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Centre number

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Candidate number

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Surname

StemUp Model Solution

Forename(s)

Candidate signature

I declare this is my own work.

A-level PHYSICS

Paper 3 Section A

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

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.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do **all** rough work in this book. Cross through any work you do not want to be marked.
- Show **all** your working.

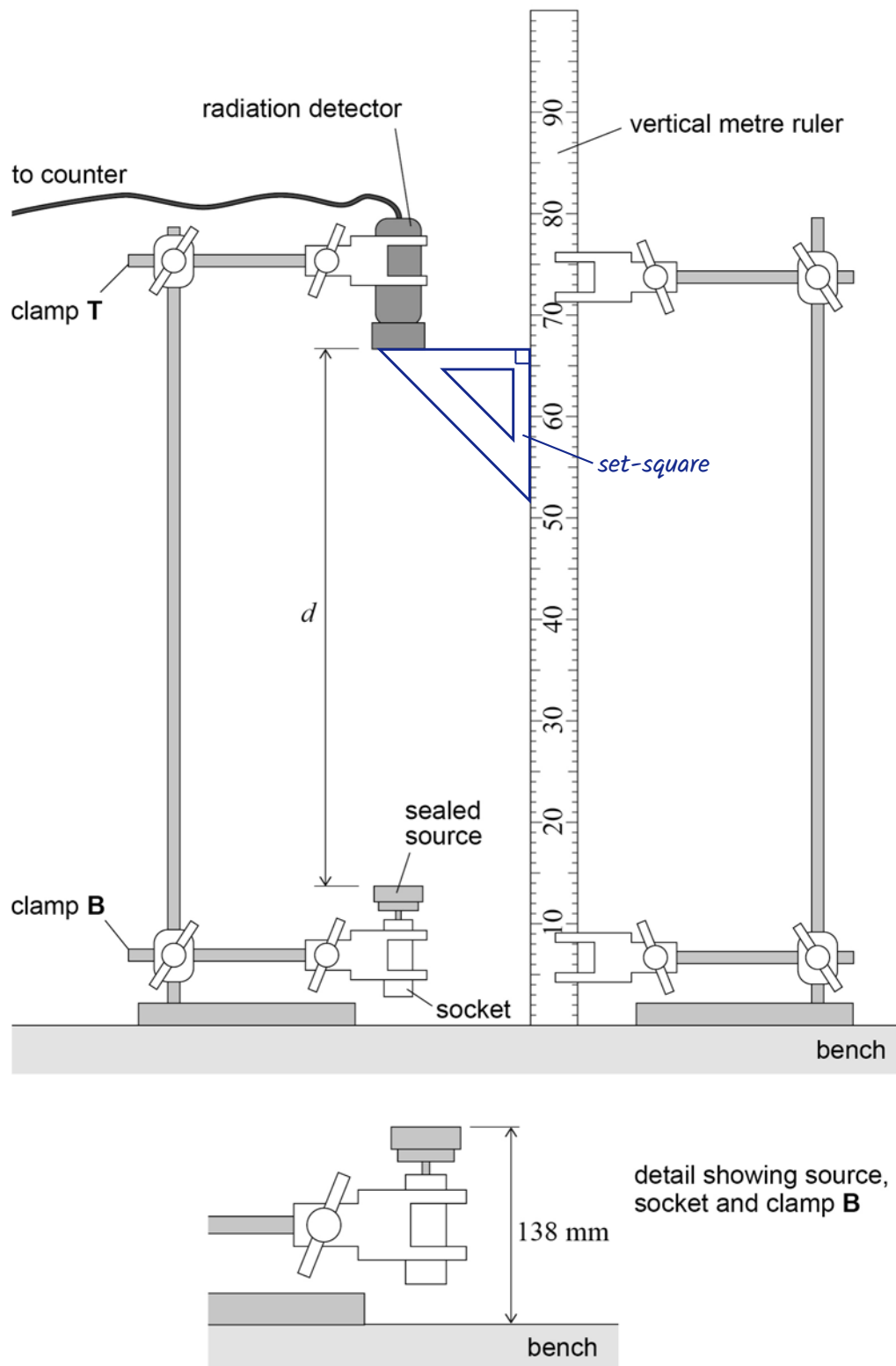
Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 45.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 70 minutes on this section.

For Examiner's Use	
Question	Mark
1	
2	
3	
TOTAL	



Section AAnswer **all** questions in this section.**0 1****Figure 1** shows apparatus used to investigate the inverse-square law for gamma radiation.**Figure 1**

A sealed source that emits gamma radiation is held in a socket attached to clamp **B**. The vertical distance between the open end of the source and the bench is 138 mm. A radiation detector, positioned vertically above the source, is attached to clamp **T**.

A student is told **not** to move the stands closer together.

0 1 . 1

Describe a procedure for the student to find the value of d , the vertical distance between the open end of the source and the radiation detector.

In your answer, annotate **Figure 1** to show how a set-square can be used in this procedure.

[2 marks]

Use a set-square with one edge against the vertical metre ruler and the other edge level with the lower (open) end of the detector, and read the position of the detector on the ruler.

Then subtract 138 mm (the height of the source above the bench) from this reading to find d .

Question 1 continues on the next page

Turn over ►



0 1 . 2

Before the source was brought into the room, a background count C_b was recorded.

$C_b = 630$ counts in 15 minutes

With the source and detector in the positions shown in **Figure 1**, $d = 530$ mm.

Separate counts C_1 , C_2 and C_3 are recorded.

$C_1 = 90$ counts in 100 s

$C_2 = 117$ counts in 100 s

$C_3 = 102$ counts in 100 s

R_C is the mean count rate corrected for background radiation.

Show that when $d = 530$ mm, R_C is about 0.3 s^{-1} .

[2 marks]

$$\text{background count rate} = 630 / (15 \times 60) = 630 / 900 = 0.70 \text{ s}^{-1}$$

$$\text{mean count} = (90 + 117 + 102) / 3 = 103 \text{ counts in } 100 \text{ s}$$

$$\text{mean count rate} = 103 / 100 = 1.03 \text{ s}^{-1}$$

$$R_C = 1.03 - 0.70 = 0.33 \text{ s}^{-1} \text{ (about } 0.3 \text{ s}^{-1}\text{)}$$



01.3

The apparatus is adjusted so that $d = 380$ mm.
Counts are made that show $R_C = 0.76 \text{ s}^{-1}$.

The student predicts that:

$$R_C = \frac{k}{d^2}$$

where k is a constant.

Explain whether the values of R_C in Questions **01.2** and **01.3** support the student's prediction.

[2 marks]

If $R_C = k/d^2$ then $d^2 \times R_C = k$ should be constant.

$d = 380$ mm: $d^2 \times R_C = 380^2 \times 0.76 = 1.10 \times 10^5$

$d = 530$ mm: $d^2 \times R_C = 530^2 \times 0.33 = 9.27 \times 10^4$

% difference = $(1.10 - 0.927) / 0.927 \times 100 \approx 18\%$

The two values of $d^2 R_C$ differ by about 18%, much more than the uncertainty, so k is not constant and the data do not support the prediction.

01.4

Describe a safe procedure to reduce d . Give a reason for your procedure.

[2 marks]

Leave the source where it is and loosen clamp T, then slide the detector down the stand towards the source, keeping hands well away from the source (any handling of the source only with long tongs).

Reason: this keeps the maximum distance between me and the source and limits my exposure time to the radiation.

Question 1 continues on the next page

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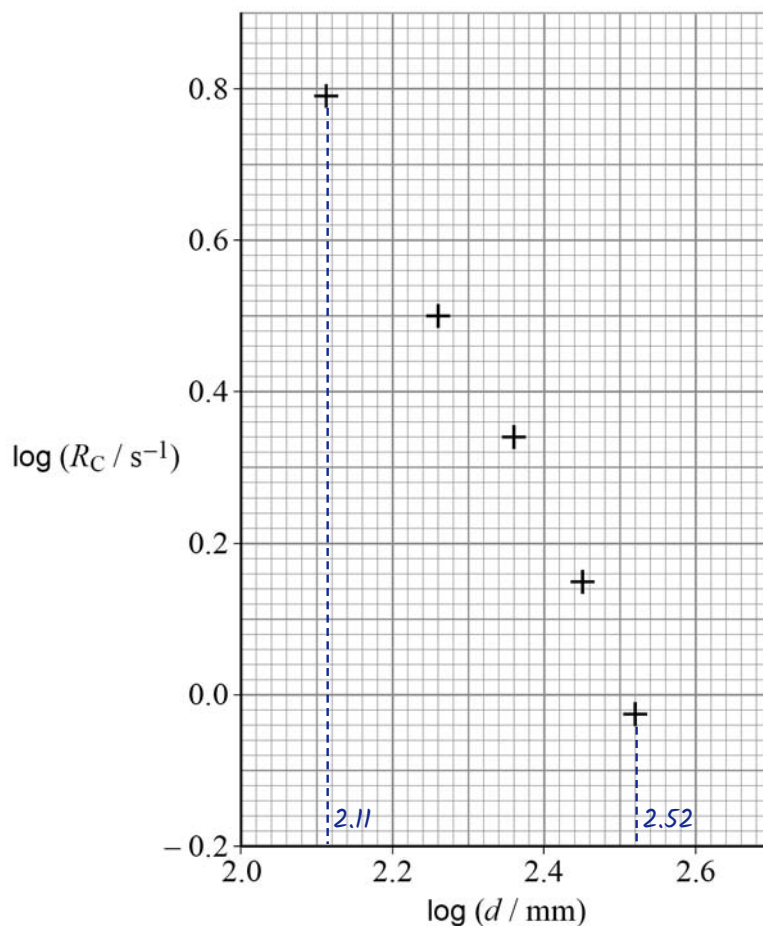


The student determines R_C for further values of d .

The values of d change by the same amount Δd between each measurement.

Figure 2 shows these data.

Figure 2



0 1 . 5 Determine Δd .

[2 marks]

first point: $\log d = 2.11$, $d = 10^{2.11} = 128.8 \text{ mm}$

last point: $\log d = 2.52$, $d = 10^{2.52} = 331.1 \text{ mm}$

5 points, so 4 equal steps of Δd :

$$\Delta d = (331.1 - 128.8) / 4 = 50.6 \text{ mm}$$

$\Delta d =$ 50.6 mm



0 1 . 6

Explain how the student could confirm whether **Figure 2** supports the prediction:

$$R_c = \frac{k}{d^2}$$

No calculation is required.

[3 marks]

*Taking logs: $\log R_c = \log k - 2 \log d$, i.e. $\log R_c = -2 \log d + \log k$,
which has the form $y = mx + c$.*

*Draw a straight line of best fit through the points on Figure 2 and
measure its gradient using a large triangle.*

*If the line is straight with a gradient of -2 (within uncertainty) the
prediction is confirmed; if the gradient is not -2 , or the best fit is a
curve, the prediction is not supported.*

Question 1 continues on the next page

Turn over ►



When a gamma photon is detected by the detector, another photon cannot be detected for a time t_d called the dead time.

It can be shown that:

$$t_d = \frac{R_2 - R_1}{R_1 \times R_2}$$

where R_1 is the measured count rate

R_2 is the count rate when R_1 is corrected for dead time error.

0 1 . 7

The distance between the source and the detector is adjusted so that d is very small and R_1 is 100 s^{-1} .

On average, two of the gamma photons that enter the detector every second are not detected.

Calculate t_d for this detector.

[1 mark]

$$R_2 = 100 + 2 = 102 \text{ s}^{-1}$$

$$t_d = (102 - 100) / (100 \times 102) = 1.96 \times 10^{-4} \text{ s}$$

$$t_d = \underline{1.96 \times 10^{-4}} \text{ s}$$

0 1 . 8

A student says that if 100 gamma photons enter a detector in one second and t_d is 0.01 s, **all** the photons should be detected.

Explain, with reference to the nature of radioactive decay, why this idea is **not** correct.

[2 marks]

Radioactive decay is random, so the gamma photons do not arrive at a steady rate of one every 0.01 s.

In some 0.01 s intervals two or more photons may arrive, so the ones arriving during the dead time are not detected, while in other intervals no photon arrives at all.



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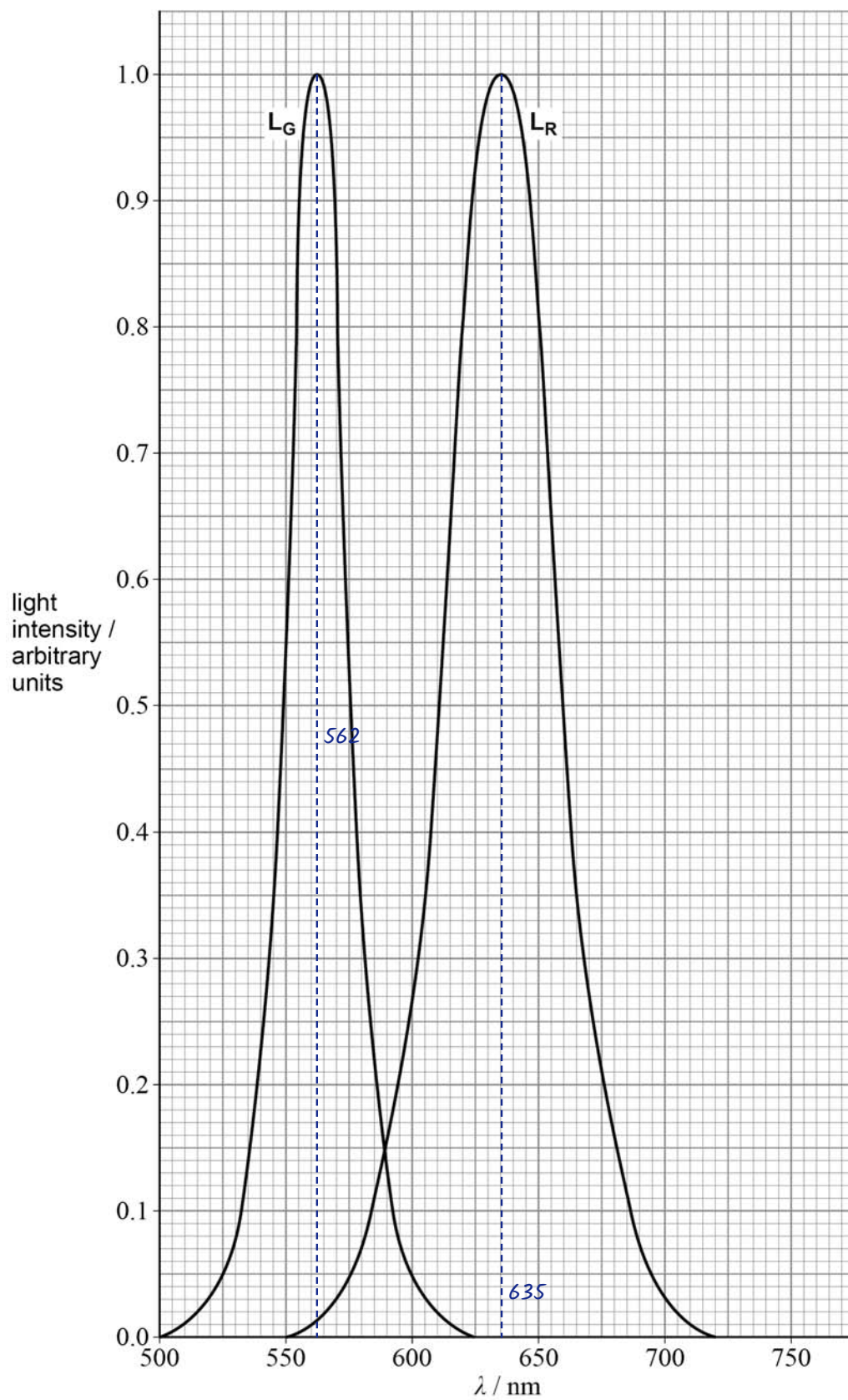
A light-emitting diode (LED) emits light over a narrow range of wavelengths. These wavelengths are distributed about a peak wavelength λ_p .

Two LEDs L_G and L_R are adjusted to give the same maximum light intensity. L_G emits green light and L_R emits red light.

Figure 3 shows how the light output of the LEDs varies with the wavelength λ .



Figure 3



Question 2 continues on the next page

Turn over ►



0 2 . 1

Light from L_R is incident normally on a plane diffraction grating.
The fifth-order maximum for light of wavelength λ_p occurs at a diffraction angle of 76.3° .

Determine N , the number of lines per metre on the grating.

[3 marks]

From Figure 3, λ_p for $L_R = 635 \text{ nm} = 6.35 \times 10^{-7} \text{ m}$

$n\lambda = d \sin \theta$, so $d = n\lambda / \sin \theta$

$d = (5 \times 6.35 \times 10^{-7}) / \sin 76.3^\circ = 3.27 \times 10^{-6} \text{ m}$

$N = 1/d = 1 / (3.27 \times 10^{-6}) = 3.06 \times 10^5 \text{ m}^{-1}$

$N = \underline{3.06 \times 10^5} \text{ m}^{-1}$

0 2 . 2

Suggest **one** possible disadvantage of using the fifth-order maximum to determine N .

[1 mark]

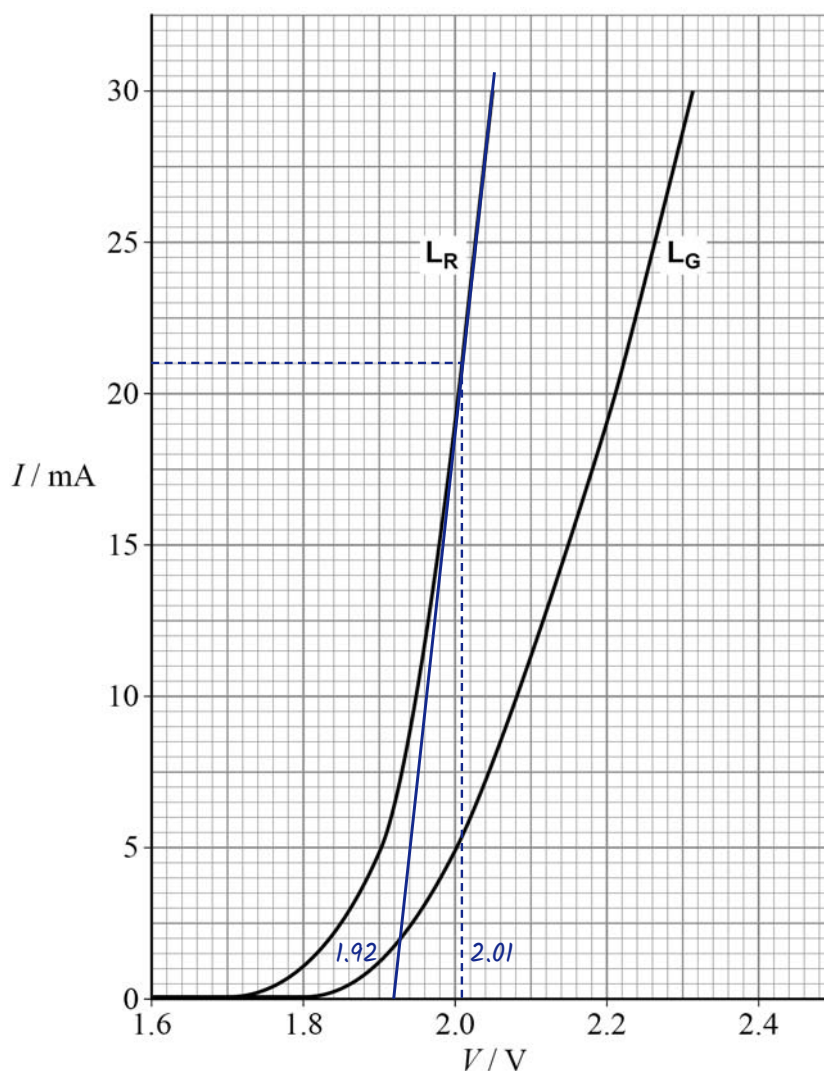
The fifth-order maximum is much fainter and wider (less sharply defined) than the lower orders, so it is harder to locate its centre accurately.



0 2 3

Figure 4 shows part of the current–voltage characteristics for L_R and L_G .

Figure 4



When the linear part of the characteristic is extrapolated, the point at which it meets the horizontal axis gives the activation voltage V_A for the LED.

V_A for L_G is 2.00 V.

Determine, using Figure 4, V_A for L_R .

[2 marks]

Ruled line through the linear part of L_R extended to $I = 0$

meets the V axis at $V_A = 1.92$ V

V_A for L_R = 1.92 V

Question 2 continues on the next page

Turn over ►



0 2 . 4

It can be shown that:

$$V_A = \frac{hc}{e\lambda_p}$$

where h = the Planck constant.

Deduce a value for the Planck constant based on the data given about the LEDs.

[2 marks]

$$h = eV_A\lambda_p / c$$

$$L_R: V_A = 1.92 \text{ V}, \lambda_p = 635 \text{ nm}$$

$$h = (1.60 \times 10^{-19} \times 1.92 \times 635 \times 10^{-9}) / 3.00 \times 10^8$$

$$= 6.50 \times 10^{-34} \text{ J s}$$

$$L_G: V_A = 2.00 \text{ V}, \lambda_p = 562 \text{ nm (from Figure 3)}$$

$$h = (1.60 \times 10^{-19} \times 2.00 \times 562 \times 10^{-9}) / 3.00 \times 10^8$$

$$= 5.99 \times 10^{-34} \text{ J s}$$

$$\text{mean } h = (6.50 + 5.99) / 2 \times 10^{-34} = 6.25 \times 10^{-34} \text{ J s}$$

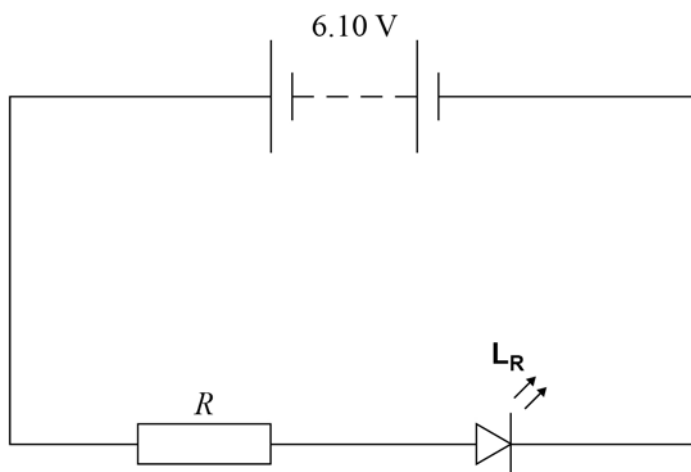
$$h = \underline{6.25 \times 10^{-34}} \text{ J s}$$



0 2 . 5

Figure 5 shows a circuit with L_R connected to a resistor of resistance R .

Figure 5



The power supply has emf 6.10 V and negligible internal resistance.
The current in L_R must not exceed 21.0 mA.

Deduce the minimum value of R .

[2 marks]

From Figure 4, at $I = 21.0 \text{ mA}$ the pd across $L_R = 2.01 \text{ V}$

pd across $R = 6.10 - 2.01 = 4.09 \text{ V}$

$R = V / I = 4.09 / (21.0 \times 10^{-3}) = 195 \Omega$

minimum value of $R =$ 195 Ω

10

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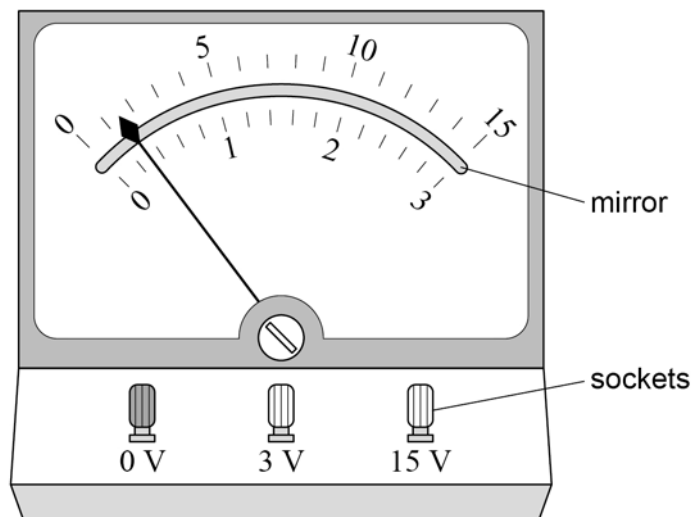
0 3

An analogue voltmeter has a resistance that is much less than that of a modern digital voltmeter.

Analogue meters can be damaged if the full-scale reading is exceeded.

Figure 6 shows a dual-range analogue voltmeter with a zero error.

Figure 6



0 3

. 1

The voltmeter is set to the **more sensitive** range and then used in a circuit.

What is the potential difference (pd) between the terminals of the voltmeter when a full-scale reading is indicated?

Tick (✓) **one** box.

[1 mark]

2.7 V

☒

3.3 V

☐

13.5 V

☐

16.5 V

☐


0	3	.	2
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Explain the use of the mirror when reading the meter.

[2 marks]

*Move my head until the needle lines up with (hides) its own reflection
in the mirror, then read the scale.*

*My eye is then directly above (perpendicular to) the scale at the needle,
so parallax error is eliminated.*

Question 3 continues on the next page

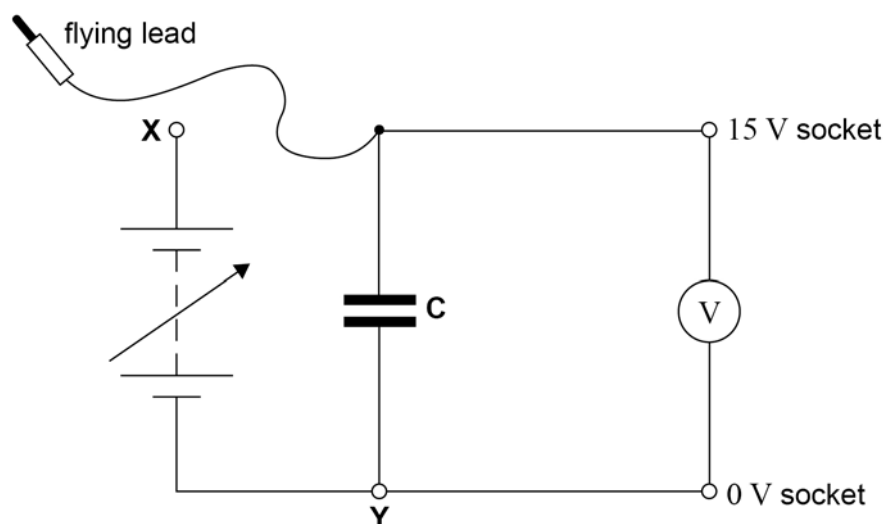
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A student corrects the zero error on the meter and then assembles the circuit shown in **Figure 7**.

The capacitance of the capacitor **C** is not known.

Figure 7



The output pd of the power supply is set to zero.

The student connects the flying lead to socket **X** and adjusts the output pd until the voltmeter reading is full scale (15 V).

She disconnects the flying lead from socket **X** so that **C** discharges through the voltmeter.

She measures the time $T_{\frac{1}{2}}$ for the voltmeter reading V to fall from 10 V to 5 V.

She repeats this process several times.

Table 1 shows the student's results, **none** of which is anomalous.

Table 1

$T_{\frac{1}{2}} / \text{s}$	12.00	11.94	12.06	12.04	12.16
------------------------------	-------	-------	-------	-------	-------

0 3 . 3 Determine the percentage uncertainty in $T_{1/2}$.

[2 marks]

$$\text{mean } T_{1/2} = (12.00 + 11.94 + 12.06 + 12.04 + 12.16) / 5 = 12.04 \text{ s}$$

$$\text{uncertainty} = \text{half the range} = (12.16 - 11.94) / 2 = 0.11 \text{ s}$$

$$\% \text{ uncertainty} = 0.11 / 12.04 \times 100 = 0.91\%$$

percentage uncertainty = 0.91 %

0 3 . 4 Show that the time constant for the discharge circuit is about 17 s.

[1 mark]

$$T_{1/2} = \tau \ln 2, \text{ so } \tau = T_{1/2} / \ln 2$$

$$\tau = 12.04 / \ln 2 = 12.04 / 0.693 = 17.4 \text{ s } (\approx 17 \text{ s})$$

Question 3 continues on the next page

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0 3 . 5

The student thinks that the time constant of the circuit in **Figure 7** is directly proportional to the range of the meter.

To test her theory, she repeats the experiment with the voltmeter set to the 3 V range. She expects $T_{1/2}$ to be about 2.5 s.

Explain:

- what the student should do, before connecting capacitor **C** to the 0 V and 3 V sockets, to avoid exceeding the full-scale reading on the voltmeter
- how she should develop her procedure to get an accurate result for the time constant
- how she should use her result to check whether her theory is correct.

[4 marks]

Before connecting C to the 0 V and 3 V sockets, discharge C fully by connecting the flying lead to Y, and turn the output pd of the supply down to zero (so it cannot exceed 3 V).

Then connect the flying lead to X and raise the output pd slowly until the meter just reads full scale (3 V). Check and correct any zero error on the 3 V range first.

Because $T_{1/2}$ is only about 2.5 s, time over a larger change in V, e.g. two half-lives from 3.0 V to 0.75 V, and halve it; repeat several times, check the readings are concordant and calculate a mean $T_{1/2}$, then the time constant = mean $T_{1/2}$ / ln 2.

If the theory is correct the time constant should be one fifth (20%) of the 15 V value, about $17.4 / 5 = 3.5$ s, i.e. the ratio of time constant to range should be the same for both ranges.



The student wants to find the resistance of the voltmeter when it is set to the 15 V range.

She replaces **C** with an $820\ \mu\text{F}$ capacitor and charges it to 15 V.

She discharges the capacitor through the voltmeter, starting a stopwatch when V is 14 V.

She records the stopwatch reading t at other values of V as the capacitor discharges.

Table 2 shows her results.

Table 2

V/V	14	11	8	6	4	3	2
t/s	0.0	3.1	7.2	11.0	16.2	19.9	25.2

0 3 . 6

Suggest **two** reasons why the student selected the values of V shown in **Table 2**.
Explain each of your answers.

[4 marks]

1 *The values of V are all whole numbers (recorded to the nearest volt), because the analogue meter has low resolution on the 15 V range, so it is hard to interpolate between the scale markings while the needle is moving.*

2 *The intervals between the values of V get smaller at lower V , because V falls exponentially; this makes the time intervals between readings roughly equal and spreads the points evenly along the graph.*

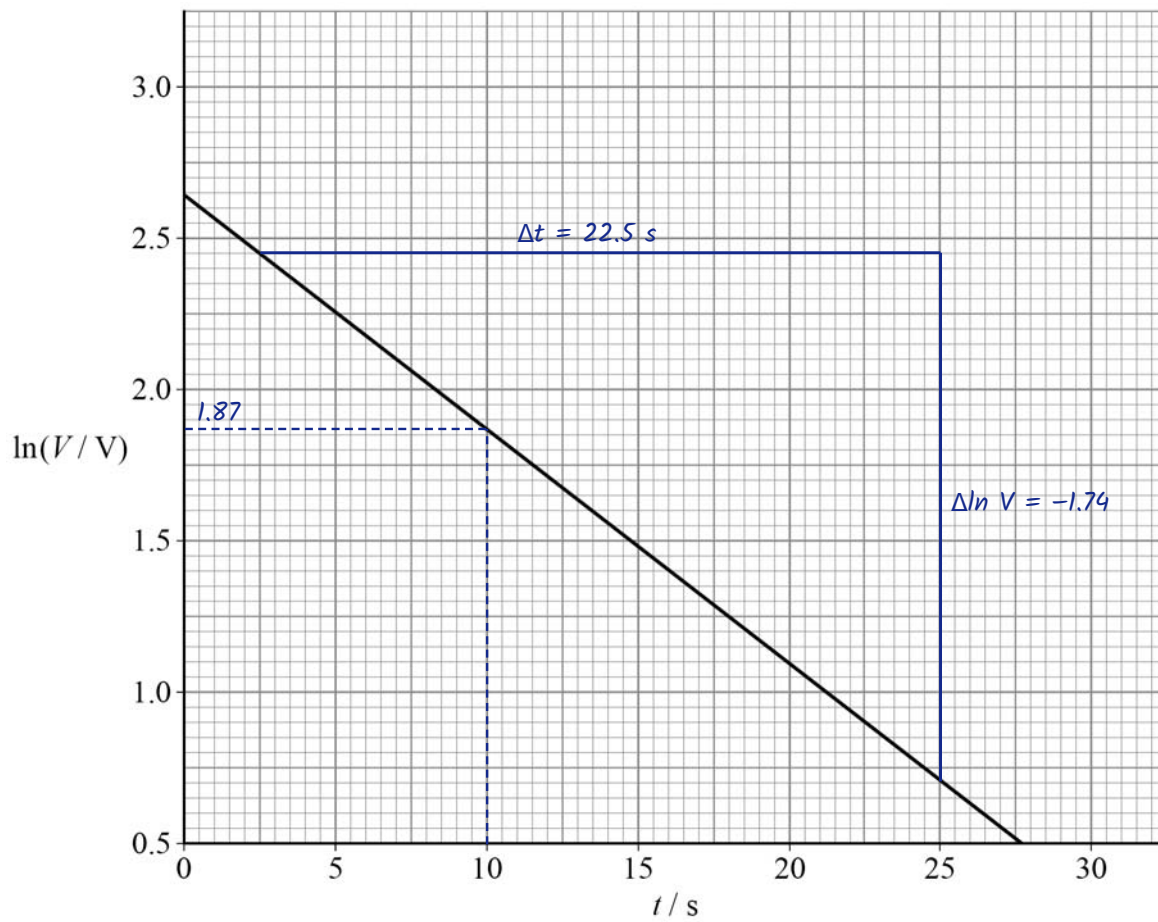
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Figure 8 shows a graph of the experimental data.

Figure 8



0 3 . 7

Show, using **Figure 8**, that the resistance of the voltmeter is about 16 kΩ.**[3 marks]**

$$V = V_0 e^{-t/RC}, \text{ so } \ln V = \ln V_0 - t/RC: \text{ gradient} = -1/RC$$

$$\text{gradient} = (0.71 - 2.45) / (25.0 - 2.5) = -1.74 / 22.5 = -0.0773 \text{ s}^{-1}$$

$$RC = 1 / 0.0773 = 12.9 \text{ s}$$

$$R = 1 / (0.0773 \times 820 \times 10^{-6}) = 1.58 \times 10^4 \text{ } \Omega$$

$$R = 15.8 \text{ k}\Omega, \text{ which is about } 16 \text{ k}\Omega$$

0 3 . 8

Determine the current in the voltmeter at $t = 10 \text{ s}$.**[2 marks]**

$$\text{At } t = 10 \text{ s, } \ln(V/V_0) = 1.87 \text{ (from Figure 8)}$$

$$V = e^{1.87} = 6.49 \text{ V}$$

$$I = V / R = 6.49 / (1.58 \times 10^4) = 4.1 \times 10^{-4} \text{ A}$$

current = 4.1 × 10⁻⁴ A

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END OF QUESTIONS

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