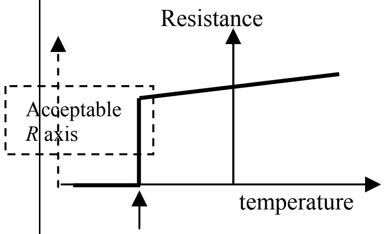
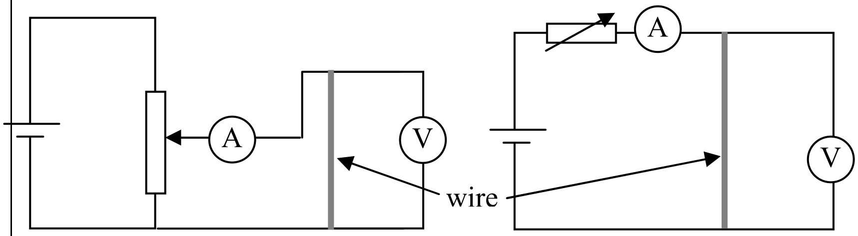
Question			Marking details	Marks Available
3	*(a)*		A material which has zero [electrical] resistance [or equiv.]	1
	(b)		 Axes (1) Line (not nec straight above T_C)(1) Temperature at which resistance [of material] drops [suddenly] to zero [or label on graph] (1)	3
	(c)		No [accept little] heat [accept energy] lost / generated (1) [Accept – large current can be produced from zero /small pd] Any application, e.g. nuclear fusion / tokamaks, particle accelerators / LHC, MRI scanners / large motors or generators (1)	2 **[6]**
4.	*(a)*		 Wire in functioning circuit with both meters correctly connected (1) Method of varying current / pd (1)	2
	(b)	(i)	Resistance values / Ω: 4.00,4.00, 4.33, 4.75, 6.00 [all correct]	1
		(ii)	Graph: Axes [scales, labels, units] (1), plots (1) line (1) [axes – no s.f. penalty; line – produced to *R* axis – accept extrapolation]	3
	(c)	(i)	0 → 0.2 A [‘at start’, ‘to begin with’] no change / constant (1) 0.2 A → 0.5 A [‘then’] increas<u>ing</u> with current (1)	2
		(ii)	0 → 0.2 A [e.c.f. from graph]	1
		(iii)	Temperature wire not constant / increases [accept changes] [with current]	1
	(d)		Current / ammeter reading would [rapidly rise from 0 then] decrease (1) and then stabilise (1)	2 **[12]**

Question			Marking details	Marks Available
8	*(a)*		[A conductor is] a material through which charge / electrons [accept ions / holes] can flow / move **or** which contains free / delocalised electrons.	1
	(b)	(i)	Volume = $2.0 \times 10^{-6} \times 2.0$ (1) [or by impl] mass = $8920 \times 4.0 \times 10^{-6}$ (1) [= 0.0357 kg] ((**unit**))	2
		(ii)	$\frac{0.0357(\text{e.c.f.})}{1.05 \times 10^{25}}$ (1) $\underline{\times 1.5}$ (1) [= 5.1×10^{23} electrons]	2
		(iii)	$n = \frac{5.1 \times 10^{23}(\text{e.c.f.})}{4.0 \times 10^{-6}(\text{e.c.f.})}$ (1) [= 1.28×10^{29} m^{-3}] $v = \frac{I}{nAe}$ [manipulation at any stage] (1) $v = \frac{1.2}{1.28 \times 10^{29} \times 2.0 \times 10^{-6} \times 1.6 \times 10^{-19}}$ (subst) (1) [e.c.f. on n] $v = 2.9 \times 10^{-5}$ m s^{-1} (1) [NB use of 5.1×10^{23} for $n \rightarrow 7.3(5)$ m s^{-1}]	4 **[9]**

Question			Marking details	Marks Available
1	*(a)*	(i)	$v = \frac{0.15\text{ m}}{0.0030\text{ s}}$ (1) [or equiv. or by impl.] = 50 m s^{-1} ((**unit**)) (1)	1
		(ii)	**Either**: T = 0.012 s (1) $f = \frac{1}{T}$ [or by impl.] (1) = 83 Hz (1) **Or**: λ = 0.60 m (1) $f = \frac{v}{\lambda}$ [in this form – or by impl] (1) = 83 Hz (1) [e.c.f. on v from (i)]	2
	(b)	(i)	<u>Two of</u>: 0.90 m, 1.20 m, 1.50 m, 1.80 m	1
		(ii)	I. Varies [smoothly] between maxima and minima / zeroes (1); Maxima midway between minima [**or** maxima 0.30 m / λ/2 apart; minima 0.30 m / λ/2 apart] (1) II. No – for a progressive wave the amplitude is constant along string [or falls gradually]	2 1
	(c)		Waves reflected by wall (1) Reflected wave interferes with wave straight from generator [or equivalent, e.g. the two waves travelling in opposite directions interfere] (1) Nodes occur where interference is destructive [accept: where the two waves cancel] (1)	3 **[12]**
2.	*(a)*	(i)	$\lambda = \frac{2.0 \times 1.8}{12.0}$ m (1) [or by impl.] = 0.30 m (1)	2
		(ii)	Reflected sound [would affect the pattern].	1
	(b)		Previously, sound from the two speakers superposed / interfered [or by implication](1) destructively [accept: cancel] at that point (1) as it arrived in antiphase [accept: exactly out of phase] (1)	3
	(c)		Quiet spots are where loud sounds used to be [or equiv.]	1
	(d)	(i)	$y = \frac{D\lambda}{a}$ (1) <u>thus</u> [or other qualification, e.g. recalculation] y halves (1) [or equiv] [because a doubles] [Qual. answer "y decreases" + correct qual reasoning → 1 mark]	2
		(ii)	Wavelength halves [or equiv] (1) Separation halves (1)	2 **[11]**

Question			Marking details	Marks Available
3	*(a)*	(i)	$[1.00]\sin x = 1.52\sin 25^{\circ}$ [or by impl, or equiv with data inserted] (1) $\sin x = 0.642$ [or by impl.] (1) $x = 40°$ (1)	3
		(ii)	65°	1
		(iii)	**Either:** [$1.52\sin c = 1.00\sin 90^{\circ}$ so] $c = 41°$ (1). 65°>*c* so no escape (1) [No penalty for omission of last point if first mark awarded] **Or:** $\sin^{-1}\left(1.52\sin 65^{\circ}\right)$ / 1.38 (1) doesn't exist (1) [so refraction doesn't occur].	2
		(iv)	I. total internal reflection [not: TIR, total or internal] reflection] II. equal	1 1
	(b)	(i)	beam confined to small angle to axis [or damage avoided to reflecting surface] [accept: fewer int. refl^{s}]	1
		(ii)	small (1); equal to a few wavelengths (1)	2
		(iii)	light propagates parallel to axis [or without being reflected **or** along only one path]. [Not – 'only one beam']	1 **[12]**
4.	*(a)*	(i)	When e-m radn^{n} [accept: light, u-v, photons] [of high enough frequency] falls on a surface [or metal] (1) electrons are emitted (1)	2
		(ii)	Photon knocks out electron [or not] **or** gives energy to e(1). Photon carries energy *hf* (1). Electron needs [a minimum] energy ϕ to escape (1) Remainder of photon's energy given to electron as KE (1) [KE_{max} corresponds to minimum energy ϕ to escape]	4
	(b)	(i)	$E_{k\,max} = 6.63\times10^{-34}\times7.99\times10^{14} - 4.97\times10^{-19}$ J (1) [or photon energy shown to be greater than ϕ] $E_{k\,max} = 3.27\times10^{-20}$ J (1)	2
		(ii)	Photon energy = 4.47×10^{-19} J < ϕ [or equiv], so no emission	1
		(iii)	3.27×10^{-20} J(1) Photons don't co-operate releasing electron [or equiv] (1)	2 **[11]**

Question			Marking details	Marks Available
5.	*(a)*	(i)	Fraction $= \frac{\left[3.297\times10^{-18} - 2.983\times10^{-18}\right](1)}{3.297\times10^{-18}}$ = 0.095 (1) [accept $\frac{2}{21}$]	2
		(ii)	$\lambda = \frac{hc}{E_{\text{photon}}}$ (1) [or $\lambda = \frac{c}{f}$ **and** $f = \frac{E_{\text{photon}}}{h}$] (1) [or by impl.] λ = 633 nm (1)	2
	(b)	(i)	A[n incident] photon (1) of energy equal to ($E_U - E_L$) (1) [or equiv.]	2
		(ii)	Now 2 photons [original and emitted] [or by impl.] (1) Photons in phase / travel in same dir^n / have same f, λ or E (1)	2
		(iii)	Fewer electrons in L than U (1) [accept pop^n inversion] [So] stimulated emission commoner than absorption (1) [**or** less pumping needed]	2
		(iv)	Mirrors cause light to traverse cavity [or HeNe etc] to and fro (1) increasing chances of stimulated emission / increases amplification / increases intensity (1) [or any other correct point, e.g. resonant selection of particular λ]. [No credit for light escaping from r.h. mirror]	2 **[12]**