Electricity QuickSheet — Exam Board: AQA AS — Saba Tutoring

The Basics

Charge, Q

- Due to electrons in the circuit carrying individual charge e.
- Measured in Coulombs, C.
- $Q = ne$.

Current, I

- The rate of flow of charge
- Measured in Amperes, A.
- $I = \frac{Q}{t}$.
- Conventional current +ve to -ve
- Electron flow -ve to +ve

Resistance, R

- Opposition to current
- Measured in Ohms, Ω.
- Property of component depending on material, length, area and temp

Voltage, V

- Energy transferred (work done) per unit charge
- Measured in Volts, V or JC^{-1}
- $V = \frac{E}{Q} = \frac{W}{Q}$

At the source

- Electromotive force (EMF), ε.
- Energy converts from chemical to electrical.
- a.k.a V_T or battery voltage

Across component.

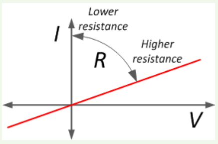
- Potential difference
- Energy converts from electrical to other e.g. light for bulb.
- Energy 'used' by the component depending on resistance

Ohm's Law

- V ∝ I under constant physical temperature (constant R)
- Introducing constant R, $V = IR$
- Voltage is the cause, current is the effect i.e. more energy per charge, faster flow of charges
- In metals, increasing T increases R as increases k.e of metal ions causes more collisions between conduction e- and metal ions.

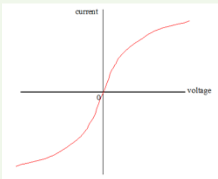
Fixed Resistor

- Gradient $= \frac{y}{x} = \frac{I}{V} = \frac{1}{R}$.
- Ohmic Conductor since constant gradient = constant R
- Steep – 'low resistance'
- Shallow – 'high resistance'



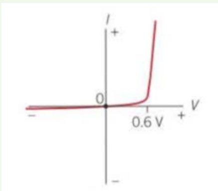
Filament Lamp

- Ohmic Conductor at low currents
- At high I, T increases, causing an increase in R and therefore shallower gradient.



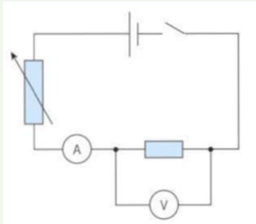
Diode/LED

- Only allows current in forward bias after approx. 0.6V.
- In reverse bias, infinite R ideally. Reverse bias is -ve current (switch cell terminals)



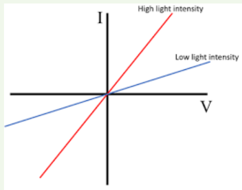
Determining I-V Characteristic Curves

- Switch: prevents overheating affecting increasing R
- Ammeter: in series, ideally 0 resistance, measures I
- Voltmeter: in parallel, measures potential difference (after-before), ideally ∞ R to prevent bypass of current around component.
- Variable Resistor: Changes total R of circuit, to change total current to yield pairs of I and V values.



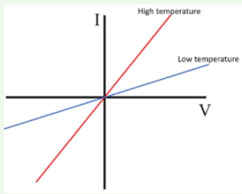
Light Dependent Resistor

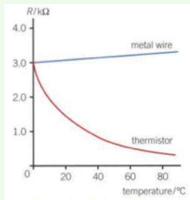
- Increase light intensity decreases R as more charge carriers (e⁻) are released.
- High light = Low R = Steep



Thermistor

- Made of semiconductors: an increase in T *decreases R* as more charge carriers (e-) are released. Known as a negative temperature coefficient (NTC). Opposite to metals, where R would increase.
- High T = Low R = Steep and vice versa
- R decreases as variable increases (exponential-like graph). Same for LDR





Resistivity

1) R ∝ l 3) $R \propto T$
2) $R \propto \frac{1}{A}$ 4) Material

- Resistivity, ρ, can be found in databases for a material at a certain T.
- The higher the T, the higher the resistivity

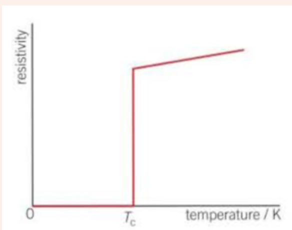
- Combining the above, $R = \frac{\rho l}{A}$. Units of resistivity are Ωm. Also, note A is cross sectional area; most wires are assumed cylindrical so πr^2.
- Units are SI, be careful when converting areas e.g. $cm^2 \rightarrow m^2$ is divide by 100^2.

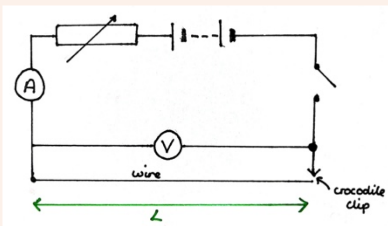
Determining Resistivity of Wire

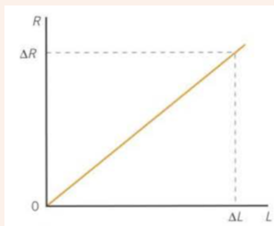
- Measure l of wire using a ruler
- Measure and average d using micrometer at diff orientations, then πr^2 or $\frac{\pi d^2}{4}$ to calculate cross sectional area (more accurate)
- Use variable resistor to yield I and V values. Calculate R.
- Repeat for different length of same wire using crocodile clips
- Rearrange eqn into $R = \frac{\rho}{A} l$ i.e. $y = mx$.
- Find gradient and extract ρ from $\frac{\rho}{A}$

Superconductivity

- In reality, even wires have resistance (negligible is assumed)
- Superconductor: a material which below critical temperature, has 0 resistivity (and R). Therefore, no p.d, energy loss and heating effect.
- Uses: Electromagnets in MRI and particle accelerators.







Power and Energy

- Power is the rate of energy transfer, measured in Watts, W. $P = \frac{E}{t}$
- Substituting the definitions of I and V, $P = IV$
- Substituting V=IR yields $P = I^2R$, or $P = \frac{V^2}{R}$
- Finally, $E = Pt = IVt$
- Note, in heating appliances such as kettles/irons, $P = I^2R$, determines power i.e. rate of heat energy transfer. This is the heating effect equation.

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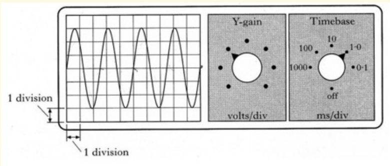
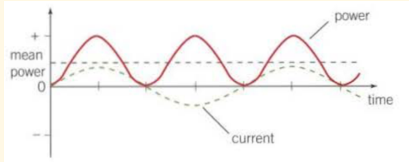
Alternating Current

- Alternating Current (a.c): current reverses direction.
- Frequency, time period and peak (amplitude) can be determined.
- Can observe by connecting to an oscilloscope. Time base: how many seconds one division on x axis is. Y-gain: how many volts one interval on the y axis is
- Could also set low frequency a.c. and watching LED flicker; cannot conduct in reverse bias, can conduct in forward bias



Power and Root Mean Square

- Power will be $P = I^2R$ at every point in time, so always +ve.
- Peak power will be at peak current I_0, hence $P_0 = I_0R^2$
- Mean power is half the peak power.
- Root mean square (RMS) current of an alternating current is the value of direct (constant) current that will deliver the same heating effect.
- I.e. the RMS current is the current that provides the mean power.
- $I_{rms} = \frac{I_0}{\sqrt{2}}$ and $V_{rms} = \frac{V_0}{\sqrt{2}}$



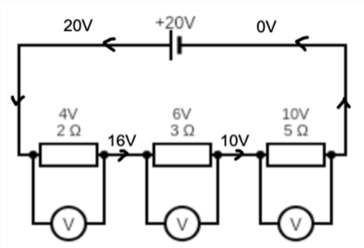
Circuit Calculations

Analogy:

- Imagine a race. The runners are charges. The hurdles are resistances. The start point where each runner is given energy is the cell. The energy of each runner is the voltage (energy per unit charge).
- Each runner starts the race with energy provided at the start point (EMF). They lose energy at the hurdles. By the end of each lap, they would like no energy left, as it will be replenished when they return to the start point. Roads (wires) require no energy as negligible R.

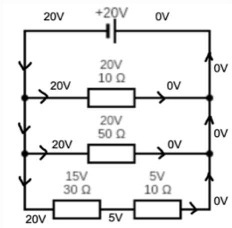
Series Circuits:

- $I_T = I_1 = I_2 = I_3$, conservation of charge. *"runners do not go missing"*
- $\varepsilon = V_1 + V_2 + V_3$ conservation of energy. EMF is shared in the ratio of resistances "*runners use more energy on higher hurdles*"
- $R_T = R_1 + R_2 + R_3$: *"one tall hurdle = multiple small hurdles"*

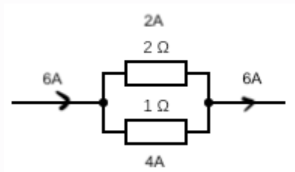


Parallel Circuits:

- $I_T = I_1 + I_2 + I_3$, conservation of charge. Current takes the route of least resistance. *"runners take different routes; less runners take higher hurdle routes"*. Apply inverse ratio
- $\varepsilon = V_1 = V_2 = V_3 + V_4$, conservation of energy. Voltage across each branch is the same as EMF. "*taking a junction doesn't make runner lose energy*"
- $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3+R_4}$.



Example of current splitting in inverse ratio (route of least resistance):

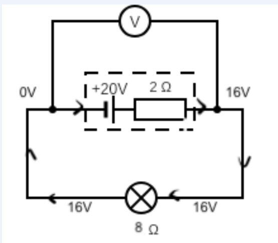


Circuit Tips:

- Follow the current and voltage around the circuit, understand the way they split!
- Combine resistors using formulas to work out R_T. Use $\epsilon = I_T R_T$ for the whole circuit, use $V = IR$ to for each individual component. Make sure the current and voltage is correct for values are for that component!

EMF and Internal Resistance

- Batteries have an internal resistance, *r,* causing lost voltage v at the source.
- This reduces the voltage available to the circuit (load voltage or terminal voltage, V).
- Since internal resistance is in series, the rules above apply (constant current, voltage shared)
- $\epsilon = V + v = V + Ir = IR + Ir$



Multiple Cells

- **In series:** If current in same direction, EMF and r adds. If current from each cell is in opposing directions, EMF cancels but r adds.
- **In parallel:** EMF remains that of one branch i.e. no change. R combines using parallel circuit rules.
- For any loop in a circuit, the sum of EMFs is equal to the sum of potential losses. For a loop 1) Choose a direction of current 2) cells in that direction have +ve EMF 3) cells in opposing directions have -ve EMF. 4) Resistors are -ve (use V=IR) 5) Sum equals 0

Measuring EMF and Internal Resistance of a cell

- Constant for a cell over short span (changes over long use)
- Similar procedure to I-V characteristic curves.
- Rearranging $\epsilon = V + Ir$ into $y = mx + c$
- $V = -rI + \epsilon$.
- Decreasing R increases current, increases lost volts and decreases load volts i.e. less voltage to 'actual' circuit.
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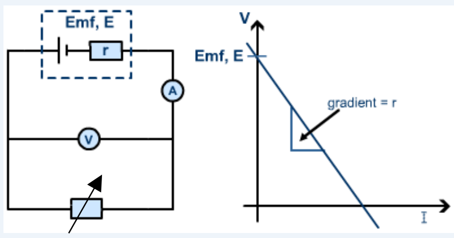
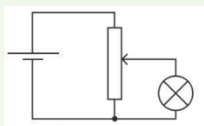


- Alternatively, if pair of I-V values, can write 2 $\epsilon = V + Ir$ equations and solve simulatenously

Potential Dividers

- Choosing the ratio of R in a circuit, allows voltage to be shared in that ratio (remember analogy)
- $V_1 = V_T\left(\frac{R_1}{R_T}\right)$ *or* $\frac{V_2}{V_1} = \frac{R_2}{R_1}$.
- Can be used for sensor circuits e.g. street lighting and thermostats, or to supply variable voltages to components (see examples)
- Resistors must be close in magnitude, otherwise most voltage will always go to the higher resistance, even if conditions change.

- **Example 1 – Potential Divider:** Sliding the contact changes the ratio of lengths, changes the ratio of resistances, so changes the voltage ratio.
- **Example 2 – LDR & Lamp Sensor Circuit:** Increasing light intensity, decreases R of LDR, decreases V across LDR, decreases V across bulb in parallel, bulb dims. I.e. if bright outside, light dims. Note voltage across resistor increases due to constant EMF (series rules).
- **Example 3-** Above could be replaced by thermistor and heater i.e. thermostat.



▲ Figure 3 *Brightness control using a variable potential divider*