Spec reference	Spec point	Additional guidance
4.1.1 Charge	(a) electric current as rate of flow of charge; $I = \frac{\Delta Q}{\Delta t}$ (b) the coulomb as the unit of charge (c) the elementary charge e equals 1.6×10^{-19} C (d) net charge on a particle or an object is quantised and a multiple of e (e) current as the movement of electrons in metals and movement of ions in electrolytes (f) conventional current and electron flow HSW7 (g) Kirchhoff's first law; conservation of charge.	Base unit is the Ampere (not Coulomb): 1C = 1As Electron and proton have the same (but opposite charge). In metals/conductors, electrons flow from negative to positive. In electrolytes, positive and negative ions flow. Taken as form positive to negative. The <u>**sum**</u> of currents into a point/junction = the <u>**sum**</u> of currents out of the point/junction
4.1.2 Mean drift velocity	(a) mean drift velocity of charge carriers (b) I = Anev, where n is the number density of charge carriers (c) distinction between conductors, semiconductors and insulators in terms of n.	Electrons' path hindered by positive ions in metals. Calculations involving volumes of (cylindrical) wires and numbers of free electrons to calculate electron density. $V = \pi r^2 L$ where r= radius of wire, L = length. n for insulators is very low, n for semiconductors is middling, and n for

		conductors is orders of magnitude larger.
4.2.1 Circuit symbols	(a) circuit symbols (b) circuit diagrams using these symbols	
4.2.2 E.m.f. and p.d	(a) potential difference (p.d.); the unit volt (b) electromotive force (e.m.f.) of a source such as a cell or a power supply (c) distinction between e.m.f. and p.d. in terms of energy transfer (d) energy transfer; V = Q/W; W = EQ (e) energy transfer eV= ½ mv^2 for electrons and other charged particles.	The energy transferred per unit charge from other forms into electrical (EMF). The energy transferred per unit charge from electrical into other forms (potential difference). Data for electrons etc. on data sheet. This links with quantum physics etc. later on in the course.
4.2.3 Resistance	(a) resistance; V = IR; the unit ohm (b) Ohm's law (c) (i) I–V characteristics of resistor, filament lamp, thermistor, diode and light-emitting diode (LED) (ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components. Investigating	Learners will also be expected to recall this equation. V α I at constant temperature. **Ohmic conductor**: straight line through the origin. Resistance is constant (inverse gradient of the I-V characteristic). **Filament light bulb:** resistance increases with temperature caused by the increase in current – increased electron-ion collisions. Interpolation of graph to calculate R.

	components and analysing data using spreadsheet. (d) light-dependent resistor (LDR); variation of resistance with light intensity.	 **Diode** – infinite/very high resistance in reverse bias, initially high resistance until a particular p.d. applied, then resistance falls. Questions often focus on I-V characteristics (e.g. of a diode and an ohmic conductor) and the distribution of currents in series and parallel circuits (see Kirchhoff's laws) and interpolation of the graphs – see past paper questions.
4.2.4 Resistivity	(a) (i) resistivity of a material; the equation: $$R = \frac{\rho L}{A}$$ (ii) techniques and procedures used to determine the resistivity of a metal. (b) The variation of resistivity of metals and semiconductors with temperature (c) Negative temperature coefficient (NTC) thermistor; variation of resistance with temperature.	Definition: state the equation in word form. Graphical method. Relate to the relative value of n (free electron density). Where n increases rapidly with temperature, reducing the resistance. This will connect with potential dividers later.

4.2.5 Power	(a) the equations $P = IV$, $P = I^2R$ = and $P = V^2/R$	For components in **series**, where current is constant $P \alpha R$ ($P = I^2R$). For components in **parallel**, where V is constant for all components $P \alpha 1/R$ ($P = V^2/R$).
	(b) energy transfer; $W = IVt$	
	(c) the kilowatt-hour (kWh) as a unit of energy; calculating the cost of energy.	Definition: the <u>**energy transferred**</u> when a device with a power of 1kW operates for 1 hour = 3.6×10^6J Comparison with the Joule and electron-volt.
4.3.1 Series and parallel circuits	(a) Kirchhoff's second law; the conservation of energy.	The <u>**sum**</u> of potential differences dropped in a loop = <u>**sum**</u> of emfs of that loop.
	(b) Kirchhoff's first and second laws applied to electrical circuits	I teach this earlier than is sequenced here (along with Kirchhoff's 1st law).
	(c) total resistance of two or more resistors in series; $R = R_1 + R_2 + R_3$……. (d) total resistance of two or more resistors in parallel; $I/R_T = 1/R_1 + 1/R_2 + 1/R_3$….	Calculations of combined resistances.
	(e) analysis of circuits with components, including both series and parallel	This could include calculations involving combined resistances or methods involving analysing loops and solving for Kirchhoff's laws.

	(f) analysis of circuits with more than one source of e.m.f.	This once again involves solving for Kirchhoff's 1st first (marking in currents) and then going round the loop using the 2nd law ($\Sigma V = \Sigma$ e.m.f. and $V = IR$.).
4.3.2 Internal resistance	(a) source of e.m.f.; internal resistance (b) 'lost volts'; Terminal p.d. (c) (i) the equations $E = I(R + r)$ and $E = V + Ir$ (ii) techniques and procedures used to determine the internal resistance of a chemical cell or other source of e.m.f.	Internal resistance caused by the fact that current flows through the cell/supply- leading to potential difference being dropped or 'lost' inside the cell/supply. Terminal p.d is the remainder of the available p.d. dropped across the external components. V = terminal p.d. I = the current r = internal resistance R = external circuit resistance. It is useful to see these equations fully in the context of Kirchhoff's laws. Descriptions of how V changes with I (caused by a change in R) in terms of the change in Ir. $V = -rI + E$ $y = mx + C$ Graph of V against I Gradient = -r Y intercept = E
4.3.3 Potential dividers	(a) potential divider circuit with components	2 or more components in series with a supply divide/have a share of the

		e.m.f. in accordance with their relative resistances. Learners will also be expected to know about a potentiometer as a potential divider.
	(b) potential divider circuits with variable components e.g. LDR and thermistor.	Discussion of the change in the share of the available p.d. - the larger the (relative) resistance, the greater its share of the available p.d.
	(c) (i) potential divider equations e.g. $V_{out} = \frac{R_2}{R_1 + R_2} \times V_{in}$ and $\frac{V_1}{V_2} = \frac{R_1}{R_2}$ (ii) techniques and procedures used to investigate potential divider circuits which may include a sensor such as a thermistor or an LDR.	Calculations will involve interpolation from graphs of Resistance against Temperature for a thermistor or Resistance against Intensity for an LDR.