Year 13 Easter work – preparation for Unit 6 EMPA

READ THIS CAREFULLY

This pdf file contains a set of questions from past EMPA Section B (written) papers. It will be very useful for you to work through these.

These refer to experiments that the candidates did during the Section A practical sessions, but you should be able to answer these questions without your own set of data.

You have all the information you need here. Solutions are given immediately after each question as a guide for you, although be warned that these are written for examiners, and are sometimes difficult to interpret.

Notes on the questions:

Question 2 (from 2013)

If you wish to see a demonstration of the two oscillation experiments, follow these links:

https://www.youtube.com/watch?v=4OFKhw3XBl0

https://www.youtube.com/watch?v=zdqqyIKU_Iw

Question 3 and Question 4 (from 2012)

These questions refer to an experiment measuring the periodic time of a metre ruler oscillating like a see-saw on a curved mirror (a diagram of the basic arrangement is shown in Question 4). {NB THE MARK SCHEME HERE HAS THE WRONG DATE at the TOP!}

Question 4 (from 2010)

This one was about another 'coupled oscillator' question. You should be aware that the oscillators were actually chains of paper clips suspended to form pendulums. The candidates measured their periodic time (T) and time to exchange energy (τ) using stop clocks, fiducial marks, etc. To see this phenomenon of coupling in action (with two pendulums), follow this link:

https://www.youtube.com/watch?v=32FMEo_igEQ

Question 3 and Question 4 (from 2011)

This experiment involved shining a light on a photocell that produced a voltage output. Glass slides were then stacked on top of the photocell and the change in voltage output was measured (the glass absorbed some of the light, so less voltage was produced).

You will also find Chapters 13-15 in the book very useful

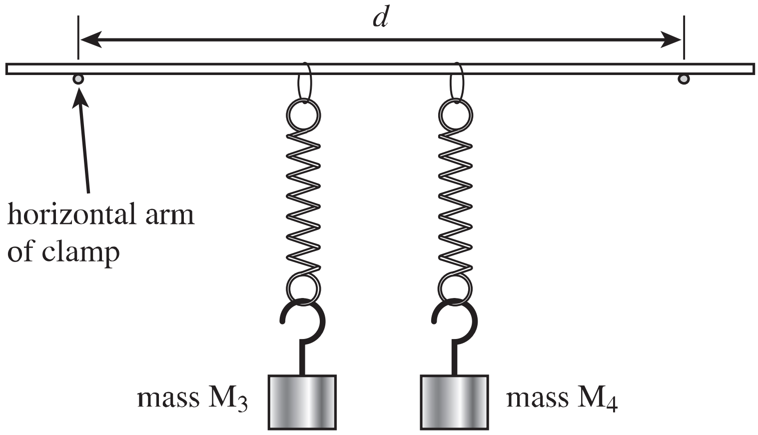
– NOTE: we are following Scheme X (EMPA) and not Scheme T (ISA)

Good luck

Mr Hicklenton.

2 In Section A Task 1 you observed the energy transfer between masses M_3 and M_4 suspended by springs from a horizontal metre ruler using the apparatus shown in **Figure 7**.

Figure 7



With the same apparatus, a student investigates how d, the horizontal distance between the arms of the clamps on which the metre ruler is supported, affects τ, the time of energy transfer between M_3 and M_4.

The student measured the times for n energy transfers between the masses, as shown in **Table 2.**

Table 2

d / cm	n	$n\tau$ / s	$n\tau$ / s	τ / s
86.0	6	212	209	
78.0	5	236	240	
70.0	6	408	*	
65.0	4	347	*	

* only one set of readings of $n\tau$ was completed for these values of d

2 (a) (i) Complete **Table 2** to show the values for τ that the student obtained.

2 (a) (ii) Justify the number of significant figures you have given for the values of τ.

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(2 marks)

2 (b) The student claimed that these results showed that τ was directly proportional to $\frac{1}{d^2}$.

Analyse the data in **Table 2** to show whether the student's claim is correct.

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(2 marks)

2 (c) Suggest **three** valid control variables for the experiment.

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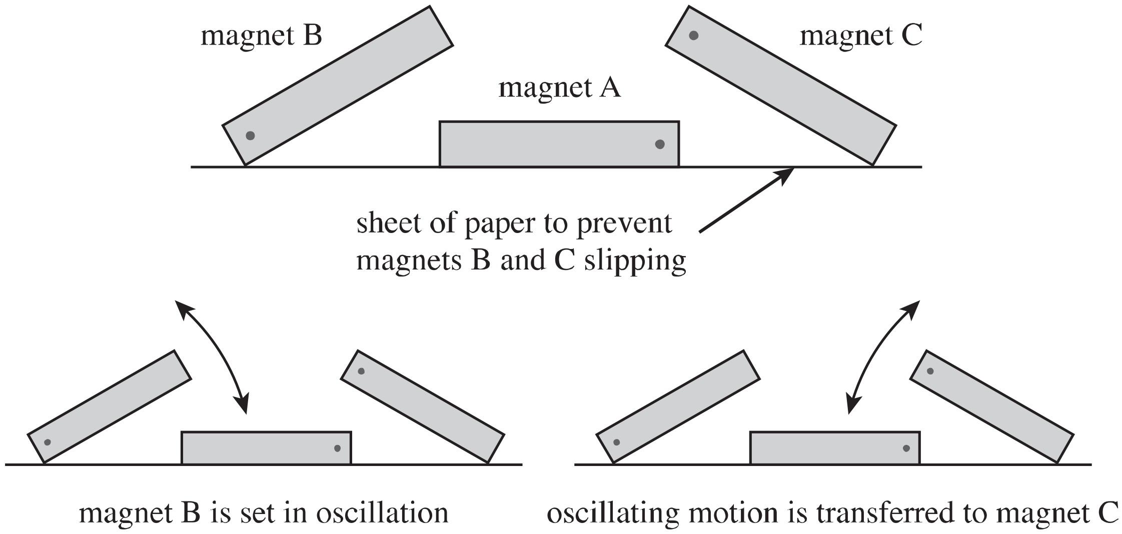
(1 mark)

THE QUESTION IS CONTINUED ON THE NEXT PAGE

2 (d) In a different experiment to illustrate energy transfer between oscillators, three bar magnets are arranged as shown in **Figure 8**.

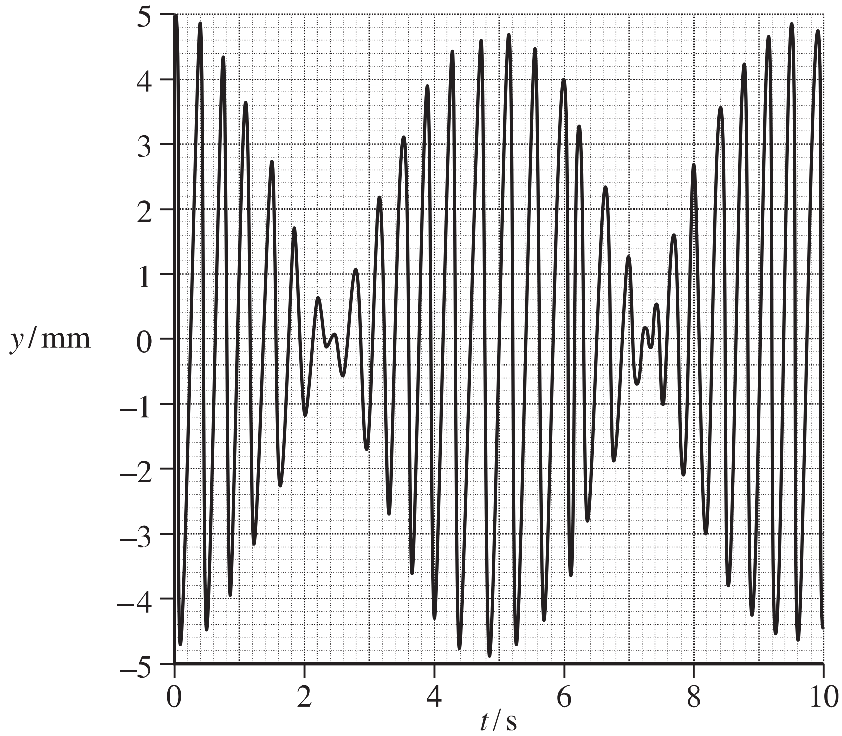
Figure 8



Magnets B and C are balanced on one edge using the repulsion produced by magnet A, the paper below providing friction to prevent B and C slipping.
When B is set oscillating about the point of contact with the paper, the oscillating motion is transferred within a few cycles to C, and then back again, as in your experiment with masses M_3 and M_4.

A student uses a motion sensor and a data logger to record the motion of magnet B; the data are then exported to a computer and analysed using a spreadsheet.
Figure 9 is based on 25 000 measurements that are transferred to the data logger in 10 seconds and shows how the displacement, y, of the moving end of magnet B, varies with time, t.

Figure 9

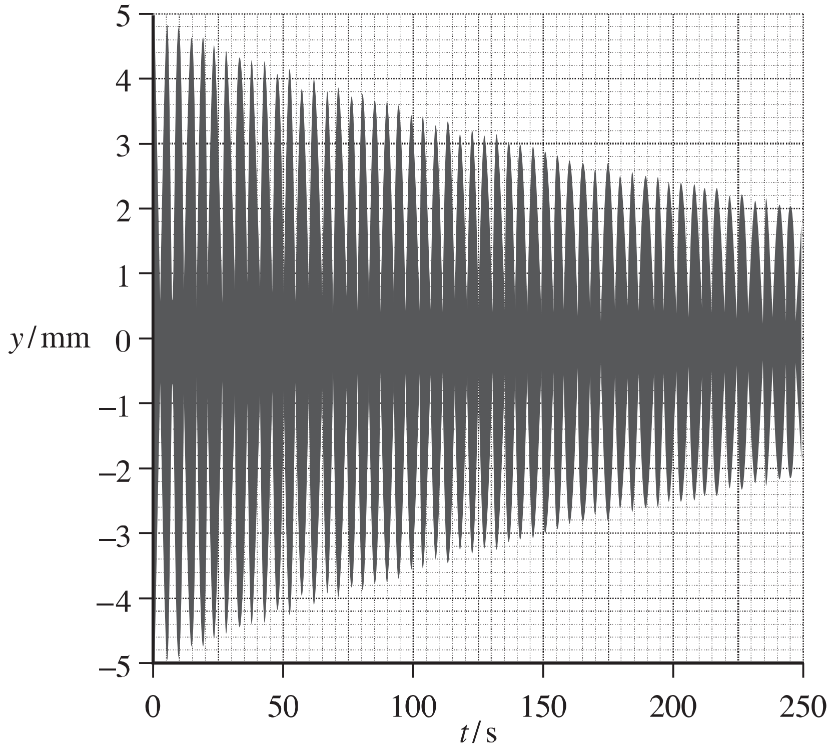


2 (d) (i) What was the *sample rate* of the data logger when the data displayed in **Figure 9** was being recorded?

sample rate = ...

The sample rate is then changed so that 25 000 measurements are transferred to the data logger in 250 seconds. These results are displayed in **Figure 10**.

Figure 10



2 (d) (ii) If τ = the time for energy transfer from magnet B to magnet C and back again to B, and T = the period of oscillations of magnet B, use **Figure 9** and **Figure 10** to determine $\frac{\tau}{T}$.
You may assume that in both **Figure 9** and **10**, y has just reached a maximum value at $t = 0$.

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$\frac{\tau}{T}$ = ...

(4 marks)

9

Section B			
1	(a)	valid attempt at gradient calculation and correct transfer of data **or** $_{12}$✓**= 0** correct transfer of *y*- and *x*-step data between graph and calculation $_1$✓ (mark is withheld if points used to determine either step > 1 mm from correct position on grid; if tabulated points are used these must lie on the line) *y*-step and *x*-step both at least 8 semi-major grid squares $_2$✓ (if a poorly-scaled graph is drawn the hypotenuse of the gradient triangle should be extended to meet the 8 × 8 criteria)	2
		G in the range –3.15 to –2.85 or 2 sf answers in the range –3.1 to –2.9 ✓✓ [–3.30 to –2.70 or –3.2 or –2.8 ✓] (ignore any unit given in error; deduct 1 mark for the omission of the minus sign unless false data has led to a positive gradient)	2
1	(b)(i)	(*n* is given by the gradient of the graph, hence nearest integer to *G*) *n* = –3 ✓ (no credit for non-integer value for *n*) [allow ecf for valid <u>non-zero</u> integer deduction if $n \neq -3$]	1
	(b)(ii)	units for *k* are $cm^3\,s^{-2}$ ✓(allow m or mm for cm; no ecf if *n* was not given as an integer) [allow ecf for valid deduction of unit if $n \neq -3$]	1
	(b)(iii)	<u>vertical</u> (condone '*y*') intercept on graph = log (*k*) ✓ (don't insist on 'read'/'find' or 'extrapolate line') when log(*d*) = 0, $\log\left(\frac{1}{T^2}-\frac{1}{T_0^2}\right)$ =log(*k*) ✓ <u>horizontal</u> (condone '*x*') intercept on graph = $\frac{-\log(k)}{n}$ ✓ $\log\left(\frac{1}{T^2}-\frac{1}{T_0^2}\right)$ = *n* log(*d*) + log(*k*) compared with *y* = *mx* + *c so* <u>*c* = log(*k*)</u> ✓ find log(*k*) by evaluating $\log\left(\frac{1}{T^2}-\frac{1}{T_0^2}\right)$ – *n* log(*d*) for a <u>point on the line</u> ✓	1 MAX
		$k = 10^{(\text{vertical intercept})}$ [<u>antilog</u> (tolerate 'inverse log' but reject '$\log^{-1}$') of vertical intercept] ✓ $k = 10^{-n(\text{horizontal intercept})}$ ✓ $k = 10^{(\log k)}$ ✓	1 MAX

2	(a)(i)	4 <u>correct</u> values of τ/s: all to 3 sf or all to 4 sf ✓	1

d/cm	*n*	*n*τ/s	*n*τ/s	τ/s
86.0	6	212	209	35.1
78.0	5	236	240	47.6
70.0	6	408		68.0
65.0	4	347		86.8

2	(a)(ii)	3 sf is justified since the *nT* values [timings] are 3 sf; no credit if all τ/s ≠ 3 sf in 2(a)(i) [condone 'same as (measured) data (in table)' as long as it can be inferred that this includes *nT*] ✓	1

<table>
<tr><td>2</td><td>(b)</td><td>evidence of <u>at least two</u> correct calculations of $d^2\tau$ recorded to 2 or more sf (treat trailing zeros as ambiguous) or $_{12}$✓ = 0: other valid ratios are acceptable [accept use of $d^2\tau$ to calculate result for τ for another value of d]

| d/m | τ/s | $d^2\tau$ /m^2 s | [$d^{-2}\tau^{-1}$ /m^{-2} s^{-1} |
| 0.860 | 35.1 | 26.0 [2.60 × 10^5 cm^2 s] | 38.5 × 10^{-2} |
| 0.780 | 47.6 | 29.0 etc | 34.5 × 10^{-2} |
| 0.700 | 68.0 | 33.3 etc | 30.0 × 10^{-2} |
| 0.650 | 86.8 | 36.7 etc | 27.2 × 10^{-2}] |

(accept minor rounding errors but candidate's values, when rounded to 2 sf, must agree with 26, 29, 33 and 37; allow ecf if 2 sf τ given in (a); there can be no ecf if wrong τ given in (a)) $_1$✓
valid observation (e.g. large <u>percentage</u> uncertainty (about mean) / large (absolute) variation about <u>mean</u> / large range [difference between largest and smallest values]) supported by <u>suitable calculation(s)</u>, hence the claim is <u>not justified</u> $_2$✓

[evidence of <u>four</u> correct calculations of $d^2\tau$ $_1$✓ statement that $d^2\tau$ increases as d decreases [as τ increases] so claim is <u>not justified</u> $_2$✓]
[$\frac{d_1^2}{d_2^2}$ compared to $\frac{\tau_2}{\tau_1}$, $\frac{d_2^2}{d_3^2}$ compared to $\frac{\tau_3}{\tau_2}$, etc, using data from <u>at least three</u> rows in the table (or $_2$✓ = 0): consistent recording and appropriate sf $_1$✓ valid observation so claim is <u>not justified</u> $_2$✓]</td><td>2</td></tr>
<tr><td>2</td><td>(c)</td><td>any 3 of the following, at least 2 of which should be <u>quantitative</u>: ✓
(same) <u>masses</u> (either or both masses may be mentioned but 'M$_3$ and M$_4$' does not count as 2 responses; allow 'size of the masses' but reject 'weight of the masses')
(same) spring <u>stiffness</u> [spring <u>constant</u>]
(allow 'same (type of) spring' as the one qualitative response allowed)
(same) ruler (<u>Young Modulus</u>, <u>stiffness</u>, <u>material</u>, <u>mass</u>) / ruler same way up /same <u>cross-sectional</u> area
<u>position</u> of springs on ruler
spring <u>separation</u> [<u>distance</u> between masses]
reject 'same initial displacement', 'length of spring', 'thickness of ruler', 'height of supports'</td><td>1</td></tr>
<tr><td>2</td><td>(d)(i)</td><td>sample rate = (25000/10 =) 2500 Hz [tolerate s^{-1}, accept 1 every 4 × 10^{-4} s] ✓</td><td>1</td></tr>
<tr><td>2</td><td>(d)(ii)</td><td>sensible working using Fig 9; T from nT where n or $\sum n \geq 15$
(e.g. $T = \frac{10}{28.5} = 0.35(1)$) ✓
sensible working using Fig 10; τ from $n\tau$ where n or $\sum n \geq 30$
(e.g. $\tau = \frac{246}{52} = 4.73$) ✓

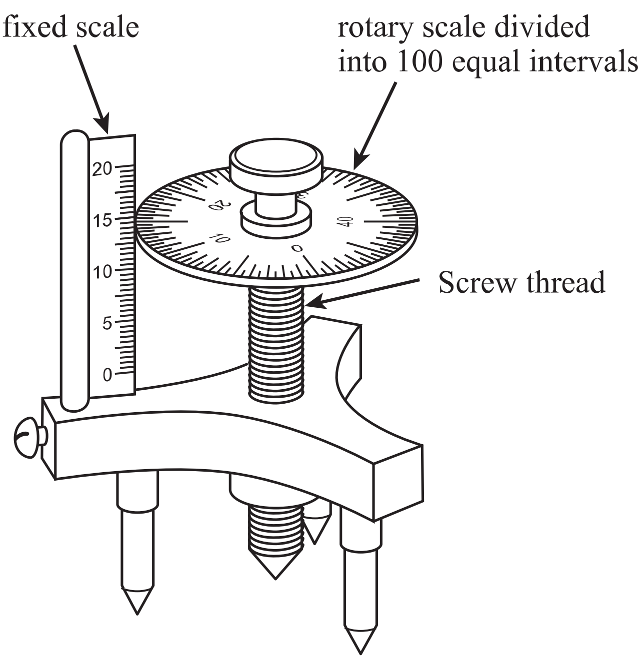
$\frac{\tau}{T}$, no unit, in range 12.8 to 13.8; 3 sf or 4 sf only unless sf already penalised elsewhere in Section B ✓
[1 MAX if T and τ interchanged but result in range 7.25×10^{-2} to 7.82×10^{-2}]</td><td>3</td></tr>
</table>

Do not write outside the box

3 In the experiment in Section A Part 1 you made measurements to calculate the radii of curvature of the surfaces of a spherical mirror. In order to check the accuracy of such an experiment, an instrument called a *spherometer* is used.

A spherometer is shown in **Figure 9**.

Figure 9



A spherometer, like a micrometer screw gauge, is a device in which a screw thread mechanism is used. One full rotation of the mechanism advances the screw 0.5 mm and this causes the rotary scale, which is divided into 100 equal intervals, to move vertically through one division of the fixed scale.
As with the micrometer screw gauge, the instrument is read by combining the readings from the fixed scale and the rotary scale.

3 **(i)** What is the precision of the spherometer?

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(1 mark)

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3 **(ii)** Measurements made with a spherometer show that the radius of curvature, R_2, of the convex surface of the mirror is 84.4 mm.
Using the oscillating metre ruler method, a student calculates a value of R_2 which is 4.5% lower than the spherometer value.
Calculate the value of R_2 obtained by the student.

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(1 mark)

3 **(iii)** To calculate the radius of curvature, R_2, of the convex surface of the mirror, the student used the formula

$$R_2 \approx \frac{1}{3g}\left(\frac{x\pi}{T}\right)^2$$

in which x = the length of the ruler, $g = 9.81\,\text{N kg}^{-1}$ and T is the period of the oscillations.

Assuming the uncertainties in x and g are negligible and the percentage uncertainty in $R_2 = 4.5\%$, calculate the percentage uncertainty in the student's result for T.

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(1 mark)

3 **(iv)** Based on a single measurement of 10 oscillations, the student calculated that $T = 2.04$ s.
Calculate the uncertainty in the student's measurement for the time of 10 oscillations of the ruler.

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(1 mark)

Turn over for next question

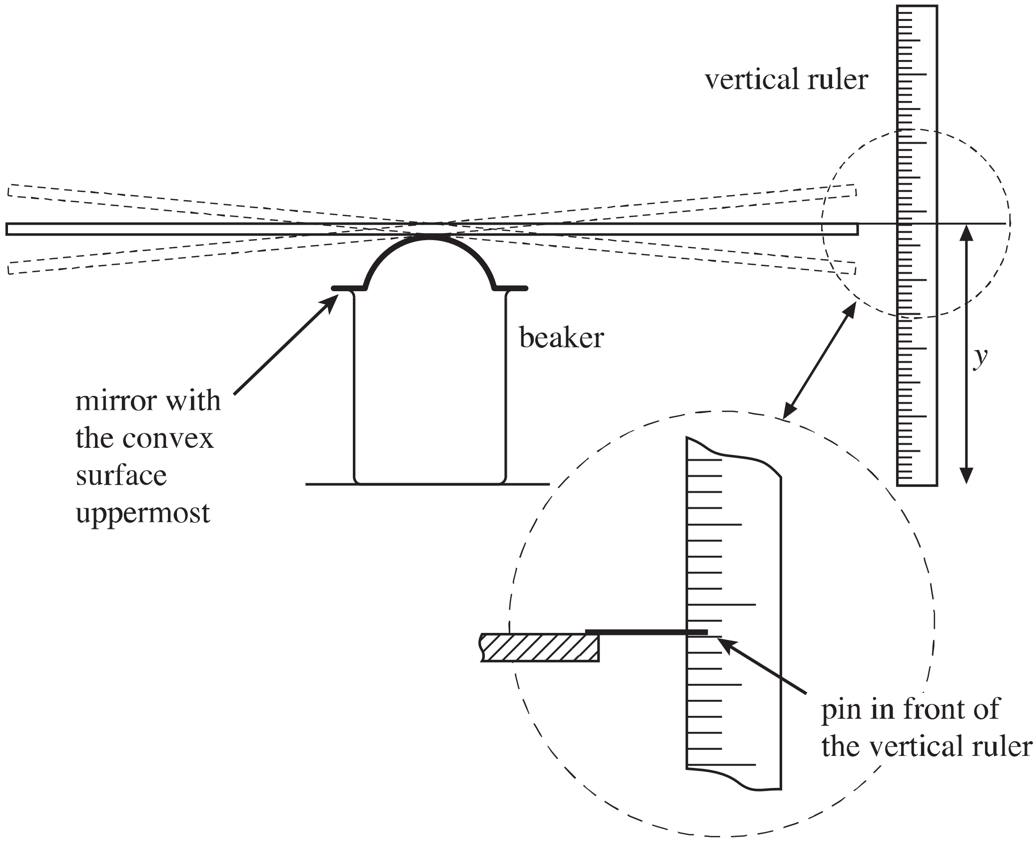
4

Turn over ▶

4 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 **Figure 10**.

Figure 10



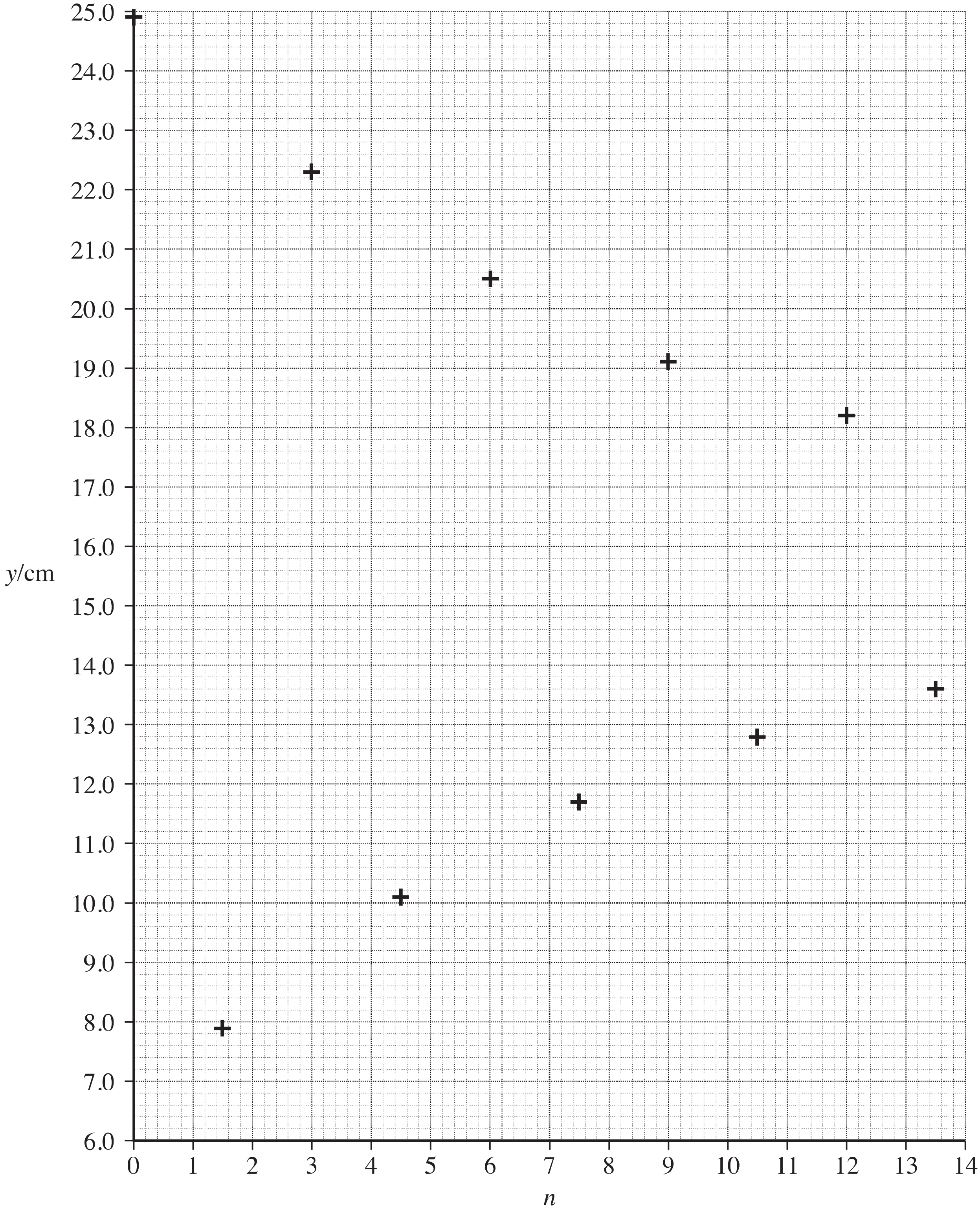
The student records the height above the bench of the tip of the pin at the top, y_t, and at the bottom, y_b, of its motion during several successive swings, n, of the ruler.

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

4 (a) Her data points are plotted on **Figure 11**.

Figure 11



On **Figure 11** 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 marks)

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

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(3 marks)

5

END OF QUESTIONS

Question 3			
3	(i)	precision = 0.005 mm [5 □m] ✓ (suitable unit essential)	**1**
3	(ii)	$R = 84.4 \times \left(\frac{100 - 4.5}{100}\right) = [84.4 \times 0.955] =$ <u>80.6</u> (mm) ✓ (reject 80.8 (mm))	**1**
3	(iii)	percentage uncertainty in *R* = 2 × percentage uncertainty in *T* ∴ percentage uncertainty in *T* = 2.25(%) [2.3(%)] ✓	**1**
3	(iv)	uncertainty in *T* = $\frac{2.25 \times 2.04}{100} = 0.0459$ (s) uncertainty in 10*T* = 0.459 (s) [0.46 (s)] ✓ (2.3% will lead to 0.47 (s); allow ecf from (iii), reject 0.5 s)	**1**
		Total	**4**

Question 4			
4	(a)	2 <u>smooth</u> 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**
4	**(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 [2*A* 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 $n_{1/2}$ = 6.3 ± 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 $\frac{A_1}{A_2}$ $\left[\frac{A_0 - A_1}{A_0}\right.$ and $\left.\frac{A_1 - A_2}{A_1}\right]$ $_2$✓; ratios obtained giving consistent results to ± 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 ± 10% **confirming exponential decay** $_3$✓	**3**
		Total	**5**

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4 In Section A Task 1 you investigated the motion of coupled pendulums, measuring the time, τ, for the amplitude of either pendulum to increase from zero to a maximum and then fall to zero again. A student performs this experiment and measures four values of τ with three, five and then seven paper clips suspended from the thread.
The student's results are shown in **Table 2**.

Table 2

n	τ_1/s	τ_2/s	τ_3/s	τ_4/s	mean τ/s	uncertainty/s	percentage uncertainty
3	112.8	111.2	115.8	114.3			
5	67.3	69.9	64.2	66.2			
7	44.8	49.1	48.7	47.9			

4 (a) Complete the relevant column of **Table 2** to show the mean value of τ for $n = 3$, $n = 5$ and $n = 7$.

(1 mark)

4 (b) (i) Calculate the uncertainty in the mean values of τ for $n = 3$, $n = 5$ and $n = 7$; show the results of these calculations in the relevant column of **Table 2**.

4 (b) (ii) Use your results to calculate the percentage uncertainty in the mean values of τ for $n = 3$, $n = 5$ and $n = 7$; show the results of these calculations in the relevant column of **Table 2**.

(2 marks)

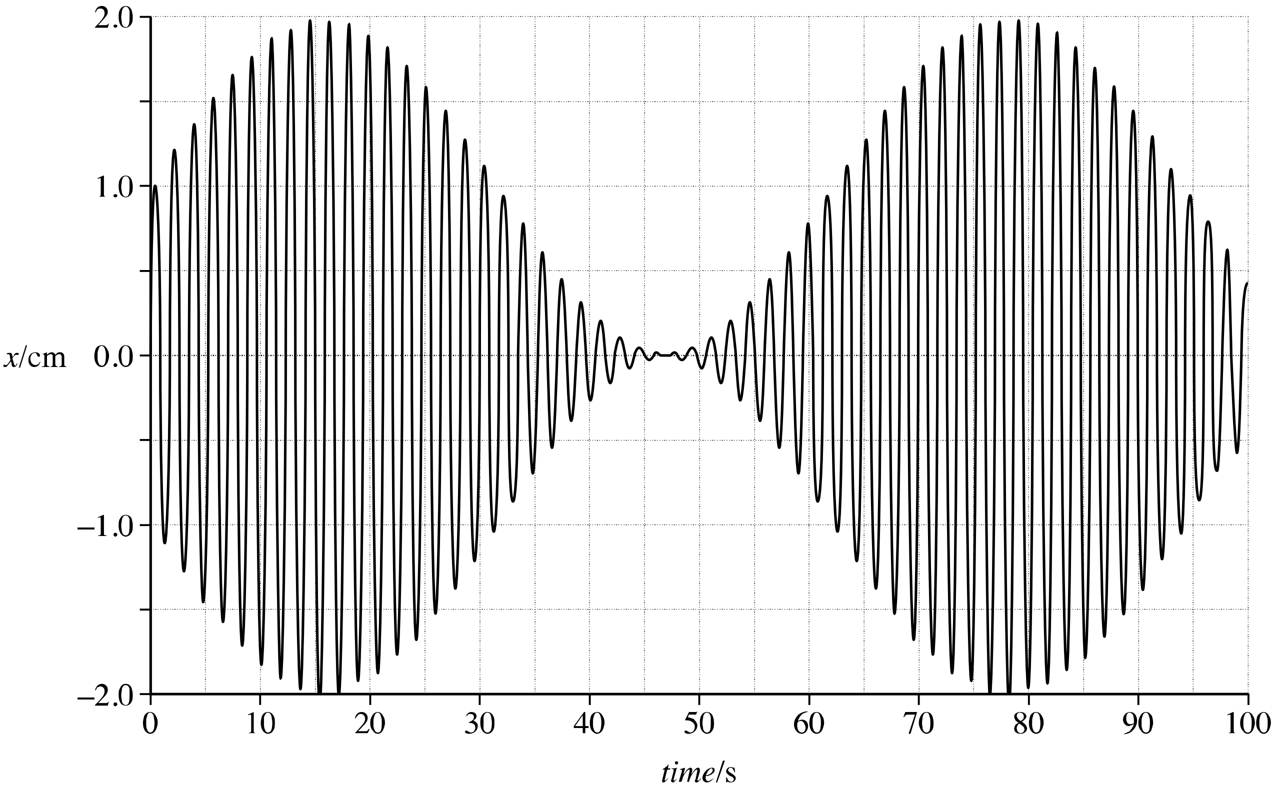
Use this space for any working.

Question 4 continues on the next page

Turn over ▶

4 (c) A student uses a motion sensor connected to a data logger to investigate the motion of one of the coupled pendulums.
Data about the displacement, x, of the pendulum bob is recorded over an interval of 100 seconds and then displayed graphically, as shown in **Figure 5**.

Figure 5



4 (c) (i) Use **Figure 5** to estimate τ for these coupled pendulums.

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τ = ...

4 (c) (ii) Determine the period of the pendulum's motion represented in **Figure 5**.

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period = ...

(3 marks)

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4 (d) State and explain **two** advantages of using a data logging technique to produce the data in an experiment such as this, compared with the method which you were required to use in Section A Task 1.

advantage 1

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advantage 2

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(4 marks)

10

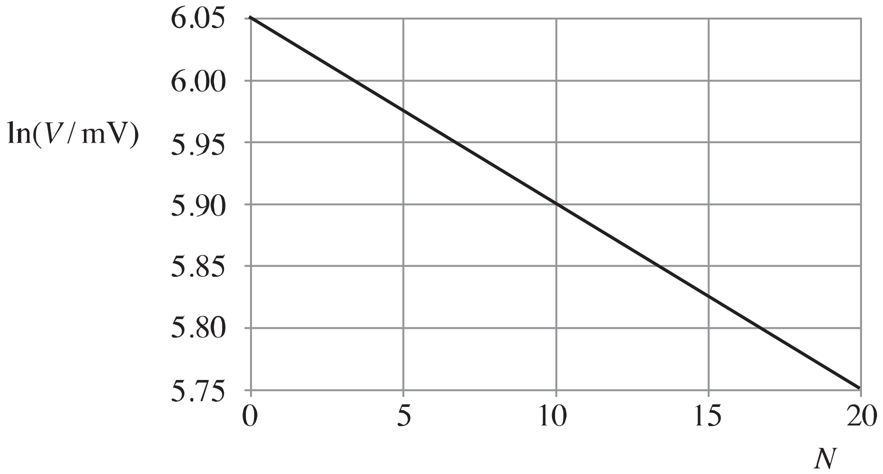
END OF QUESTIONS

Question 4		
Table 2	<table><tr><td>*n*</td><td>mean τ/s</td><td>uncertainty/s</td><td>percentage uncertainty</td></tr><tr><td>3</td><td>113.5</td><td>2.30 [2.3]</td><td>2.03% [2.0%]</td></tr><tr><td>5</td><td>66.9</td><td>2.85 [2.9]</td><td>4.26% [4.3%]</td></tr><tr><td>7</td><td>47.6</td><td>2.15 [2.2]</td><td>4.51% or 4.52% [4.6%]</td></tr></table>	
(a)	mean τ/s values correct to 0.1 s; reject > 1 dp ✓	**1**
(b) (i)	uncertainty from 0.5 × range, values correct, either all to 3 sf or all to 2 sf ✓ (no ecf from (a))	**1**
(b) (ii)	percentage uncertainty from 100 × $\Delta T/T$, result to same sf as in (b)(i) ✓ [any two correct rows showing consistency in sf for cols 3 & 4 earns 1 mark]	**1**
(c) (i)	τ = 62(.0) ± 1 s ✓	**1**
(c) (ii)	*period* to 0.01 s in range 1.67 to 1.77 s (reject 1.7 s) ✓ or 0/2 from *n* × period where $\Sigma n \geq 20$ ✓ (reject cycles in a fixed time)	**2**
(d)	***statement of advantage*** (*eg elimination of human error*) *and* ***explanation*** (*eg better precision*) *earns 2 marks – full credit can be gained for two linked answers: 1 mark can be earned for statement without explanation, but* ***not vice-versa****; only 2 marks max for each response* ***statement*** do not have to release the bob and start timing at same moment [or other valid example associated with overcoming systematic error] ✓ (no credit for 'avoid parallax error') ***explanation*** τ is measured with greater **accuracy** (reject 'more reliable') ✓ ***statement*** no **human/random/reaction error** is involved in the timing process ✓ and/or it is easier to ascertain the moment/point of maximum [minimum] amplitude ✓ and/or samples can be taken at very high frequency/greater **sensitivity** obtained using digital sensors (allow 'can record to more decimal places; reject 'can take more data' and 'measure over short intervals of time') ✓ and/or can collect data for many cycles of energy transfer [over longer time] (hence can calculate a more reliable mean) ✓ ***explanation*** τ is measured with greater **precision** (allow 'more **reliably**') ***statement*** the experiment does not require the experimenter's constant attention (reject 'data logger is automatic' idea)/the information can be analysed or manipulated later/can scroll through the data line by line ✓ and/or the data is easily (transferred to a spreadsheet to be) graphed [can draw the envelope around the displacement – time graph to determine τ] ✓ ***explanation*** data logging is **convenient** (allow 'labour/time saving') ✓ (while giving credit for any valid improvement, do not credit the claim that this leads to better accuracy *and* better precision)	**4 max**
	Total	**10**

3 A student adapts the experiment to investigate how light is absorbed by glass.
The student uses a varying number of glass microscope slides (up to a maximum of 20 slides) placed in a single stack on top of the solar cell to produce different thicknesses of the glass.

The student plots a graph of his results, as shown in **Figure 5**.
Note that N = number of glass microscope slides placed on top of the solar cell.

Figure 5



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.

3 (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.

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(3 marks)

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

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

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

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

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3 (b) (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 marks)

6

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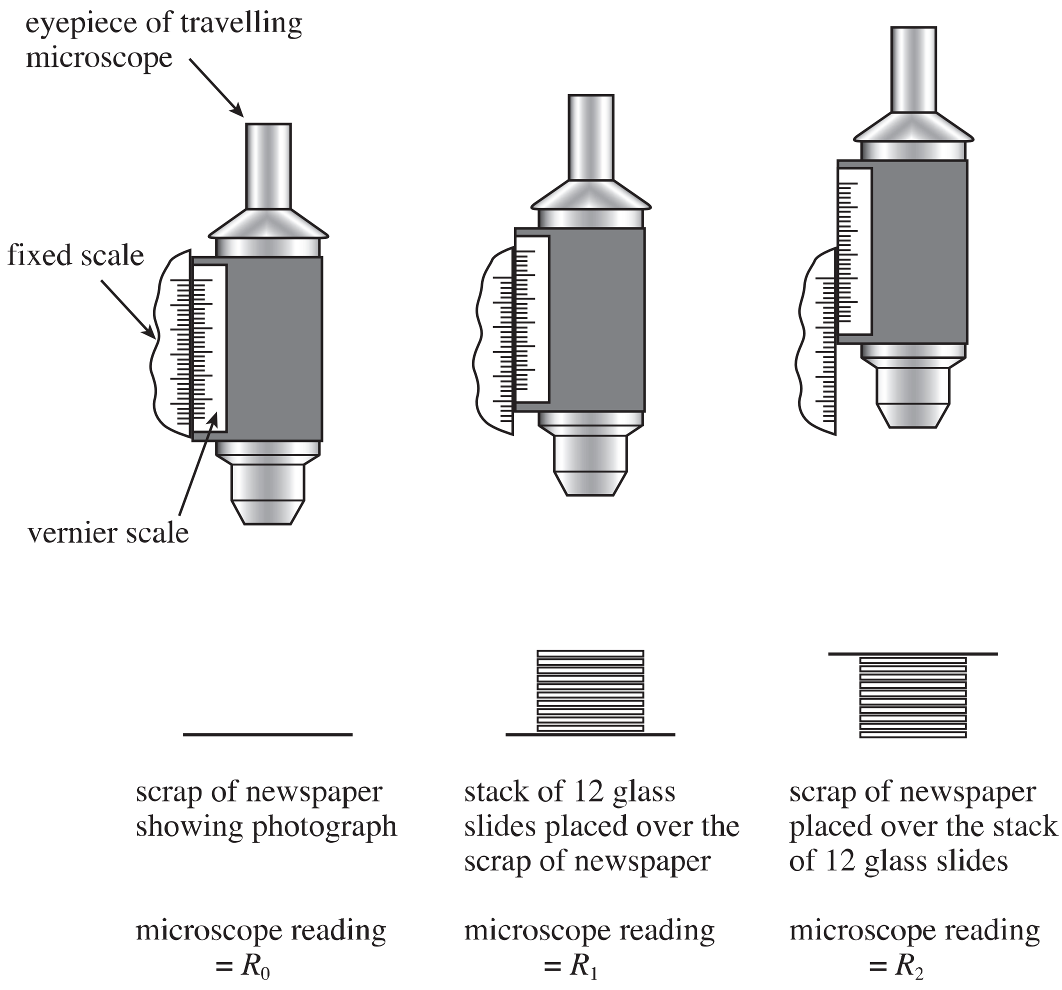
4 The student uses a travelling microscope to learn more about the properties of the glass slides.

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 in **Figure 6**.

Figure 6



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**

Do not write outside the box

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

....

....

(1 mark)

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

....

....

(1 mark)

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

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

....

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

....

4 (c) (iii) Hence calculate the percentage uncertainty in n.

....

....

....

....

....

....

(3 marks)

5

END OF SECTION B

Question 2		
a i	difficult to read (the graduations on the) measuring cylinder against background of dark-coloured liquid or difficult to see **the position of the meniscus** (reject bland 'hard to see meniscus') [meniscus was not at continuous level/ink had wetted the inside of measuring cylinder] or any other reasonable comment, eg effect of bubbles at the surface (reject comments about precision or idea that some residual ink is left in the measuring cylinder) ✓	**1**
a ii	read volume of ink solution by reading position of the **bottom** of the meniscus against the scale (accept evidence of sketch) ✓ view at eye level (accept sketch) to avoid/reduce **parallax** error ✓ place measuring cylinder on a level surface (tolerate 'bench') before making measurement ✓	**max 1**
b i	(idea that) readings made (when *Q* small) by student A lack **precision** [intervals between *V* readings are (initially) large] (allow 'harder to get ink at level of graduations on measuring cylinder') ✓ [to transfer ink in the small increments when $Q < 200$ ml, the (percentage) uncertainty [error] in Q is greater for student A]	**1**
b ii	(idea that) student B has to make **more** (accept 2) readings [experiment takes a long time to complete/is time-consuming] ✓ (reject 'the measuring cylinder is not big enough to transfer (40 to 70 ml) of ink') [to transfer ink in larger increments when $Q > 200$ ml the cylinder has to be used **more than once** for student B]	**1**
	Total	**4**

Question 3		
a	λ [the gradient] = (–) 0.015 $\left[(-)\frac{0.3}{20}\text{ or similar}\right]$ ✓ $N_{½}$ 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 3(a) × *t*] ✓	**1**
b 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**

b	iii	procedure: **close** jaws and check reading (= zero) [‘check for **zero error**’] ✓ (reject idea of measuring ‘known’ dimension and checking reading or that micrometer is ‘zeroed/‘set to zero’/‘zero calibrated’ before use’)	**1**
		Total	**6**

Question 4			
a		t from $\frac{(R_2 - R_0)}{12}$ = 1.19 **mm** (3 sf only) ✓	**1**
b		$n = \frac{14.28}{9.71}$ = 1.47, no unit (3 sf preferred but tolerate 4 sf, do not penalise here and in part a for sf) ✓	**1**
c	i/ii	$\Delta (R_2 - R_0) = \Delta(R_2 - R_1)$ = 0.08 **mm** ✓	**1**
c	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**
		Total	**4**

	UMS conversion calculator www.aqa.org.uk/umsconversion	