A2 Practical Skills

Name:

Class:

Date:

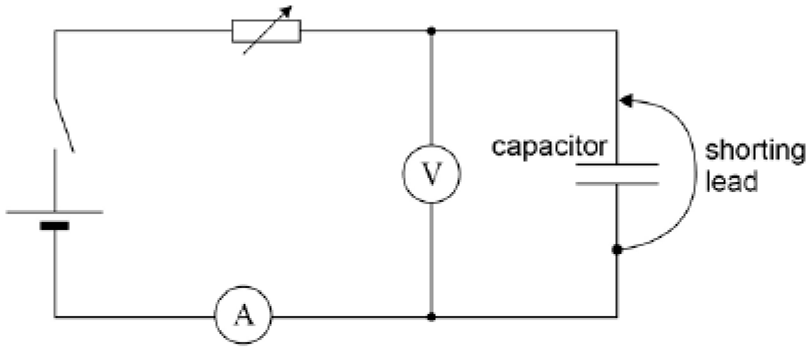
Time: **193 minutes**

Marks: **79 marks**

Comments:

1 This question is about capacitor charging and discharging.

A student designs an experiment to charge a capacitor using a constant current. The figure below shows the circuit the student designed to allow charge to flow onto a capacitor that has been initially discharged.



The student begins the experiment with the shorting lead connected across the capacitor as in the figure above. The variable resistor is then adjusted to give a suitable ammeter reading. The shorting lead is removed so that the capacitor begins to charge. At the same instant, the stop clock is started.

The student intends to measure the potential difference (pd) across the capacitor at 10 s intervals while adjusting the variable resistor to keep the charging current constant.

The power supply has an emf of 6.0 V and negligible internal resistance. The capacitor has a capacitance of 680 μF. The variable resistor has a maximum resistance of 100 kΩ.

(a) The student chooses a digital voltmeter for the experiment. A digital voltmeter has a very high resistance.

Explain why it is important to use a voltmeter with very high resistance.

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(1)

(b) Suggest **one** advantage of using an analogue ammeter rather than a digital ammeter for this experiment.

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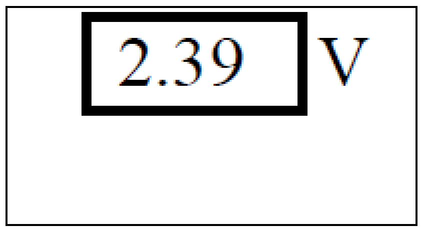
(1)

(c) Suggest a suitable full scale deflection for an analogue ammeter to be used in the experiment.

full scale deflection = ____________________

(2)

(d) The diagram shows the reading on the voltmeter at one instant during the experiment. The manufacturer gives the uncertainty in the meter reading as 2%.



Calculate the absolute uncertainty in this reading.

uncertainty = ____________________V

(1)

(e) Determine the number of different readings the student will be able to take before the capacitor becomes fully charged.

number = ____________________

(3)

(f) The experiment is performed with a capacitor of nominal value 680 μF and a manufacturing tolerance of ± 5 %. In this experiment the charging current is maintained at 65 μA. The data from the experiment produces a straight-line graph for the variation of pd with time. This shows that the pd across the capacitor increases at a rate of 98 mV s^{-1}.

Calculate the capacitance of the capacitor.

capacitance = ____________________ μF

(2)

(g) Deduce whether the capacitor is within the manufacturer's tolerance.

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(1)

(h) The student decides to confirm the value of the capacitance by first determining the time constant of the circuit when the capacitor **discharges** through a **fixed** resistor.

Describe an experiment to do this. Include in your answer:

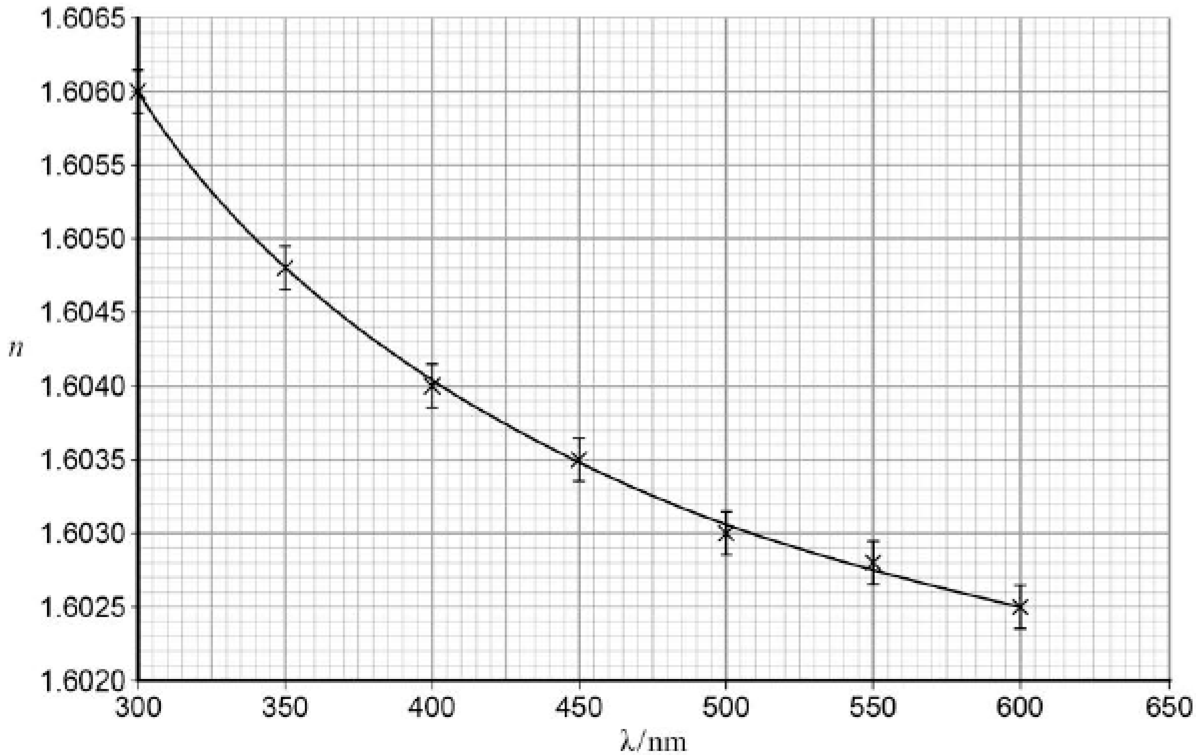
- a circuit diagram
- an outline of a procedure
- an explanation of how you would use the data to determine the time constant.

(4)

(Total 15 marks)

2 **Figure 1** shows how the refractive index n of a type of glass varies with the wavelength of light λ passing through the glass. The data for plotting the graph were determined by experiment.

Figure 1



(a) A student says that **Figure 1** resembles that of the decay of radioactive atomic nuclei with time and that it shows half-life behaviour.

Comment on whether the student is correct.

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(1)

(b) The dispersion D of glass is defined as the rate of change of its refractive index with wavelength. At a particular wavelength $D = \frac{\Delta n}{\Delta \lambda}$.

Determine D at a wavelength of 400 nm. State an appropriate unit for your answer.

D ____________________ unit __________

(3)

(c) It is suggested that the relationship between n and λ is of the form

$$n = a + \frac{b}{\lambda^2}$$

where a and b are constants. The data plotted in **Figure 1** are given in the table below.

λ / nm	n			
300	1.6060			
350	1.6048			
400	1.6040			
450	1.6035			
500	1.6030			
550	1.6028			
600	1.6025			

You are to determine a using a graph of n against $\frac{1}{\lambda^2}$.

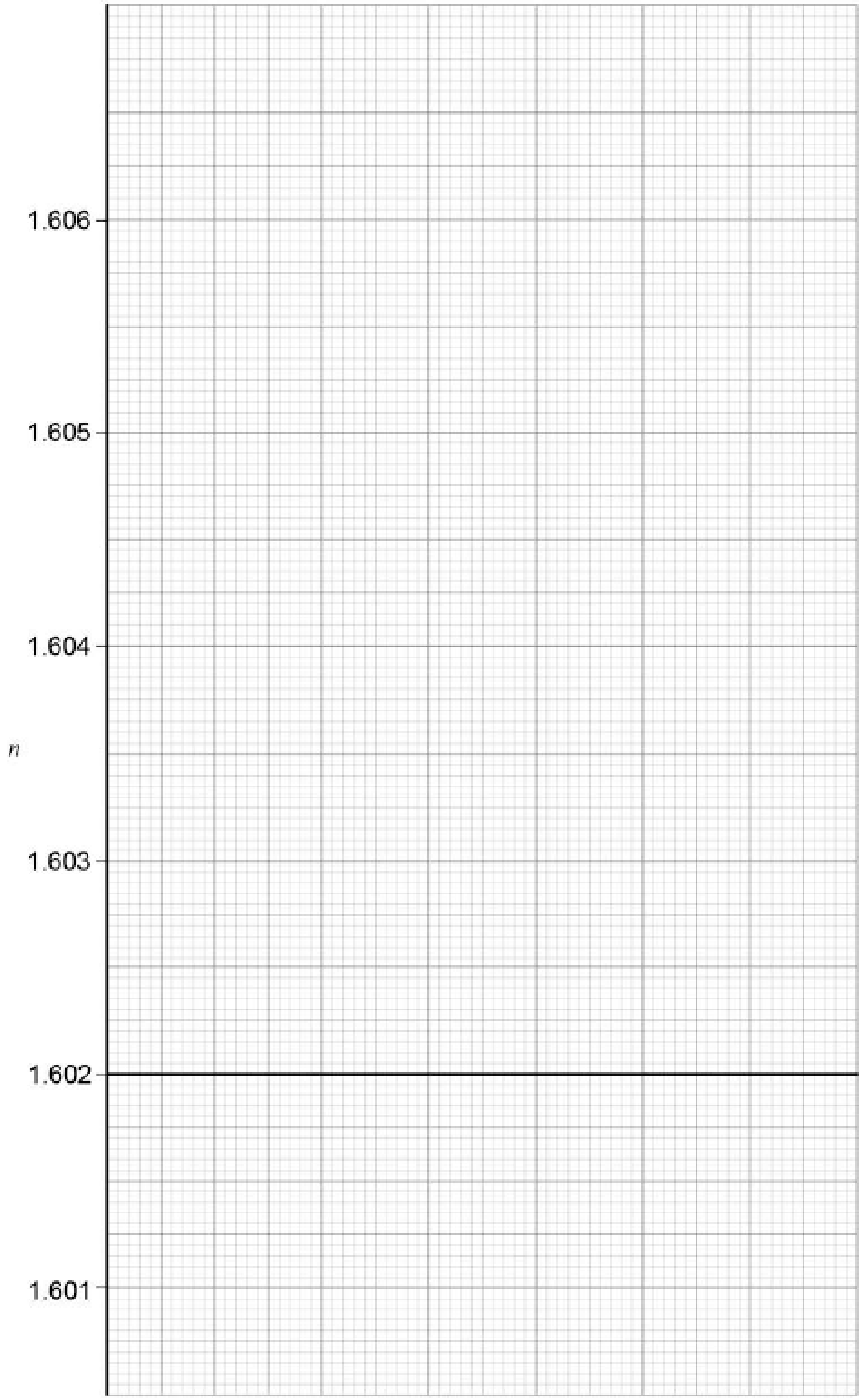
.

Make any calculations that you need to in order to plot your graph. The columns in the table are for you to use to calculate and tabulate the derived data that you need.
You may not need all the columns.

(3)

(d) Plot your graph on **Figure 2**. The values of n are provided on the y-axis.

Figure 2



(3)

(e) Use your graph to determine a.

(1)

(f) State the significance of a.

(1)

(g) Another suggestion for the relationship between n and λ is that

$$n = c\lambda^d$$

where c and d are constants.

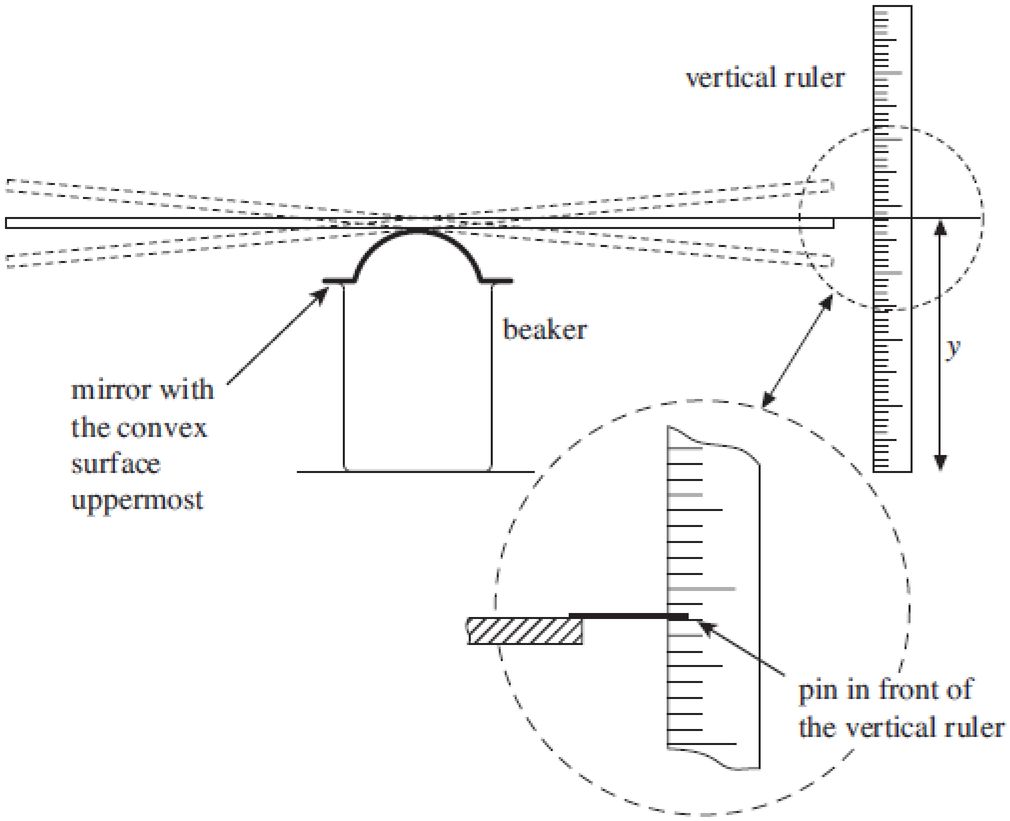
Explain how d can be determined graphically. Do not attempt to carry out this analysis.

(3)

(Total 15 marks)

3 It is suggested to a student who is watching a metre ruler oscillating on the convex surface of a mirror that the amplitude of the oscillations decreases exponentially.
The student is challenged to show whether or not this is true.

The student decides to record the motion of the ruler using a video camera. She attaches a pin to the end of the ruler and positions a vertical scale behind the tip of the pin, as shown in the diagram below.

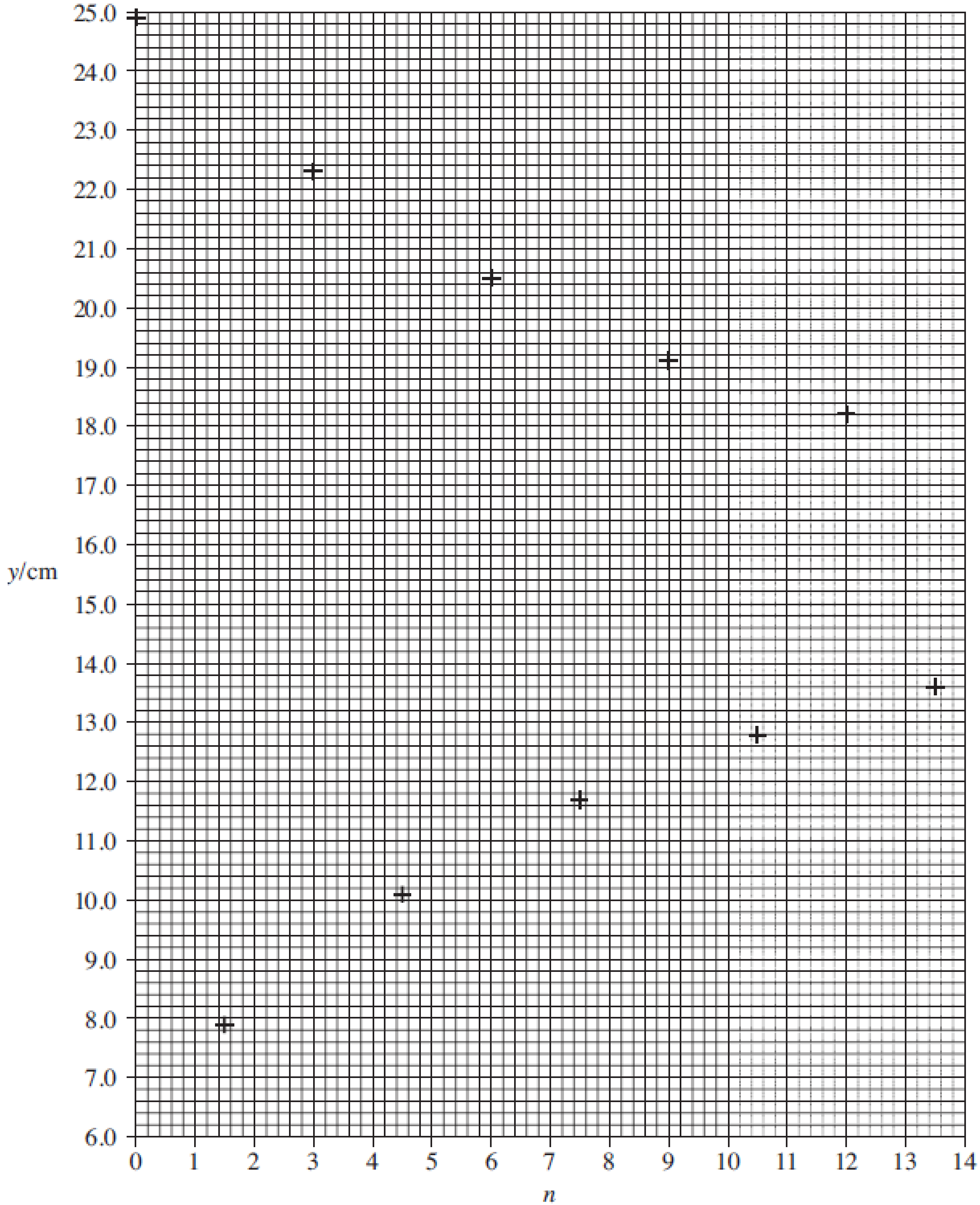


The student records the height above the bench of the tip of the pin at the top, y_t, and at the bottom, y_b, of its motion during several successive swings, n, of the ruler.

Her results are shown below.

n	0	1.5	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5
y_t/cm	24.9		22.3		20.5		19.1		18.2	
y_b/cm		7.9		10.1		11.7		12.8		13.6

(a) Her data points are plotted on the graph below.



On the graph draw

(i) a line to show how y_t varies with n,

(ii) a line to show how y_b varies with n,

(iii) a line parallel to the horizontal axis to mark the position of the tip of the pin against the vertical scale when the ruler is at the equilibrium position.

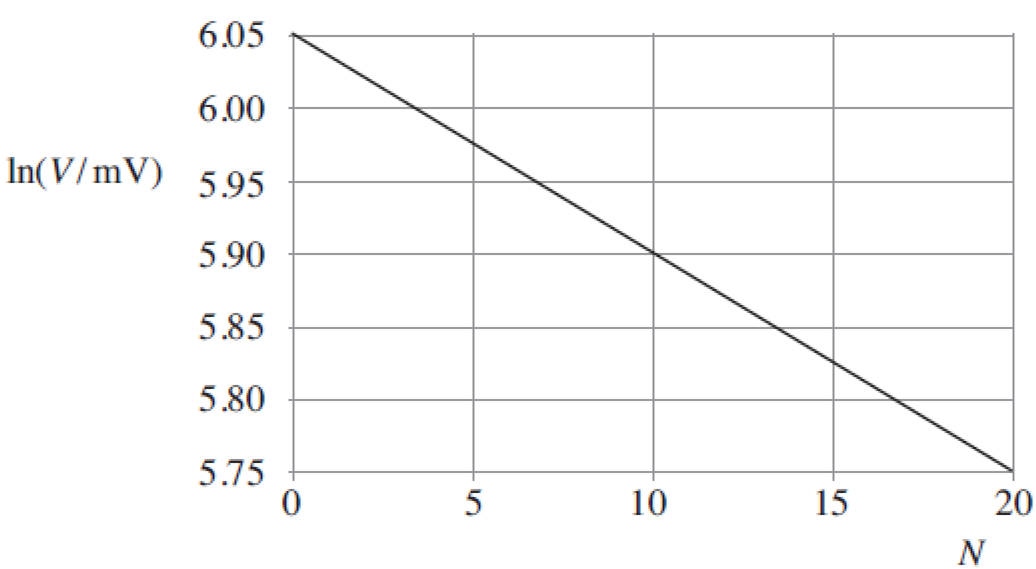
(2)

(b) Hence or otherwise, explain whether the student's data confirms the suggestion that the amplitude of the oscillations decreases exponentially.

(3)

(Total 5 marks)

4 The voltage produced by a solar cell may be assumed to be proportional to the light intensity incident on it. A student uses a solar cell in an experiment to determine the half value thickness for glass i.e the thickness of glass that reduces the output voltage by half. The student uses a varying number N of microscope slides between a light source and the solar cell and measures the output voltage V for each value of N. The graph below was produced from the student's data.



Assuming that the output voltage of the solar cell is directly proportional to the light intensity incident upon it, the student intends to determine the half-value thickness of glass, ie the thickness of glass that would reduce the output voltage by half.

(a) Use the information provided in the student's graph to calculate $N_{0.5}$, the value of N equivalent to the half-value thickness of the glass.

(3)

(b) To determine the half-value thickness of the glass in mm, the student needs to make one additional measurement.

(i) Identify the measurement the student needs to make and explain how this is used to determine the half-value thickness of the glass.

The student uses a micrometer screw gauge to make the additional measurement.

(ii) Identify **one** procedure that can be used to reduce the effect of random errors when making the measurement.

(iii) Identify **one** procedure that can be used to detect, and hence correct, for possible systematic errors in the measurements made with the micrometer screw gauge.

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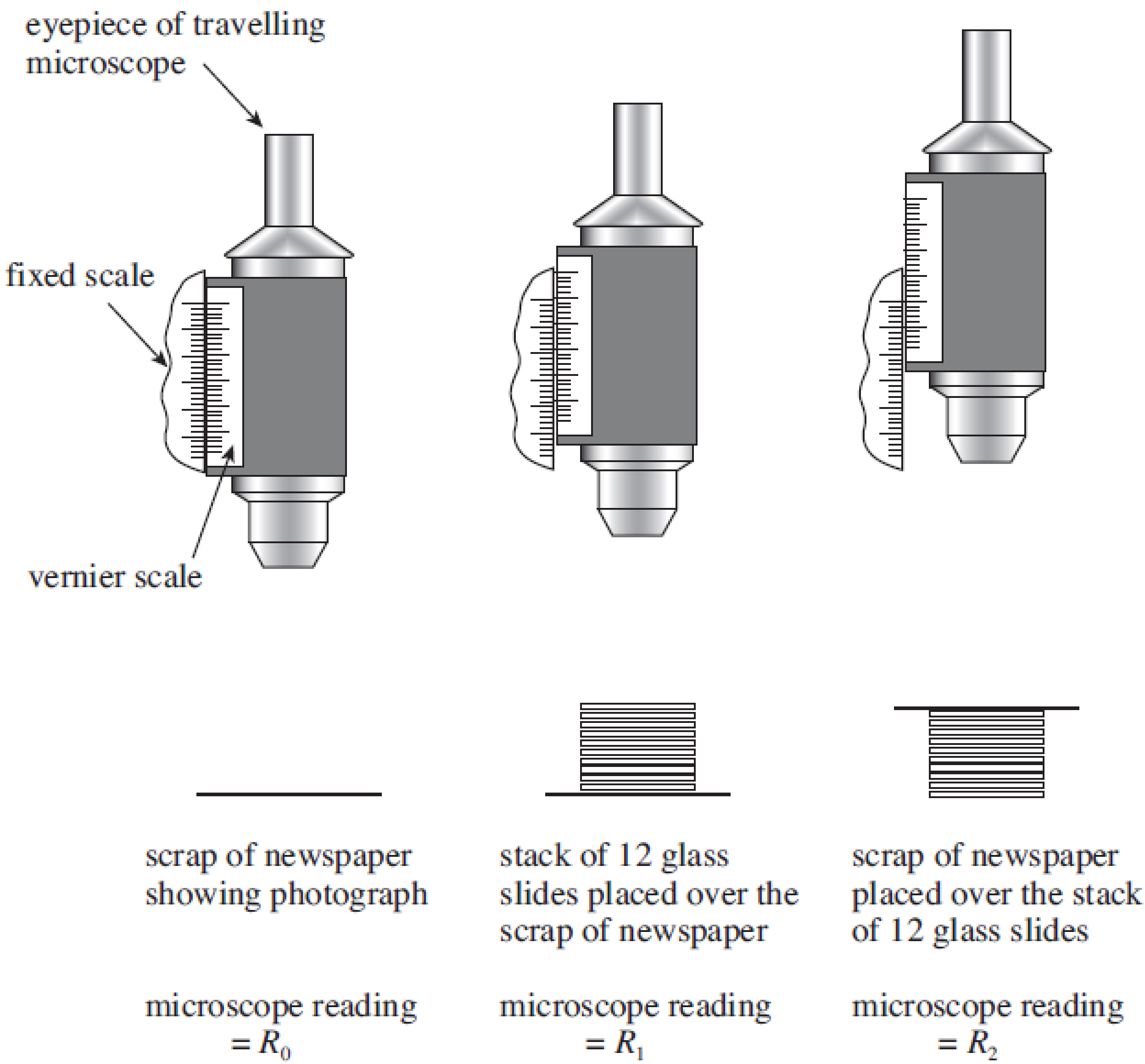
(3)

The student uses a travelling microscope to learn more about the properties of the glass slides.

The eyepiece of the microscope is arranged to move vertically up or down above a scrap of newspaper showing a photograph.
The photograph is composed of dots which are only clearly visible when viewed through the microscope. By adjusting the position of the microscope the student brings the dots into focus and then reads the position of the microscope, R_0, using the vernier scale.
The student then places a stack of 12 slides over the photograph and refocuses the microscope. She records the new reading, R_1.
Finally, she places the photograph on top of the slides, refocuses the microscope, and records the new reading R_2.

The sequence of operations is illustrated below.



The readings made by the student are shown in the table below.

R_0/mm	R_1/mm	R_2/mm
2.74	**7.31**	**17.02**

(c) Assuming that the slides have identical dimensions, use the readings to determine the thickness of one glass microscope slide.

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(1)

(d) Determine n, the refractive index of the glass, given by $n = \frac{R_2 - R_0}{R_2 - R_1}$.

(1)

(e) The uncertainty in each of the readings R_0, R_1 and R_2, is 0.04 mm.

(i) State the uncertainty in $R_2 - R_0$.

(ii) State the uncertainty in $R_2 - R_1$.

(iii) Hence calculate the percentage uncertainty in n.

(3)

(Total 11 marks)

5 The decay of a radioactive substance can be represented by the equation

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

where A = the activity of the sample at time t
A_0 = the initial activity at time t = 0
λ = the decay constant

The half life, $T_{½}$ of the radioactive substance is given by

$$T_{½} = \frac{ln(2)}{\lambda}$$

An experiment was performed to determine the half-life of a radioactive substance which was a beta emitter. The radioactive source was placed close to a detector. The total count for exactly 5 minutes was recorded. This was repeated at 20 minute intervals. The results are shown in the table below.

time, t / minutes	total count, C, recorded in 5 minutes	count rate, R / counts minute^{-1}	corrected count rate, R_C / counts minute^{-1}	ln (R_C / minute^{-1})
0	1016	203	183	5.21
20	892	178	158	5.06
40	774	155	135	4.90
60	665	133	113	4.73
80	608	122	102	4.62
100	546	109	89	4.49

(a) A correction has been made to the count rate, R, to give the corrected count rate, R_C. Explain why this correction has been made and deduce its value from the table.

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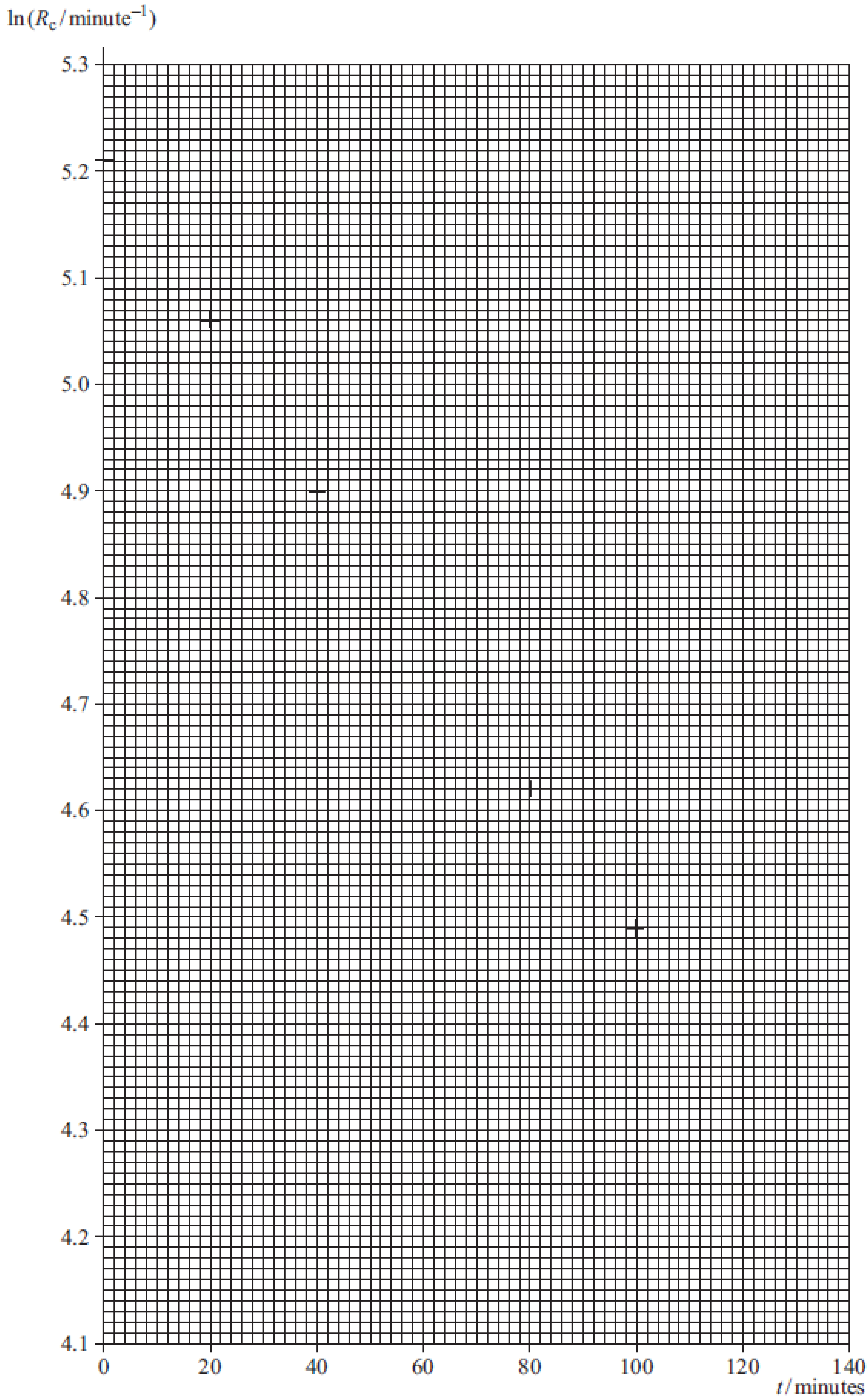
(2)



(b) Draw an appropriate straight line through the plotted points.

(1)

(c) Determine the gradient G of your graph.

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(3)

(d) Use your graph to determine the half-life in minutes of the radioactive substance used in this experiment.

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half-life, $T_{½}$ ______________________ minutes

(2)

(e) Due to the nature of a radioactive decay there will be an uncertainty in the total count recorded. What type of error is this called?

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(1)

(f) (i) It can be shown that the error in the total count C, is given by

uncertainty in total count $C = \pm \sqrt{C}$

Using data from the table, calculate the uncertainty **in the smallest total count, C**.

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(1)

(ii) Hence calculate the percentage uncertainty **in the smallest total count, C**.

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(1)

(iii) Another student performed the same experiment with identical equipment but took total counts over a 1 minute period rather than a 5-minute period. The total count, C, at 140 minutes was equal to 84 counts. Estimate the percentage uncertainty in this total count, and hence explain the advantage of using a larger time.

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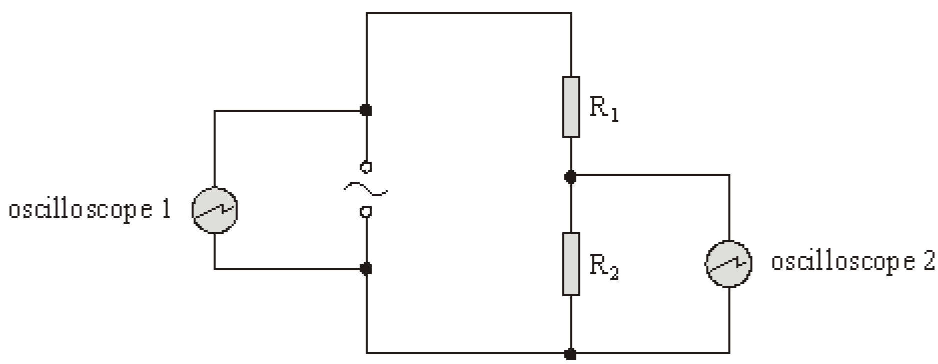
(2)

(Total 13 marks)

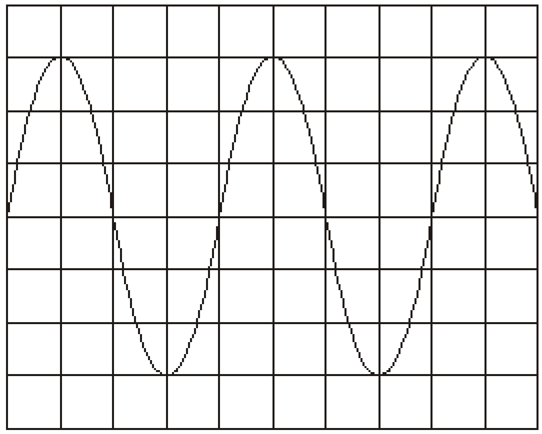
6 The circuit in **Figure 1** shows a sinusoidal ac source connected to two resistors, R_1 and R_2, which form a potential divider. Oscilloscope 1 is connected across the source and oscilloscope 2 is connected across R_2.

Figure 1



(a) **Figure 2** shows the trace obtained on the screen of oscilloscope 1. The time base of the oscilloscope is set at 10 m/s per division and the voltage sensitivity at 15 V per division.

Figure 2



For the ac source, calculate

(i) the frequency,

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(ii) the rms voltage.

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(4)

(b) The resistors have the following values: $R_1 = 450\ \Omega$ and $R_2 = 90\ \Omega$.
Calculate

(i) the rms current in the circuit,

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(ii) the rms voltage across R_2.

____

(2)

(c) Oscilloscope 2 is used to check the calculated value of the voltage across R_2. The screen of oscilloscope 2 is identical to that of oscilloscope 1 and both are set to the same time base. Oscilloscope 2 has the following range for voltage sensitivity: 1 V per div., 5 V per div., 10 V per div. and 15 V per div.
State which voltage sensitivity would give the most suitable trace. Explain the reasons for your choice.

(3)
(Total 9 marks)

7 Iodine-123 is a radioisotope used medically as a tracer to monitor thyroid and kidney functions. The decay of an iodine-123 nucleus produces a gamma ray which, when emitted from inside the body of a patient, can be detected externally.

(a) Why are gamma rays the most suitable type of nuclear radiation for this application?

(2)

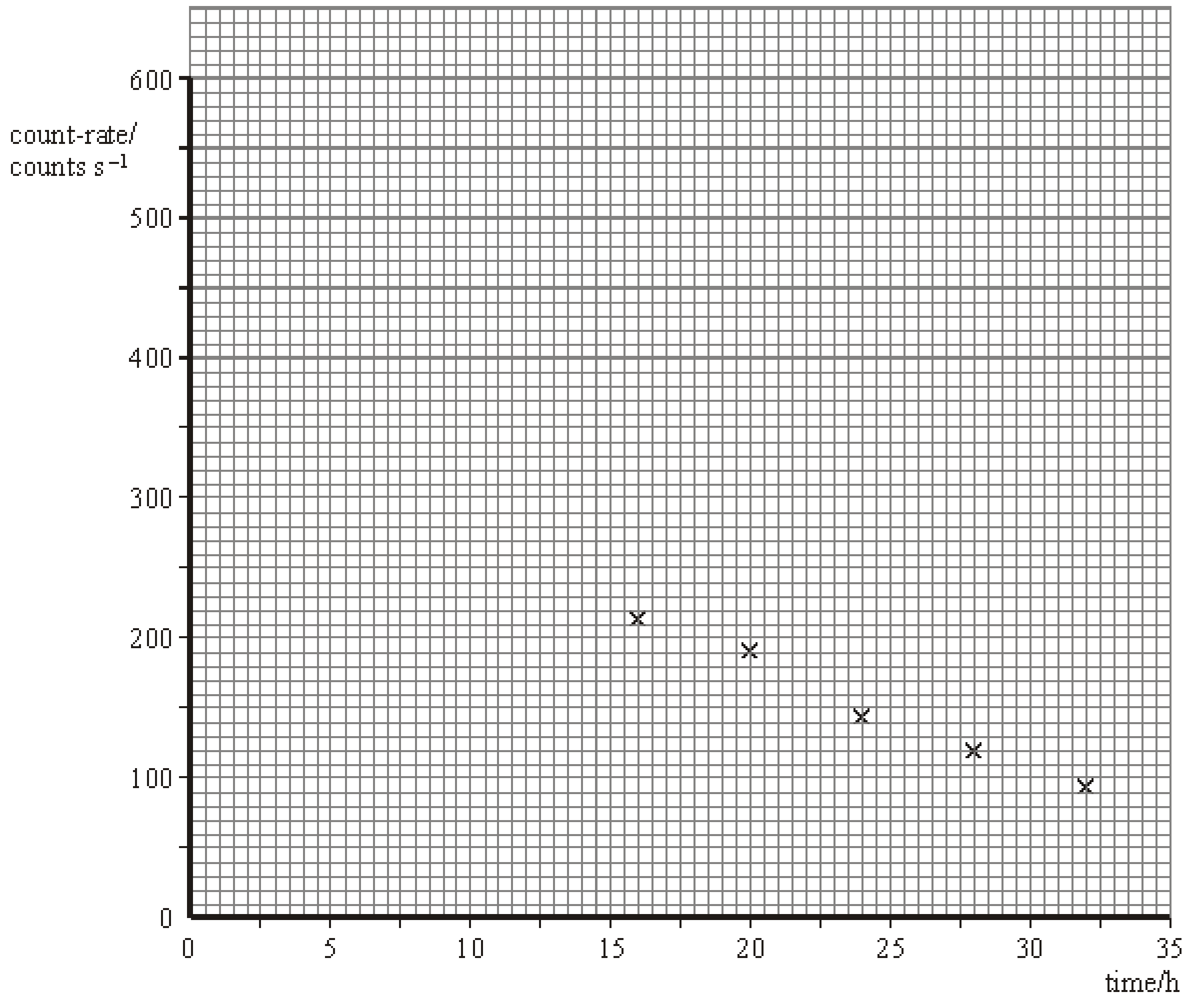
(b) In a laboratory experiment on a sample of iodine-123 the following data were collected.

time/h	0	4	8	12	16	20	24	28	32
count-rate /counts s–1	512	410	338	279	217	191	143	119	91

Why was it unnecessary to correct these values for background radiation?

(2)

(c) On the axes provided in the diagram below, complete the graph of count-rate against time.



(2)

(d) Use your graph to find an accurate value for the half-life of iodine-123.
Show clearly the method you use.

Half-life ____________________

(3)

(e) Give **two** reasons why radioisotopes with short half-lives are particularly suitable for use as a medical tracer.

(2)
(Total 11 marks)

Mark schemes

1 (a) Capacitor must not lose charge through the meter ✓

1

(b) Position on scale can be marked / easier to read quickly etc ✓

1

(c) Initial current = $\frac{6}{100000}$ = 60.0 μA ✓

100 μA or 200 μA ✓ (250 probably gives too low a reading)

Give max 1 mark if 65 μA (from 2.6) used and 100 μA meter chosen

2

(d) 0.05 V ✓

1

(e) Total charge = 6.0 x 680 x 10^{-6} (C) (= 4.08 mC) ✓

Time = 4.08 x 10^{-3} / 60.0 x 10^{-6} = 68 s ✓

Hence 6 readings ✓

3

(f) Recognition that total charge = 65 *t* μC and final pd = 0.098 *t*

so C = 65μ / 0.098✓

660 μF ✓

Allow 663 μF

2

(g) (yes) because it could lie within 646 – 714 to be in tolerance ✓

OR

it is 97.5 % of quoted value which is within 5% ✓

1

(h) Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓

Plot ln V or ln I versus time ✓

gradient is 1 / RC ✓

OR

Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals✓

Use *V* or *I* versus time data to deduce half-time to discharge ✓

1 / RC = ln 2 / $t_{½}$ quoted ✓

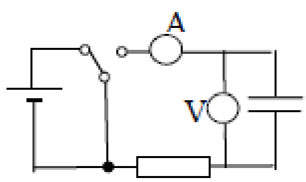
OR

Suitable circuit drawn ✓

Charge C then discharge through R and record V or I at 5 or 10 s intervals ✓

Plot V or I against t and find time T for V or I to fall to 0.37 of initial value ✓

$T = CR$ ✓



Either A or V required

For 2nd mark, credit use of datalogger for recording V or I.

4

[15]

2 (a) n changes by 4 units, 2 units, 1 unit for each change in 100 nm ✓

OR

this is not half-life behaviour because graph has false origin for n

OR

the magnitude of n does not halve every interval

1

(b) Sensible long (> 8 cm) tangent drawn, correct read-off for points from triangle at least half length of line and readings taken ✓

Substitution correct✓

(–) $(1.5 \pm 0.2) \times 10^4$ **and** m^{-1} ✓

Condone power of ten error in first two marks

3

(c) Column heading correct ✓

All calculations correct ✓

appropriate (3) sfs✓

$1 / \lambda^2 / 10^{-12}\ m^{-2}$
11.1
8.16
6.25
4.94
4.00
3.31
2.78

Accept if calculated in nm^{-2} instead of m^{-2}

$11.1 \times 10^{-6}\ nm^{-2}$ etc

Units as follows: $1 / \lambda^2 / m^{-2}$. Alternative acceptable labelling includes $1 / \lambda^2\ (m^{-2})$, $1 / \lambda^2$ in m^{-2}. The 10^{-12} can be in the body of the table or at top of column.

3

(d) Graph axes labelled correctly and sensible axes✓

Plots correct to within half a square ✓

Best-fit line by eye ✓

Suitably large graph scale (do not award if scale on axis could have been doubled) Scale must be sensible divisions which can be easily read. eg scales in multiples of 3, 6, 7, 9 etc are unsatisfactory.

2nd mark is independent mark i.e. if candidates have used an unsuitable scale they can still achieve marks for accurately plotting the points.

The line of best fit should have an approximately equal distribution of points on either side of the line.

Check bottom 3 plots.

3

(e) Intercept correct to within half a square ✓

[1.6014]

1

(f) The value of refractive index at infinite / very long wavelength✓

1

(g) states that $\log n = \log c + d \log \lambda$✓

plot $\log n$ versus $\log \lambda$ ✓

d is the gradient of the graph ✓

3

[15]

3 (a) 2 smooth curves to show envelope of exponential decay waveform; lines to be continuous from first to fifth points, maximum deviation from best-fit lines thorough each set of 5 points must not be greater than 1 mm ✓

1

equilibrium position marked on grid with horizontal line at A = 15.7 ± 0.1 cm ✓

1

(b) evidence of **valid** working (using the line(s) and/or the equilibrium position) established in (a)(iii) to **test for** the exponential nature of the decay (working may be shown on the graph): do not penalise confusion between n and time

either

evidence of relevant A values [$2A$ ie $A-(-A)$] measured from graph (correct to nearest mm) or deduced from difference between tabulated values and equilibrium position of pointer) **or 0/3** $_1$ ✓

<u>at least</u> two half life measurements (expect evidence of working) $_2$ ✓

values obtained giving $n_{½} = 6.3 \pm 0.3$ from **either or both** curves **confirming exponential decay** $_3$ ✓

or

$_1$ ✓ as above; evaluates <u>at least</u> two ratios of successive amplitudes [or the fractional change in successive amplitudes], eg

$\frac{A_0}{A_1}$ and $\frac{A_1}{A_2}$ $\left[\frac{A_0 - A_1}{A_0} \text{ and } \frac{A_1 - A_2}{A_1}\right]$ $_2$ ✓; ratios obtained giving consistent results to $\pm$ 5% **confirming exponential decay** $_3$ ✓

or

$_1$ ✓ as above; evaluates difference between natural logs of <u>at least</u> two successive amplitudes, eg $\ln(A_0) - \ln(A_1)$ and $\ln(A_1) - \ln(A_2)$ ✓ differences obtained giving results consistent to $\pm$ 10% **confirming exponential decay** $_3$ ✓

3

5

4

(a) λ [the gradient] = (−) 0.015 $\left[(-)\frac{0.3}{2.0} \text{ or similar}\right]$ ✓

$N_{½}$ from (−) $\frac{ln}{\lambda}\left[(-)\frac{ln2}{0.015}\right]$ ✓

46.2(1) slides (accept 46 but do not penalise '47 slides needed to halve V')✓

[λ = 0.015 or use of ratio $\frac{0.3}{20}$ ✓

determination of V_0 = 424(.1) mV; $\ln(V_0/2)$ = 5.36 [5.357] ✓

$\frac{6.05-5.36}{0.015}$ = 46(.0) slides (accept 46.2, '47 slides needed to halve V' etc ✓]

3

(b) (i) (student must measure or calculate) thickness of slide, t; half-value thickness = $N_{½} \times t$ [= result from (a) × t] ✓

1

(ii) procedure: measure the thickness of multiple slides (either singly or in a stack) and calculate average thickness [divide by number of slides]✓ (reject bland 'repeat and average')

[measure the thickness at **different points** on the slide, and **average** by number of readings or measure the thickness of different slides and average]

1

(iii) procedure: **close** jaws and check reading (= zero) ['check for **zero error**'] ✓

(reject idea of measuring 'known' dimension and checking reading or that 1 micrometer is 'zeroed'/'set to zero'/'zero calibrated' before use')

1

(c) t from $\frac{(R_2 - R_0)}{12}$ = 1.19 **mm** (3 sf only) ✓

1

(d) $n = \frac{14.28}{9.71}$ = 1.47, no unit (3 sf preferred but tolerate 4 sf, do not penalise here and in part a for sf) ✓

1

(e) (i)/(ii) $\Delta (R_2 - R_0) = \Delta(R_2 - R_1)$ = 0.08 **mm** ✓

1

(iii) P_{2-0} = % uncertainty in $(R_2 - R_0) = 100 \times \frac{0.08}{14.28}$ = 0.56(0)% [0.6%] and

P_{2-1} = % uncertainty in $(R_2 - R_1) = 100 \times \frac{0.08}{9.71}$ = 0.82(4)% [0.8%] ✓

working must be shown; allow ecf from i/ii but only if working is correct

P_n = % uncertainty in $n = (P_{2-0}) + (P_{2-1})$ = 1.38(4)% (accept 1.4 %) ✓

for ecf from i/ii working in iii must be valid; for AE in iii allow ecf in final calculation

[max and min values calculated, eg $n_{min} = \frac{14.28 - 0.08}{9.71 + 0.08}$, $n_{max} = \frac{14.28 + 0.08}{9.71 - 0.08}$;

difference = ½ range (✓) convert to % = 1.38 (± 0.02)% (✓)]

2

[11]

5 (a) Background radiation ✓

Background count = 20 count/minute unit required ✓

Ignore any –ve sign for background count
Must be written to 2 sf

2

(b) Correct line of best fit ✓

The line must be a straight line (as instructed), with approximately an equal number of points on either side of the line.

1

(c) Triangle drawn with smallest side at least 8 cm ✓
(or 8 grid squares)
correct values read from graph ✓
gradient = – 0.00698 (± 0.00030) min^{-1} ✓
must have –ve sign and must be to 2 or 3 sf ✓

Gradient must lie within limits stated. No ecf from incorrectly read values unless it falls within stated limits. No unit penalty.

3

(d) Recognises gradient = (–) λ **or**
Uses gradient for value of λ = 7.0 (± 0.30) × 10^{-3} minute^{-1} ✓
$T_{½}$ = 99 minutes to 2 or 3 sf ✓

For 1st mark accept evidence that value of gradient has been substituted into correct formula for half life. No penalty for missing –ve sign. Allow ect from incorrect gradient value.
Unit penalty if half life has been calculated in different unit (to minutes stated in question)

2

(e) Random ✓

1

(f) (i) Uncertainty = (± √429) = ± 21
No sf penalty ✓

Details of calculation not required. Marks can be awarded for correct numerical answers. Also no penalty for quoting uncertainty or % uncertainty without '±'.

1

(ii) % uncertainty = ± 4.9% ✓
No sf penalty. (Note that % uncertainty in total count is same as % uncertainty in corresponding count rate.)

Accept also 4.8% (number achieved keeping all sig figs in calculator)
No penalty for omitting % or '±'.
No sf penalty

1

(iii) % uncertainty for 84 counts is ± 10.9% ✓
Taking data over larger time period / larger total count will have smaller percentage uncertainty. ✓

Accept ±11%
No penalty for omission of ± sign. No sf penalty for estimated % uncertainties.

2

[13]

6

(a) (i) T = 40(ms) **(1)**

$f\left(=\frac{1}{T}\right) = 25$ Hz **(1)**

(allow C.E. for value of T)

(ii) peak voltage (= 3 × 15) = 45 (V) **(1)**

rms voltage $= \frac{45}{\sqrt{2}}$ =32 V **(1)**

(31.8 V)

4

(b) (i) Irms = $\frac{31.8}{540}$ = 59mA **(1)**

(58.9mA)

(use of 32 V gives 59(.2) mA)

(allow C.E. for value of V_{rms} from (a))

(ii) $V_{rms} = 59 \times 10^{-3} \times 90 = 5.3(1)$ V **(1)**

(allow C.E. for value of I_{rms} from (i)) [or $V_2 = V_1 \frac{R_2}{R_1 + R_2}$]

2

(c) $V_{peak} = 5.31 \times \sqrt{2}$ =7.5(1) (V) **(1)**

best choice: 5 V per division **(1)**

(allow C.E. for incorrect V_{rms} and for suitable reason)

reason: others would give too large or too small a trace **(1)**

3

[9]

7 (a) Gamma rays are very penetrating/alpha/beta rays would not be detected

B1

(outside body)
Gamma rays are **less** ionising/**less** hazardous
(to patients)/ alpha/beta are more ionising/**more** hazardous

B1

2

(b) Background radiation/count is much smaller/negligible

B1

Random fluctuations in the readings greater than background

B1

2

(c) Accurate plotting *check all four points (± ½ square)*

M1

reasonably smooth curve with even point scatter

A1

2

(d) two or more half-lives averaged

B1

Half-life calculated from best fit line

C1

Half-life = 13 ± 1 hour

A1

3

allow ecf from inaccurate plotting, but straight line = P.E.

(e) High activity (so only a small sample needed)

B1

Decays quickly

B1

Less risk to patient/other people

B1

(Short half-life ok because) medical test doesn‘t last long

B1

Any two from four

2

[11]