1. (a) (i) $I \propto V$ (1)

Providing the temperature / physical conditions remain constant (1) — 2

(ii) V A^{-1} circled — 1

(b) (i)

Switch combination	P	Q	S	
X open, Y open	On	On	Off	
X closed, Y open	Off	On	Off	(1)
X open, Y closed	On	On	On	(1)
X closed, Y closed	Off	On	On	(1)

3

(ii) **Either** $R = \frac{9}{0.18}$ (1) (= 50 Ω) → $R_P + R_Q$ = 50 (1)

R_{each} buzzer = 25[Ω] (1) ecf between 2nd and 3rd marks — 3

Or $R = \frac{4.5\ (1)}{0.18}$ (1) = 25[Ω] (1)

(iii) $R_{Total} = 16\frac{2}{3}$ [Ω] (1) $I = \frac{9}{16\frac{2}{3}}$ = 0.54 [A] (1) — 2

ecf from (b)(ii) / no ecf for R_{Total}

(iv) <u>Either</u> ecf from (b)(ii) or (b)(iii) or both

$P_S = \left(\frac{2}{3} \times 0.54\right)^2 \times 25$ (1) P_S = 3.24 [W]

$P_Q = \left(\frac{1}{3} \times 0.54\right)^2 \times 25$ (1) P_Q = 0.81 [W]

<u>Or</u>

$P_S = \frac{9^2}{25}$ (1) = 3.24 [W] $P_Q = \frac{4.5^2}{25}$ (1) = 0.81 [W]

<u>Or</u>

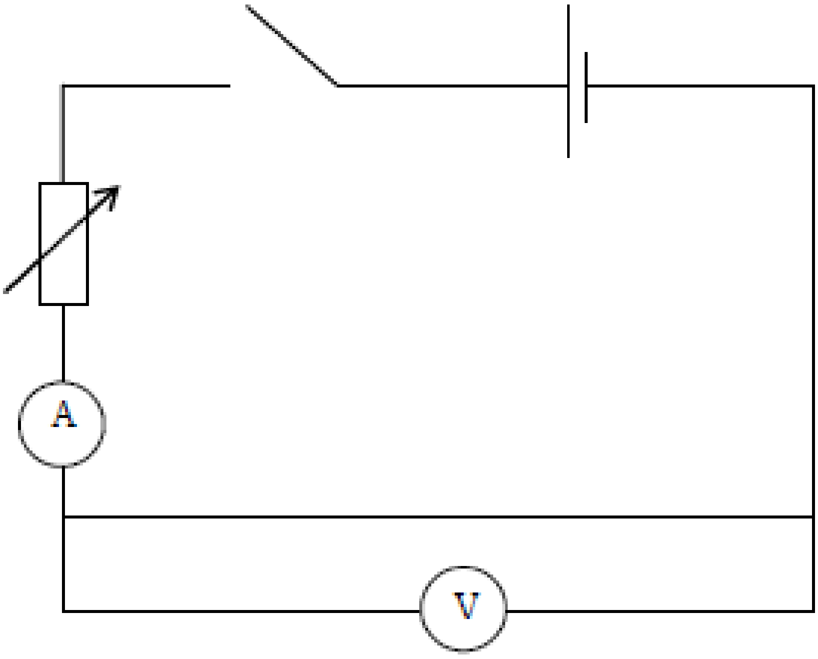
$P_S = \frac{2}{3} \times 0.54 \times 9$ (1)= 3.24 [W]$P_Q = \frac{1}{3} \times 0.54 \times 4.5$ (1) = 0.81 [W]

$\rightarrow \frac{3.24}{0.81} = 4$ (1) or any correct algebraic solution = 3 marks — 3

2.

(a)	(i)	Diagram to include • Correct electric circuit with ohmmeter or power supply with ammeter + voltmeter with correct symbols and positioning (1) • Method of heating shown (1) • Method of recording temperature shown (1)	3
	(ii)	Linear [or approximately linear] graph with positive gradient (1) and positive intercept on R axis (1).	2
(b)	(i)	Conducting / delocalised / free electrons (1) collide (1) with metal lattice / atoms / ions (1) [not with other free electrons]	3
	(ii)	The greater the temperature the greater the vibrational energy of the lattice / metal ions (1) producing a greater chance [or rate] of collisions/ collisions more often / greater frequency of collisions (1) [not harder] .	2

3. (a) (i)



Circuit (without voltmeter and ammeter) (1)

Voltmeter and Ammeter correctly positioned (1) 2

(ii) $R = \frac{10}{0.9}$ $= 11.11$ [Ω] (1)

$A = 3.14\text{x}10^{-8}$ [m^2] (1)

$\rho = \frac{11.11 \text{ x } 3.14\text{x}10^{-8}}{3.2}$ (1) substitution $\rho = 1.09\text{x}10^{-7}$ [Ω m] (1)
ecf for R and A 4

(iii) Platinum and Tin 1

(b) $\rho = \frac{0.74\text{x}10^{-3}}{(3.14\text{x}10^{-8} \text{ x } 3.2)(1)}$ $= 7365$ [kg m^{-3}] (1) ecf for A

Tin (1) ecf from density value 3

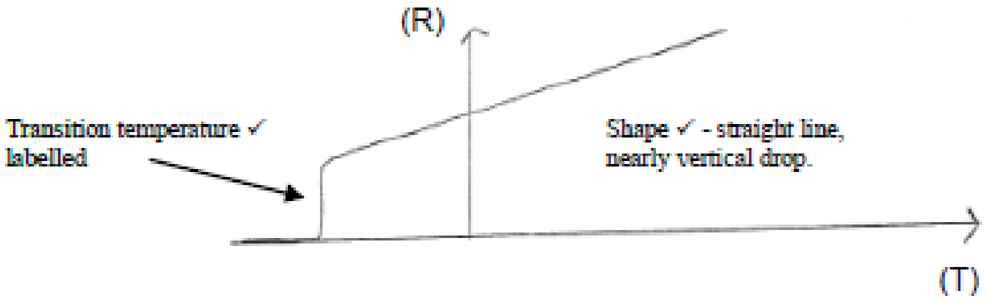
4.

(a)	(i)	Correct and convincing use of $\rho = \frac{RA}{l}$ (including unit conversion)	[1]
	(ii)	$\left(\frac{2000}{11.2}\right)$ = 179 A unit mark	[1]
	(iii)	$v = \frac{I}{nAe}$ rearranged (or shown numerically) (1) $n = 6.0 \times 10^{28} \times 3$ (1) $v = 1.55 \times 10^{-5}$ [m s^{-1}] (ecf on I and n) (1)	[3]
(b)	(i)	Same (or equivalent)	[1]
	(ii)	v increased (1) because…; A decreased, I,n,e unchanged by implicaton (1)	[2]
	(iii)	Increased frequency / more collisions <u>between electrons and lattice</u> / atoms / ions or electrons carry greater kinetic energy (1) leading to <u>increased vibrational / kinetic energy of lattice atoms</u> (1)	[2]

5.

Question			Marking details	Marks Available
4	*(a)*	(i)	Water bath or method of heating shown. Wire [coiled or uncoiled] shown (1). Voltmeter and ammeter and power supply correctly connected **or** ohmmeter only shown (1) Thermometer clearly identifiable. (1) Subtract 1 mark for poorly drawn diagrams. Method of cooling water to 0 °C not credited here.	3
		(ii)	<u>Method</u> of cooling water to 0 °C (1) [Can be credited from (i)] Resistance values taken [or V and I values taken and R calculated](1) ..at different temperatures [minimum 5 implied or implication that a number of temperatures considered] (1) Method to reduce experimental error/ ensure accuracy e.g. water stirred/ resistance of leads/heat slowly/remove heat to allow temperature to settle (1) Accept repeat the experiment again or obtain readings whilst cooling down or using a digital thermometer. Don't accept just repeat readings. Graph of R vs θ drawn (1)	5
	(b)	(i)	[-163 °C] is the temperature at which <u>a sudden decrease in resistance</u> occurs and the metal [alloy] (1) ...becomes a <u>superconductor</u> or resistance becomes zero (1)	2
		(ii)	<u>Liquid nitrogen</u> [Accept liquid helium, liquid oxygen, liquid hydrogen]	1
			Question 4 Total	**[11]**

6. *(a)*	(i)	Ruler and wire shown and labelled (1) Moving pointer **or** jockey **or** crocodile clip indicated (1) **Either**: Correctly positioned ohmmeter with no power supply; **or** correctly positioned voltmeter and ammeter with power supply (1) [No labelling required for either method].	[3]
	(ii)	Diagonal line through origin	[1]
	(iii)	CSA from <u>diameter of wire</u> (1) Gradient from graph $= (R/l)$ **or** (ρ/A) **Or** stated take a pair of R and l values from the graph (1) ρ = gradient × CSA **or** use of $\rho = RA/l$ (1)	[3]
(b)	(i)	$R = \frac{144}{32} = 4.5\,[\Omega]$ (1) Correct substitution into $R = \rho l/A$ (1) $l = 0.375$ [m] (1) (**ecf** on R)	[3]
	(ii)	$I = 2.7$ [A] (from V/R **or** P/V etc) (1) (**ecf** on I) Correct substitution into $I = nAve$ (1) $v = 1.24 \times 10^{-2}$ [m s^{-1}] (1) accept 0.01 m s^{-1}	[3]
		Question 5 Total	**[13]**

7. *(a)*		A <u>material</u> with <u>zero/negligible</u> resistance	1
(b)	(i)	Transition temperature (accept critical temperature)	1
	(ii)	 If axes labelled, must be correct.	2
	(iii)	0 / negligible / almost zero	1
(c)		Collisions between <u>free/delocalised/flowing/conducting</u> electrons and ions/atoms in lattice/atoms/particles (1) increase vibrations of ions /atoms / particles or electrons transfer <u>KE</u> to ions (1)	2

8.

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
1.	(a)	(i)	The current [through a metal conductor at constant temperature] is proportional to the pd [across it] Accept $I \propto V$ with well-defined symbols.	1			1		
		(ii)	Constant [or independent of current [or pd]] (1)	1			1		
	(b)	(i)	pd across X = 0.70 [V] (1) or by impl so R_X = 58 [Ω] (1) **or** total resistance = 183 [Ω] (1) or by impl so R_X = 58 [Ω] (1)		2		2	2	
		(ii)	R_X = 16 [Ω] or equivalent (1) So Ohm's law not obeyed (1) [not freestanding] **no ecf** **or** If R_X stayed at 58 [Ω] (or 58.3 Ω), then I = 27 (or 26) mA (1) Not so, therefore Ohm's law not obeyed (1) **no ecf**			2	2	1	
		(iii)	No. Filament resistance increases with increasing pd [or current] or equivalent **ecf** on calculated value of R_X in (b)(ii)			1	1		
	(c)	(i)	Temperature at which a material [that is classed as a superconductor] loses all its resistivity [accept resistance] [when cooled]. Accept "... below which a material [...] has no resistivity [accept resistance]"	1			1		
		(ii)	Coil for MRI machine, power cables, magnets / electromagnets or anything reasonable (1) Can be kept below transition temp [cheaply] by liquid nitrogen [accept: superconducts in liquid nitrogen] (1)	2			2		
			Question 1 total	**5**	**2**	**3**	**10**	**3**	**0**

Question			Marking details	Marks available					
				AO1	AO2	AO3	Total	Maths	Prac
4	*(a)*		**Indicative content:** **Description:** D1: At very low temperatures resistance of superconductor is zero ohms D2: Reference to transition temperature or critical temperature...... D3: .....where resistance suddenly drops to zero as temperature drops (or jumps up from zero as temperature rises) D4: Above transition temperature resistance increases with temperature D5: This increase in resistance with temperature is [approximately] linear **[Sketch graph can show some of these points]** Explanation: **No explanation required for superconducting state.** **Above transition temperature:** **E1:** As temperature increases, the ions in the metal lattice vibrate more quickly **E2:** Which makes it more likely that an electron will interact (accept collide) with the ion.... E3: So electrons lose kinetic energy and the drift velocity decreases **E4:** ....and collisions will cause ions to gain kinetic energy making further collisions more likely **5-6 marks** Comprehensive description and explanation provided. *There is a sustained line of reasoning which is coherent, relevant, substantiated and logically structured.* **3-4 marks** Comprehensive description or explanation provided or limited attempt at both description and explanation. *There is a line of reasoning which is partially coherent, largely relevant, supported by some evidence and with some structure.* **1-2 marks** Limited attempt at description or explanation. *There is a basic line of reasoning which is not coherent, largely irrelevant, supported by limited evidence and with very little structure.* **0 marks** No attempt made or no response worthy of credit.	6			6		
	(b)		One benefit to society given for each application: **Particle accelerator 1 × (1) from:** • Improve understanding of the nature of particles, • Skilled workforce opportunities • Have led to more powerful computing • Particle discoveries used in everyday applications e.g. TV sets • Well-reasoned economic benefits **MRI scanner 1 × (1) from:** • Improved diagnoses and treatment of many ailments • Skilled workforce opportunities • Benefits more people Reasoned choice of application [1]			3	3		
			Question 4 total	**6**	**0**	**3**	**9**	**0**	**0**