Question	Answer	Marks	Guidance
1	s^{-1} ; m^{-1} ; m^{-3}	3	**not** equivalent units not listed e.g. Hz / D
	Total	3	

Question	Answer	Marks	Guidance
2(a)	waveform is periodic / (main peaks) repeats itself regularly ;	1	idea of time required **not** constant wavelength or reference to length **not** just reference to repeated main peaks
	but more complex than pure sine wave / has harmonics / higher frequency (oscillations) / other (smaller) oscillations / smaller peaks (between large ones)	1	**not** smaller frequencies / noise
(b)	evaluation (11 x 1000 / 40) = 275 ≈ 280 (Hz)	1	(11 waves in 40 ms / 3.6 ms / wave) **accept** answers in range 270 to 280 Hz
	Total	3	

Question	Answer	Marks	Guidance
3(a)	12 k(Hz)	1	12 000 (Hz)
(b)	9 (bits)	1	**ignore** $2^9 = 512$ if answer not stated **not** 8.6 (bits)
(c)	bandwidth ≈ bit rate / ≈ bit rate /2 bit rate = sampling frequency x bits per sample	1 1	**not** reference to (highest f – lowest f) **allow** 1 mark for evaluation 108 k / 108/2 = 54 k **allow** 2 marks for evaluation with bandwidth units Hz **accept** ecf on (a) x (b) **accept** bandwidth = sampling frequency x bits per sample for 2 marks
	Total	4	

Question	Answer	Marks	Guidance
4(a)(b)(c)	10^3 ; 10^{-6} ; 10^{-6}	**3**	
	Total	**3**	

Question	Answer	Marks	Guidance
5 (a)	$n = I / e$ / = $8 \times 10^{-12} / 1.6 \times 10^{-19}$;	**1**	method: words / numbers / algebra ;
	5×10^7	**1**	evaluation one **POT** error can score 1, two **POT** errors score 0
	Total	**2**	

Question	Answer	Marks	Guidance
6(a)	V^2 / R / $12^2 / 4.7$;	**1**	method: words / numbers / algebra **accept** I = 2.6 A for 1st mark alternative method
	30.6 / 31 (W) / 31.8 (W) or 31.2 (W) premature rounding	**1**	evaluation **accept** $P = I V$ correctly evaluated for 2nd mark
(b)	method $L = RA / \rho$ / $4.7 \times 1.8 \times 10^{-8} / (4.5 \times 10^{-7})$;	**1**	method: words / numbers / algebra
	= 0.188 / = 0.19 (m)	**1**	evaluation **accept** 0.2 (m) no S.F. penalty here **not** 0.20 / 0.18 (m) R.E.
	Total	**4**	

Question	Answer	Marks	Guidance
7(a)	f further from lens ; λ similar use marking tool all wavelengths should be between the length of the red (min) and green (max)	2	**ignore** curvature if correct sign / waves to right of focus / position of first wavefront **expect** wavefronts to F
(b)	smaller because lens adds less curvature to the wavefronts / because light is not slowed so much / because light is not refracted so much	1	**accept** smaller because f larger / because $P = 1 / f$ **ignore** response to (a) standalone mark **ignore** bent less Scroll down this image to check that page 6 of the paper has no candidate response to be credited. Use **BP** annotation on every blank page. Responses must be annotated / marked and credited to relevant question total. If no credit due use ^ annotation to show work seen.
	Total **Total Section A**	**3** **22**	

Question			Answer	Marks	Guidance
8	(a)	(i)	*R* and LDR correct symbols in complete series circuit	1	either way round **ignore** labelling / Voltmeter if drawn **accept** for LDR (with /without) circle and 2 arrows / variable resistor / general transducer symbol for LDR (thermistor) **not** LED or lamp or fuse or photodiode or other symbols
	(a)	(ii)	resistance ratio changes / voltage is shared (between resistors) ; correct direction of change in resistance ratio (R_f / R_{LDR} increases or v.v.) ; Link resistance to p.d. by : use of potential divider equation or voltage ratio = resistance ratio **OR** as light intensity rises R_{LDR} falls so R_{total} falls ; current increases ; p.d. across R_{FIXED} rises / p.d. across LDR falls	1 1 1	applying the potential divider or voltage ratio equation with correct sense can score all 3 marks **expect** candidates to make clear which R they are talking about **accept** voltage is shared in proportion to the resistances **not** current is constant (in series circuit) **QoWC** 3rd mark only if steps in reasoning are clear and no logical errors
	(b)	(i)	change in output / change in input / Δdependent / Δindependent / Δy / Δx / ΔV_{out} / Δintensity / Δ_{out} / Δ_{in}	1	**ignore** ± signs **accept** gradient of graph **not** resolution / how sensitivity changes with intensity **not** voltage change for a set/given lux change (don't read for as per)

Question	Answer	Marks	Guidance
(ii)	sensible tangent / triangle ;	1	method from graph with Δlux $\geq$ 400 lux. If Δlux < 400 max 2 out of 3 for in range answer chord method approximation from graph if in range max 1 mark
	e.g. (5 - 2.5 V) / (1900 lux) ;	1	**not** any credit 3.8 / 1000 (graph values) for last 2 marks **accept** sensible values from graph
	{1.2 ± 0.2} x 10^{-3} (V lux^{-1})	1	evaluation **accept** in range 1.0 x 10^{-3} to 1.4 x 10^{-3} (V lux^{-1}) correct bare answer scores 3
(iii)	(V_{FIXED}) = 3.8 V ;	1	read from graph **accept** V = 3.8 (V) standalone credit
	EITHER I = 3.8 / 800 = 4.75 mA / 4.8 mA ;	1	**allow** small graph reading errors $\pm$ 0.1 V correctly worked through (in range 430 to 500 Ω) for the next 3 marks. Gross reading errors score 0 total.
	V_{LDR} = 6.0 - 3.8 = 2.2 V ;	1	
	R_{LDR} = 2.2 / 0.00475 = 460 Ω / 4.6(3) x 10^2 Ω	1	
	OR potential divider equation or voltage ratio equation rearranged for R_{LDR} ;		**accept** substitution / rearrangement in either order e.g. 3.8 = 6.0 x 800 / (800 + R_{LDR})
	equation correctly substituted ;		
	evaluation R_{LDR} = (4800 – 3040) / 3.8 = 460 Ω		1380 Ω scores 2 out of 4 bare correct answer 460 Ω scores 4 marks
	Total	**12**	

Question			Answer	Marks	Guidance
9	(a)	(i)	image area $\approx 10^{-18}$ m^2 / 60 x 10^{18} atoms m^{-2} ; mass per m^2 = 2 x 10^{-26} (kg) x 60 x 10^{18} (atoms m^{-2}) ; = 1.2 x 10^{-6} (kg)	1 1 1	**accept** mass of 60 atoms = 1.2 x 10^{-24} kg alt first mark **accept** number of atoms between 55 to 65 for those who have tried to count **not** any further credit if area = 10^{-9} m^2 max 1 out of 3 **expect** 2 S.F. for show that in range (1.1 to 1.3) x 10^{-6} (kg)
	(a)	(ii)	(ρ = 1.2 x 10^{-6} / (1 x 1 x 0.34 x 10^{-9})) = 3500 kg m^{-3}	1	**accept** 3529 kg m^{-3} / 29(41) kg m^{-3} from show that **accept** ecf in range 3800 to 3200 kg m^{-3}
	(a)	(iii)	F = (σ_B x A) $\approx$ 4 x 10^{10} (Pa) ×(0.1 x 0.34 x 10^{-9} (m^2)) ; 1.4 (N)	1 1	method **expect** correct substitution of values evaluation **expect** 2 S.F. for show that **accept** 1.36 (N) **ORA** 1N of force gives stress = 2.9 x 10^{10} Pa ; < 4 x 10^{10} Pa
	(b)		$\sigma = IL / (VA)$ OR $\sigma = GL / A$ and $G = I / V$; = 6.7 x 10^{-15} x 0. 34 x 10^{-9} / (0.15 x 10^{-3}) x {200 x 10^{-9}}^{2} ; = 3.8 x 10^{-7} (Sm^{-1})	1 1 1	method **accept** G = I / V = 4.4(7) x 10^{-11} S / R = 2.2(4) x 10^{10} Ω for first mark **accept** inverse substitution for ρ substitution penalise each **POT** error by a mark lost evaluation

Question	Answer	Marks	Guidance
(c)	**(i)** mechanical e.g. cycle frames / car bodies / space elevator cable / carrier bags / space craft / aircraft / bridge cables / other built structures / protective clothing / bullet proof vests / graphene reinforcing a plastic composite etc. ;	1	First two marks awarded for two plausible applications. **not** pencils / lubricants / heat conduction / just cars / just cycles / just buildings / just clothing
	(ii) electrical e.g. solar cells / transistors / circuits / LEDs / doped layers to make gates / touch screen / sensors / electrical cables / connectors / switches / insulators (in semiconducting orientation) etc. ;	1	one application repeated only scores 1 mark even if both properties relevant
	high strength / low density / high stiffness (directional) **AND** specified conductivity (high / metallic / semiconducting / both / high charge carrier density)	1	Third mark awarded for a correctly stated property related to **each** application
	e.g. touch screen conducting layers separated by insulators, which contact under pressure / electrical cables useful to minimise heat losses / weight / size car bodies strong for protection against impact / light weight for fuel saving / strong and lightweight carrier bags stiffness anisotropy stiff to bear load and flexible to wrap around items	1	**QoWC** further detail or development of link between one property and application or two relevant properties applied to one application for 4th mark e.g. car bodies strong and low density / lightweight OR circuits using two orientations of graphene deposit to use metallic conduction for connectivity and semiconduction for constructing components / due to electrical anisotropy
	Total	13	

Question			Answer	Marks	Guidance
10	(a)		contain more information / less error prone ; contain information in 2-d (rather than 1-d) / more combinations / more alternative / more possibilities / more patterns / better resolution required to measure bar width	1 1	**accept** more data / bits / details / other plausible suggestions **not** data security **accept** in pixel form rather than "smeared" linear array / squares take less area than bars / AW **not** more variations
	(b)	(i)	$(33^2 / 8) =$ 136 (bytes)	1	**accept** 136.125 (bytes) **not** 137 / 140 (bytes)
	(b)	(ii)	2^8 / 256	1	
	(b)	(iii)	to help with recognising the alignment / orientation of the code / so that bits are considered in correct order for reading by software	1	**accept** to recognise as QR code / detect edges / boundaries / corners of code / locate the data / to aid focus by scanner **not** parity bits
	(c)	(i)	size of image = *M* x size object / ≈ 5/100 x 33 mm = 1.7 mm (< 2.0 mm) **OR** check that 2/33 > 5 /100 ; comparing magnifications **OR** compare angles subtended at lens ; 33 /100 < 2 / 5	1 1	**allow** magnification = 0.05 for 1 mark **accept** 1.65 mm **allow** correct answer from M = 20 allow 1 out of 2 marks **i.e.** check actual *M* < 2/33 **accept** comparing triangles **not** any credit for correct v = 5.3 mm here (lens formula)
	(c)	(ii)	$1/v$ = 1/(-0.1) + 1/(0.005) / = -10 + 200 = 190 D ∴ v = 1/190 = 5.26×10^{-3} m / 5.3 mm *f* x 1.05 = 5 x 1.05 = 5.25 mm / (5.26 – 5.0) / 5.0 = 0.052 (5.2%)	1 1 1	method evaluation **accept** 5.26 mm **not** 5 mm / 0.005 m **SF** penalty **allow** 1 mark (from first 2) for sign error (u = + 0.1) giving 210 D and v = 4.8 mm calculation of 105% x *f* **allow** as standalone mark **only allow** credit for working in c(i) if referenced here **accept** 5.3% **not** any credit for u v transposition leading to -5.3 mm and 5%

Question		Answer	Marks	Guidance
(c)	(iii)	image of several QR modules can cover 1 camera pixel / details of code not resolved / there will only be 1 pixel per module at limit of resolution **EITHER** (M = v/u = pixel size / module size) 5/u = 0.002/1 in mm u = (1/0.002) x 5 = 2500 mm / 2.5 m **OR** module image size = 1/500 x 1 mm / 2 x 10^{-6} m ; pixel size = 2 mm / 1000 / 2 x 10^{-6} m	1 1 1	**credit** a sensible further problem explicitly stated e.g. resolution **accept** resolution too high / too low **not** just information lost / averaged **accept** calculations for other u values near to 2.5 m if supported by sensible reasoning Scroll down this image to check that page16 of the paper has no candidate response to be credited. Use **BP** annotation on every blank page. Responses must be annotated / marked and credited to relevant question total. If no credit due use ^ annotation to show attempt seen.
		Total **Total Section B** **Total for paper**	**13** **38** **60**	