28 \times 10^{-5} \text{ Wb} \approx 6.3 \times 10^{-5} \text{ Wb}
 \end{aligned}$$

[2]

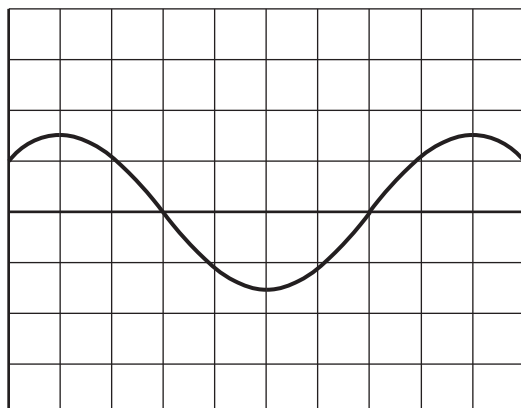
The coil is rotated at a constant rate as shown in **Fig. 4.2**. An emf is produced across the coil.

Fig. 4.2



An oscilloscope trace of the emf produced is shown in **Fig. 4.3**.

Fig. 4.3



- (ii) Suggest and explain why the trace has the shape shown on **Fig. 4.3**.

..An emf is induced when the flux linkage changes: $emf = -d(N\Phi)/dt$
 ..Rotating at a constant rate, the flux linkage varies sinusoidally, so the.....
 ..emf is sinusoidal.....
 ..Rate of cutting flux is maximum when the coil plane is parallel to the.....
 ..field, zero when perpendicular; emf reverses twice per rotation..... [2]

- (iii) The horizontal divisions on the trace representing time are set at 0.625 s/div.
 Using the trace shown in **Fig. 4.3**, calculate the angular frequency, ω , of the coil.

One period = 8 divisions (peak to peak)

$$T = 8 \times 0.625 = 5.0 \text{ s}$$

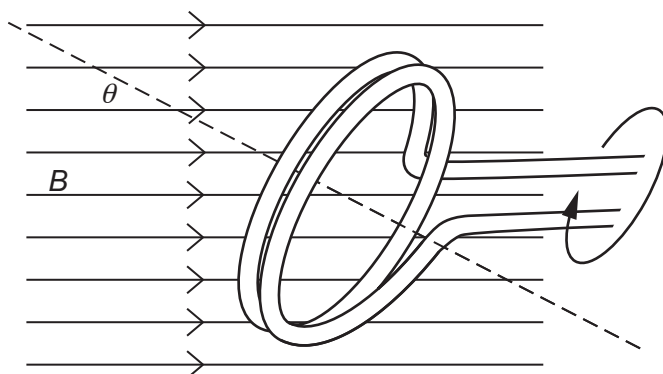
$$\omega = 2\pi f = 2\pi/T = 2\pi/5.0 = 0.4\pi$$

$$\omega = 1.26 \text{ rad s}^{-1}$$

Angular frequency, ω = ...1.26..... rad s^{-1} [3]

- (iv) The angle θ , that the normal to the plane of the coil makes with the field lines varies with time as the coil rotates. Angle θ is shown in **Fig. 4.4**.

Fig. 4.4



By considering θ , show that the flux in the coil can be given by $\phi = BA \cos \omega t$.

The coil turns at constant angular velocity ω , so $\theta = \omega t$

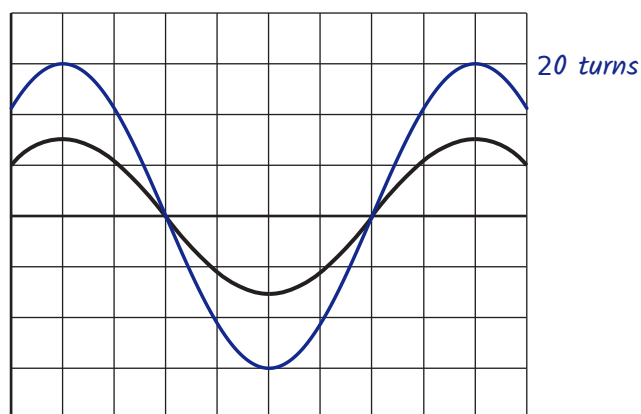
The component of B along the normal (perpendicular to the coil) is $B \cos \theta$

so $\phi = BA \cos \theta = BA \cos \omega t$

[2]

- (b) The original trace of the coil is shown in **Fig. 4.5**.

Fig. 4.5



The number of turns of the coil is changed to 20. Nothing else is changed.

- (i) Add to **Fig. 4.5** a drawing of the trace produced by the 20-turn coil.

[2]

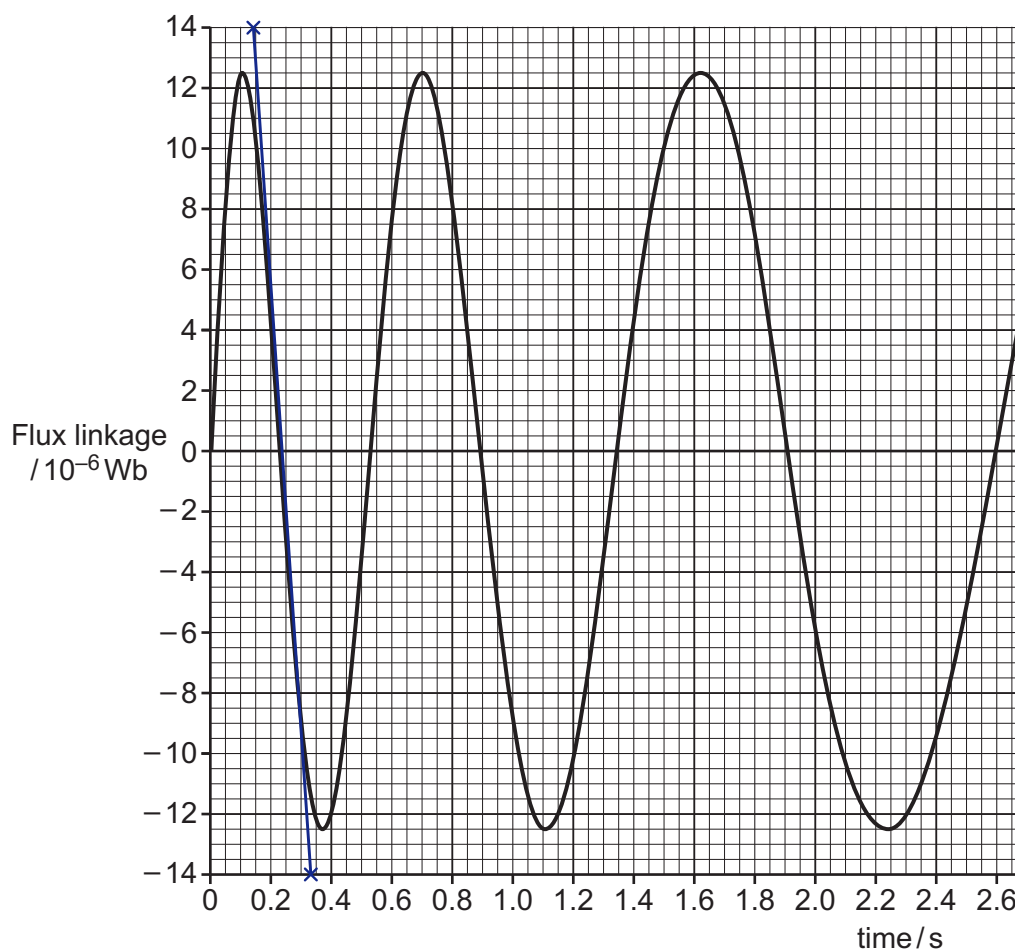
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Question 4(b) continues on page 16

The driving force spinning the coil is removed. **Fig. 4.6** shows how the flux linkage varies with time for three whole revolutions.

Fig. 4.6



- (ii) Using the graph in **Fig. 4.6**, estimate the emf induced in the coil at the instant the flux linkage is zero at 0.23 s. Show all your working.

Tangent at $t = 0.23 \text{ s}$ through $(0.14 \text{ s}, 14 \times 10^{-6} \text{ Wb})$

and $(0.33 \text{ s}, -14 \times 10^{-6} \text{ Wb})$:

$$\text{gradient} = (-14 - 14) \times 10^{-6} / (0.33 - 0.14) = -1.47 \times 10^{-4} \text{ Wb s}^{-1}$$

$$\text{emf} = -d(N\Phi)/dt = 1.5 \times 10^{-4} \text{ V}$$

$$\text{emf} = \dots\dots\dots 1.5 \times 10^{-4} \dots\dots\dots \text{ V [3]}$$

- (iii)* It is suggested that the peak emf generated by the coil falls by the same fraction in each cycle.

Explain how this suggestion can be tested by using data from **Fig. 4.6**.

Carry out your test on the data and state your conclusions.

Peak emf = maximum rate of change of flux linkage = the maximum gradient of the graph, which occurs where the flux linkage is zero. The peaks stay at 12.5×10^{-6} Wb but the time period increases each cycle, so the maximum gradient (peak emf) decreases each cycle.

Test: find the gradient (or time period) at the same point in successive cycles and calculate the ratio of successive values. If the peak emf falls by the same fraction each cycle these ratios are equal within experimental uncertainty.

Peaks at 0.10, 0.70, 1.62 s: periods 0.60 s then 0.92 s, ratio $0.92/0.60 = 1.53$. Troughs at 0.37, 1.11, 2.24 s: periods 0.74 s then 1.13 s, ratio 1.53.

Since peak emf $= N\Phi_{\max}\omega = N\Phi_{\max} \times 2\pi/T$, peak emf falls to $1/1.53 = 0.65$ of its value each cycle. Tangent gradients at the zero crossings (1.5, 1.2, 0.97, 0.76, 0.63×10^{-4} V) give cycle ratios $0.97/1.5 = 0.65$, $0.76/1.2 = 0.64$, $0.63/0.97 = 0.65$.

Conclusion: the ratios agree within the reading uncertainty (about ± 0.02 s), so the data support the suggestion that the peak emf falls by the same fraction (about 35 %) in each cycle.

[6]

END OF QUESTION PAPER

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