2(b)	1. Use a metre rule to measure amplitude **(1)** 2. Clamp a metre rule close to the card **Or** Use a set square to ensure metre rule is vertical **Or** View the scale perpendicularly **(1)** 3. Record the amplitude A at known value of n **(1)** 4. Record at least 5 sets of data (for different values of n) **(1)** 5. Plot a graph of ln A against n **(1)** 6. Read value for n when A has halved (from the graph) **and** multiply by time period T **Or** Calculate the gradient ($-\lambda$) and use $n = \ln 2 / (-)$ gradient **and** multiply by time period T **Or** Calculate the gradient ($-\lambda$) and calculate n from $0.5 = e^{-\lambda n}$ **and** multiply by time period T **(1)**	**6**
	Total for question 2	**13**

Question Number	Answer	Mark
2(a)(i)	Calculation of mean shown **(1)** Mean $T = 1.51$ s Accept 2 d.p. only **(1)** Example of calculation Mean $5T = \frac{(7.69 + 7.58 + 7.43 + 7.51)\text{ s}}{4} = 7.55$ s Mean $T = \frac{7.55\text{ s}}{5} = 1.51$ s	**2**
2(a)(ii)	Calculation of half range shown **Or** Calculation of furthest from mean shown **(1)** Percentage uncertainty = 1.7% Accept 1 or 2 sig fig, e.c.f (a)(i) **(1)** Example of calculation Half range $= \frac{(7.69 - 7.43)\text{ s}}{2} = 0.13$ s Percentage uncertainty $= \frac{0.13\text{ s}}{7.55\text{ s}} \times 100 = 1.7\%$	**2**
2(a)(iii)	Use a (timing) marker (at the centre of the oscillation) **(1)** Allow the oscillations to settle before timing **(1)** Use a small displacement **Or** Ensure displacement is vertical (to avoid movement in other planes) **(1)**	**3**

Question Number	Answer		Mark
1(a)	**EITHER**		
	Measure time	**(1)**	
	For a known volume (of water to flow out of the tube)	**(1)**	
	Use (volume flow rate =) $\frac{\text{volume}}{\text{time}}$	**(1)**	
	OR		
	Measure volume (of water to flow out of the tube)	**(1)**	
	For a known time	**(1)**	
	Use (volume flow rate =) $\frac{\text{volume}}{\text{time}}$	**(1)**	**3**
1(b)	Uses number of divisions × 50 ms per division	**(1)**	
	Use of $f = \frac{1}{T}$	**(1)**	
	f = 6.3 Hz Accept 6.25 Hz	**(1)**	**3**
	<u>Example of calculation</u>		
	Number of divisions = 6.4		
	Time for $2T$ = 6.4 divisions × 50 ×10^{-3}s = 0.32 s		
	$T = \frac{0.32\text{s}}{2} = 0.16$ s		
	$f = \frac{1}{0.16\text{s}} = 6.25$ Hz		
1(c)	Measure the flow rate and frequency (at the same h)	**(1)**	
	Repeat for different values of h	**(1)**	
	Plot a graph of flow rate against f	**(1)**	**3**
1(d)	The data logger can be used remotely (without monitoring)	**(1)**	
	The data logger can record measurements over a long period of time **Or** The data logger can record a large amount of data	**(1)**	**2**
	Total for question 1		**11**

4(c)(ii)	**EITHER** Uses 2 × %U in d Accept $2 \times \frac{\Delta d}{d}$ **(1)** %U in n = 1% Accept 1.1% **(1)** Allow use of value from (b) <u>Example of calculation</u> %U in $\frac{d^2}{8tf} = (2 \times \frac{0.02\text{cm}}{5.02\text{cm}} + \frac{0.01\text{mm}}{4.28\text{mm}} + \frac{0.2\text{cm}}{11.6\text{cm}}) \times 100$ $= 0.797\% + 0.234\% + 1.72\% = 2.8\%$ %U in $n = \frac{(0.63 \times 0.028)}{1.63} \times 100 = 1.1\%$ **OR** Correct calculation of maximum or minimum n **(1)** %U in n = 0.9% Accept 0.92% **(1)** <u>Example of calculation</u> Maximum $n = 1 + \frac{(5.04\text{cm})^2}{8 \times 0.427\text{cm} \times 11.4\text{cm}} = 1.65$ Minimum $n = 1 + \frac{(5.00\text{cm})^2}{8 \times 0.429\text{cm} \times 11.8\text{cm}} = 1.62$ %U $= \frac{(1.65 - 1.62)}{2 \times 1.63} \times 100 = 0.92\%$	**2**
4(c)(iii)	**EITHER** Correct value of relevant limit (e.c.f. (c)(i), (c)(ii)) **(1)** Conclusion based on comparison of relevant limit to n = 1.52 **(1)** MP2 dependent MP1 <u>Example of calculation</u> lower limit of $n = 1.63 \times (1 - 0.01) = 1.61$ As the lower limit is greater than 1.52 the lens could not be made of crown glass **OR** Correct calculation of %D shown (e.c.f. (c)(i), (c)(ii)) **(1)** Conclusion based on comparison of %D and %U **(1)** MP2 dependent MP1	**2**

4(b)	**EITHER** Uses %U in u **and** v Accept fractional uncertainty $=\frac{\Delta u}{u}$ and $\frac{\Delta v}{v}$ **(1)** Calculation of %U in $(u + v)$ Accept fractional uncertainty **(1)** Addition of all %U Accept fractional uncertainty **(1)** U = 0.15 (cm) 2 s.f. only **(1)** Example of calculation %U in $u = \frac{0.1\text{cm}}{29.6\text{cm}} \times 100 = 0.34\%$ %U in $v = \frac{0.1\text{cm}}{19.2\text{cm}} \times 100 = 0.52\%$ %U in $u + v = \frac{(0.1 + 0.1)\text{cm}}{(29.6 + 19.2)\text{cm}} \times 100 = \frac{0.2\text{cm}}{48.8\text{cm}} \times 100 = 0.41\%$ %U in $f = 0.34\% + 0.52\% + 0.41\% = 1.3\%$ U in $f = 11.6 \times 1.3\% = 0.15$ (cm) **OR** Uses uncertainties to calculate maximum or minimum f **(1)** Correct calculation of maximum or minimum f **(1)** Calculation of half range shown **(1)** U = 0.15 (cm) 2 s.f. only **(1)** Example of calculation maximum $f = \frac{(29.6 + 0.1)\text{cm} \times (19.2 + 0.1)\text{cm}}{(29.6 - 0.1)\text{cm} + (19.2 - 1)\text{cm}} = \frac{(29.7 \times 19.3)\text{cm}^2}{(29.5 + 19.1)\text{cm}} = \frac{573.2\text{cm}^2}{48.6\text{cm}} = 11.8$ (cm) minimum $f = \frac{(29.6 - 0.1)\text{cm} \times (19.2 - 0.1)\text{cm}}{(29.6 + 0.1)\text{cm} + (19.2 + 0.1)\text{cm}} = \frac{(29.5 \times 19.1)\text{cm}^2}{(29.7 + 19.3)\text{cm}} = \frac{563.5\text{cm}^2}{49\text{cm}} = 11.5$ (cm) U in $f = \frac{(11.8 - 11.5)\text{cm}}{2} = 0.15$ (cm)	**4**
4(c)(i)	Uses $n = 1 + \frac{d^2}{8tf}$ **(1)** $n = 1.63$ 3 s.f. only **(1)** Example of calculation $n = 1 + \frac{(5.02\text{cm})^2}{8 \times 0.428\text{cm} \times 11.6\text{cm}} = 1 + \frac{25.2\text{cm}^2}{39.7\text{cm}^2} = 1.63$	**2**

Question Number	Answer	Mark
4(a)(i)	**EITHER** Repeat at different orientations and calculate a mean **(1)** To reduce (the effect of) random errors **(1)** MP2 dependent on MP1 **OR** Check and correct for zero error on the calipers **(1)** To eliminate systematic error **(1)** MP2 dependent on MP1	**2**
4(a)(ii)	Calculation of %U shown using half resolution **(1)** States instrument based on justification using calculation of %U from corresponding resolution **(1)** Example of calculation $\%U = \frac{0.005\text{mm}}{5\text{mm}} \times 100 = 0.1\%$ So use a micrometer screw gauge as the %U is small	**2**

4(b)(i)	**EITHER** Uses 2 × percentage uncertainty in D [Accept $2 \times \frac{\Delta D}{D}$] **(1)** Uncertainty in $D = 0.069$ (cm^2) 2 SF only **(1)** Example of calculation %U in $D^2 = 2 \times \frac{0.01}{3.45} \times 100 = 0.58\%$ U in $D^2 = 3.45^2 \times \frac{0.58}{100} = 0.069$ (cm^2) **OR** Calculation of half range of D^2 shown **(1)** Uncertainty in $D = 0.069$ (cm^2) 2 SF only **(1)** Example of calculation U in $D^2 = \frac{3.46^2 - 3.44^2}{2} = 0.069$ (cm^2)		**2**
4(b)(ii)	**EITHER** Addition of uncertainties shown **(1)** U in $A = 0.052$ (cm^2) 2 SF only e.c.f. (b)(i) **(1)** Example of calculation U in $A = (0.07 + 0.06 + 0.07) \times \frac{\pi}{12} = 0.052$ (cm^2) **OR** Calculation of maximum and minimum A shown **(1)** U in $A = 0.053$ (cm^2) 2 SF only **(1)** Example of calculation Maximum $A = (11.97 + 9.42 + 10.63) \times \frac{\pi}{12} = 8.383$ cm^2 Minimum $A = (11.83 + 9.30 + 10.49) \times \frac{\pi}{12} = 8.278$ cm^2 U in $A = \frac{8.383 - 8.278}{2} = 0.053$ (cm^2)		**2**

4(a)(iv)	The measurement is larger but the uncertainty is the same **Or** The measurement is larger but the resolution (of the micrometer) is the same **(1)** **(1)** So the percentage uncertainty is reduced (by a factor of 4) MP2 dependent on MP1	**2**
4(a)(v)	The length x of the rubber band does not take into account the fold (at the ends). **(1)** The (length x of the) rubber band could be measured when it is not taut **Or** The width w could be measured when the rubber band is compressed **(1)**	**2**

Question Number	Answer	Mark
4(a)(i)	**EITHER** Repeat at different places **and** calculate a mean **(1)** To reduce (the effect of) random error **(1)** MP2 dependent on MP1 [Allow MP2 if MP1 partially correct] **OR** Use the ratchet to avoid squashing the rubber **(1)** To reduce (the effect of) random error **(1)** MP2 dependent on MP1 [Allow MP2 if MP1 partially correct] **OR** Check **and** correct for zero error **(1)** To eliminate systematic error [Accept reduce for eliminate] **(1)** MP2 dependent on MP1 [Allow MP2 if MP1 partially correct]	**2**
4(a)(ii)	Mean t = 1.04 (mm) 3 SF only **(1)** Example of calculation Mean $t = \frac{(1.02 + 1.06 + 1.05 + 1.01)\text{mm}}{4} = 1.035 = 1.04$ (mm)	**1**
4(a)(iii)	Calculation using half range shown **Or** Calculation of furthest from the mean shown **(1)** Percentage uncertainty in t = 3 % e.c.f. (a)(ii) Accept 2 SF **(1)** Example of calculation Half range $= \frac{(1.06 - 1.01)\text{mm}}{2} = 0.025 = 0.03$ (mm) $\%U = \frac{0.03\text{mm}}{1.04\text{mm}} \times 100 = 2.9\% = 3\%$ Note: use of 0.025 in calculation gives 2.4% or 2%	**2**

Question Number	Answer	Mark
2(a)	**EITHER** The hot plate **or** glass beaker will be hot **Or** the hot plate **or** glass beaker will cause burns (if touched) **Or** hot water may spill onto student **(1)** Use tongs or insulated gloves (to move the beaker) **(1)** **OR** The hot plate will be hot **Or** the hot plate will cause burns (if touched) **(1)** So turn off the hot plate (when water has boiled) **(1)** **OR** Thermometer may break (when moving beaker) **(1)** So remove the thermometer (before moving the beaker) **(1)**	**2**
2(b)	1. Use a stopwatch (to measure time) **(1)** 2. Record the initial temperature and start the stopwatch (simultaneously) **(1)** 3. Stir the water (before measuring the temperature) **(1)** 4. Record the temperature at (regular) time intervals **Or** Record the time at (regular) temperature intervals **(1)** 5. Record many temperature readings (as the water cools) **Or** Keep recording until temperature similar to temperature of the surroundings **(1)** 6. Plot a graph of $\ln\theta$ against t to check it is a straight line **Or p**lot a graph of $\ln\theta$ against t to check the gradient is constant **(1)**	**6**
	Total for question 2	**8**