Question number	Answer		Mark
4(a)(i)	Vernier calipers as the range of the micrometer is too small	(1)	**1**
4(a)(ii)	There may be a source of <u>systematic error</u> **Or** the Vernier calipers may not have been checked for zero error Therefore the values may not be close to the true value	 (1) (1)	 **2**
4(b)	Mean x = <u>2.12</u> (mm) Uncertainty of <u>0.02</u> (mm) from calculation of half range [Accept furthest from the mean] <u>Example of calculation</u> mean x = (2.11+2.10+2.13+2.14+2.11) mm/5 = 2.118 = 2.12 mm Uncertainty = (2.14–2.10) mm/2 = 0.02 mm	(1) (1)	**2**
4(c)(i)	Use of $n = 1 + \frac{d^2+(t-x)^2}{8f(t-x)}$ Correct value of n to 2 or 3 s.f. [e.c.f (b)] <u>Example of calculation</u> $n = 1 + \frac{d^2+(t-x)^2}{8f(t-x)} = 1 + \frac{5.10^2+(0.830-0.212)^2}{8\times9.8\times(0.830-0.212)} = 1 + \frac{26.01+0.618^2}{48.45}$ $= 1.54$	(1) (1)	**2**
4(c)(ii)	Addition of uncertainties shown Conversion to %U to minimum 2 s.f. [e.c.f (b)] <u>Example of calculation</u> U = 0.01 + 0.02 = 0.03 %U = 0.03 / (8.30 – 2.12) × 100% = 0.49 %	(1) (1)	**2**

4(c)(iii)	Use of 2× %U in d **and** 2× %U $(t–x)$ shown [e.c.f (b)] Calculation of U in d^2 **and** U in $(t–x)^2$shown Addition of uncertainties shown Correct value of U to 3 s.f. (do not penalise if square root of final value is taken) <u>Example of calculation</u> %U in $d^2 = 2 \times (0.01/5.1 \times 100) = 0.392\%$ U in $d^2 = 5.1^2 \times 0.392/100 = 0.102$ %U in $(t - x)^2 = 2 \times 0.49 = 0.98\%$ U in $(t - x)^2 = 0.618^2 \times 0.98/100 = 0.004$ U = 0.102 + 0.004 = 0.106	(1) (1) (1) (1)	**4**
4(c)(iv)	Correct calculation of %U in n shown [e.c.f. (c)(ii) and (iii)] Calculation of relevant limit shown [e.c.f (c)(i)] Valid conclusion based on comparison of calculated values [MP3 dependent on MP2] <u>Example of calculation</u> %U = (0.106/26.4 × 100) + 0.485 + (0.3/9.8 × 100) = 0.402 + 0.485 + 3.06 = 3.95% Upper limit = 1.54 × 1.04 = 1.60 Lower limit = 1.54 × 0.96 = 1.48 The lens is most likely to be made of crown glass as it is the only value to fall within the range **Or** Correct calculation of %U in n shown [e.c.f. (c)(ii) and (iii)] Correct calculation of relevant %D shown [e.c.f (c)(i)] Valid conclusion based on comparison of calculated values [MP3 dependent on MP2]	(1) (1) (1) (1) (1) (1)	**3**

	Example of calculation %U = (0.106/26.4 × 100) + 0.485 + (0.3/9.8 × 100) = 0.402 + 0.485 + 3.06 = 3.95% Crown glass %D = (1.54–1.52)/1.52 × 100 = 1.32 % Flint glass %D = (1.66–1.54)/1.66 × 100 = 7.23 % The lens is most likely to be made of crown glass as the %D is less than the %U whereas %D is larger than %U for flint glass.		
		Total mark for Question 4 = 16	