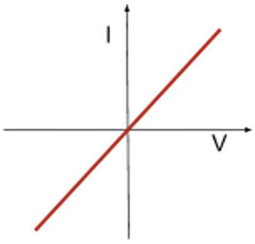
3.5.1 Current electricity

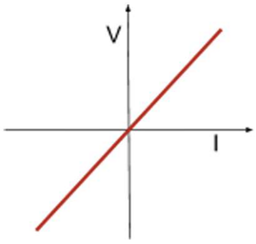
3.5.1.1 Basics of electricity

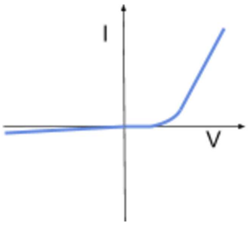
- Charge
    - Measured in coulomb (C)
    - ★ Charge of 1 electron = -1.6×10^{-19} C
- Electric current (I)
    - The flow of charge per unit time / the rate of flow of charge
    - $I = \frac{\Delta Q}{\Delta t}$
- Potential difference (V)
    - The energy transferred per unit charge between two points in a circuit
    - When a charge of 1 C passes through a p.d. of 1 V, it does 1 J of work
    - $V = \frac{W}{Q}$
- Resistance (R)
    - A measure of how difficult it is for charge carriers to pass through a component
    - $R = \frac{V}{I}$
- Capacity
    - A measure of the total amount of charge which the battery can push around a circuit
    - Commonly measured in ampere-hours (A h)
    - ★ 1 Ah = a current of 1 A can flow for 1 hour = 3600 C
- Types of charge carriers
    - Insulator
        - Each electron is attached to an atom and cannot move away from the atom
    - Metallic conductor
        - Most electrons are attached to metal ions but some are delocalised
        - Delocalised electrons can carry charge through the metal
        - When a voltage is applied across the metal these conduction electrons are attracted towards the positive terminal of the metal
    - Semiconductor
        - Number of charge carriers increase with an increase of temperature (electrons break free from the atoms of the semiconductor)
        - Resistance fall as temperature rise

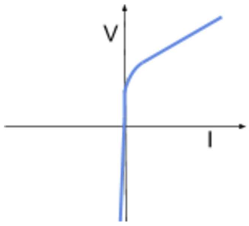
3.5.1.2 Current-voltage characteristics

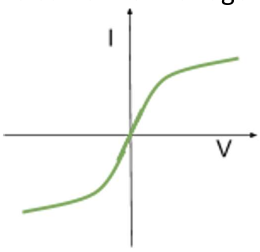
- Ohm's law
    - The current through a conductor is directly proportional to the potential difference across the conductor provided that temperature and other physical conditions remain constant
    - $V = IR$
    - * **Not** the definition of voltage
- Types of different conductors
    - Ohmic conductor
        - Follows Ohm’s law
        - Constant resistance as long as temperature and other physical conditions remain constant
        - Current-voltage graph will look like a straight line through the origin

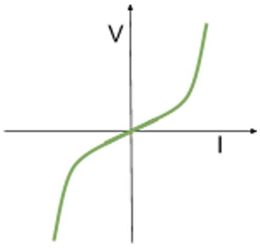
- 



- Semiconductor diode
  - Only lets current flow in one direction, converts AC to DC
  - Forward biased: allow current to flow easily past the threshold voltage (smallest voltage needed to allow current to flow)
  - Reverse biased: the resistance of the diode is extremely high so that only a very small current can flow
  - 



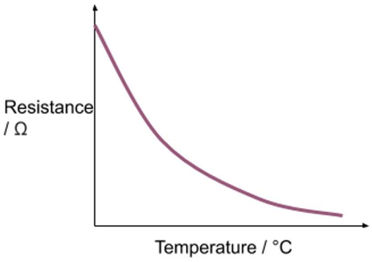
- Non-ohmic conductors e.g. filament lamp
  - Does not have a constant resistance
  - As voltage increases current increases
  - More electrons flow through the wire per second
  - Higher **rate** of collisions between ions in the lattice structure and electrons
  - Conducting electrons slow down more and lose more kinetic energy so current falls and resistance increases
  - As current or voltage increases resistance increases so the gradient is not constant
  - 

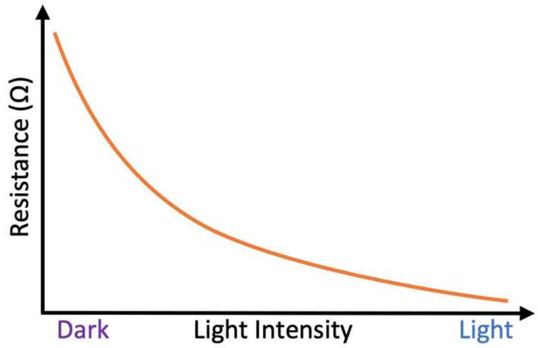


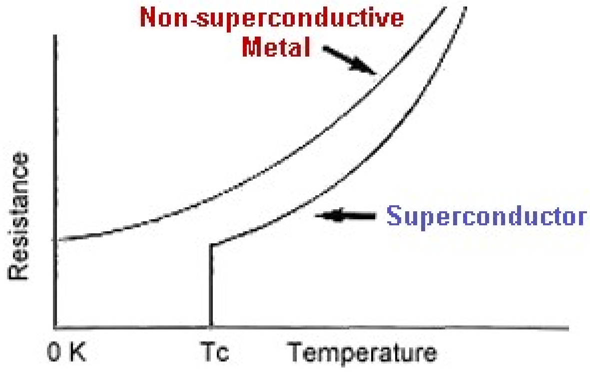
- Assumptions
  - Assume ammeters and voltmeters are ideal unless otherwise stated
  - Ammeters can be assumed to have zero resistance
  - Voltmeters can be assumed to have infinite resistance

3.5.1.3 Resistivity

- Resistivity (ρ)
  - Resistance per unit length × area of cross section
  - $\rho = \frac{RA}{L}$ or $R = \frac{\rho L}{A}$
  - Unit = Ω m
- Effect of temperature on the resistance of metal conductors
  - When the temperature of a metal conductor increases its resistance will increase
  - Metal ions gain KE from heating and vibrate more so they take up more space
  - More collisions between electrons and metal ions **per second** so they slow down more
  - Current falls so resistance increases
- Effect of temperature on the resistance of thermistors
  - When the temperature of a thermistor increases, its resistance will decrease
  - Increasing the temperature of a thermistor causes electrons to be emitted from atoms = more charge carriers = current increase

- 

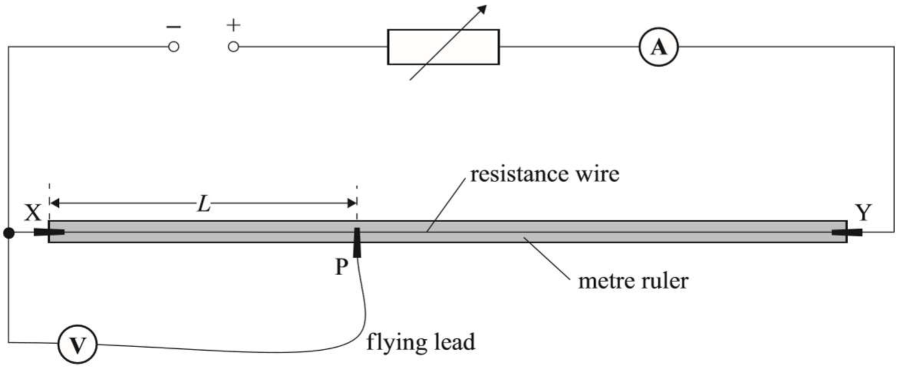
- Application of thermistors
  - Temperature sensors
    - Trigger an event to occur once the temperature drops or reaches a certain value
    - e.g. turn on the heating once room temperature drops below a specific value
- LDR
  - Resistance decreases as light intensity decreases
  - Used to trigger certain events
  - 

- Superconductivity
  - A property of certain materials which have **zero resistivity** at and below a critical temperature (T_c) which depends on the material
  - Resistivity decreases with temperature
  - Zero resistivity = zero resistance
  - Critical temperature normally extremely low (close to 0 K)
  - 

- Applications of superconductors
  - Power cables
    - Reduce energy loss due to heating to zero during transmission
  - Production of strong magnetic fields
    - Do not require a constant power source
    - Used in maglev trains / certain medical applications
- Resistance of a wire
  - Normally assumed to be 0 so no PD is lost between 2 points on a wire with no resistors between them
  - The assumption can break down if the current is high / resistance in the rest of the circuit is low

Required practical 5 - determining wire resistivity

- Method
  - Set up the circuit as shown

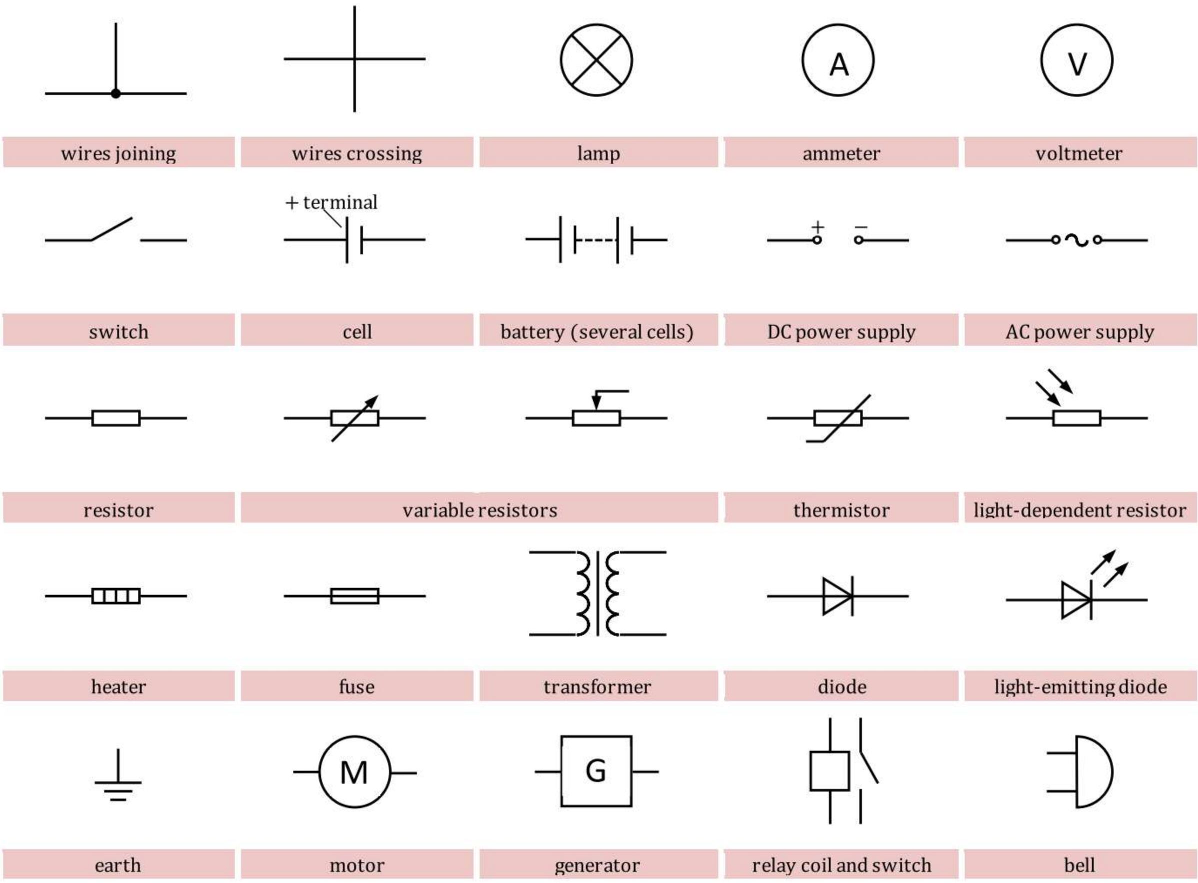


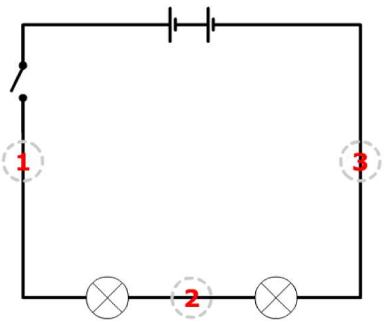
- Connect the flying lead to the wire so that 0.10 m of the wire has its resistance measured
- Switch on the power supply and adjust the voltage of it so that the current in the circuit is 0.50 A
- Turn off the power supply between readings so the wire does not heat up and increase in resistance
- Measure and record the length and voltage across the wire by taking reading on the voltmeter
- Move the flying lead to increase the length by 0.10 m and repeat the measuring process for lengths up to 1.00 m
- Repeat the experiment twice for each reading and calculate an average voltage at each length
- Calculate resistance at each length by $R = \frac{V}{I}$
- Plot a graph of resistance against length
- Resistivity = gradient × cross sectional area (gradient = $\frac{\rho}{A}$)

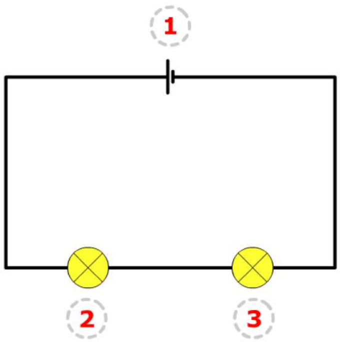
- Errors
  - Random Errors
    - The current flowing through the wire will cause its temperature to increase and increase its resistance and resistivity
      - Only allow small currents to flow through the wire
      - Therefore the temperature is kept constant and low by small currents
      - The current should be switched off between readings so its temperature doesn't change its resistance
    - Make at least 5-10 measurements of the diameter of the wire with the micrometer screw gauge and calculate an average diameter to reduce random errors in the reading
    - The wire should be free from kinks and held straight so the measurement of the length is as accurate as possible.
  - Systematic errors
    - Zero error when measuring wire length
- Safety Considerations
  - When there is a high current, and a thin wire, the wire will become very hot
  - Make sure never to touch the wire directly when the circuit is switched on
  - Switch off the power supply right away if you smell burning
  - Make sure there are no liquids close to the equipment, as this could damage the electrical equipment

3.5.1.4 Circuits

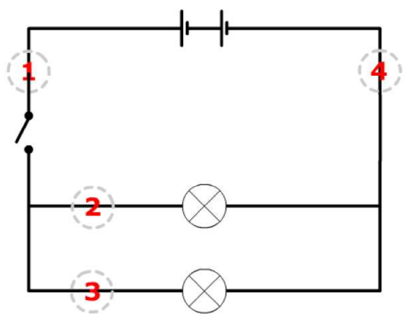
- Circuit symbols

- 

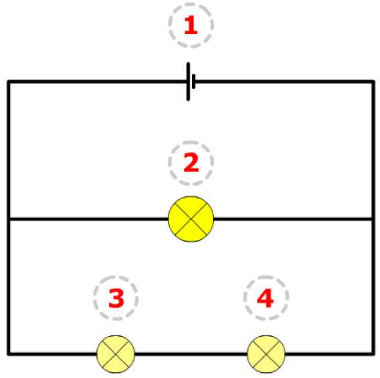
- Series circuit properties
  - The current is the same at all points
    - 

    - ① = ② = ③
  - The sum of potential differences across the components is equal to the total EMF of the power supply
    - 

    - ① = ② + ③
- Parallel circuit properties
  - The current splits up
    - Some of it going one way and the rest going the other
    - Total current in the circuit = sum of the currents in the branches

- 

- ① = ② + ③ = ④

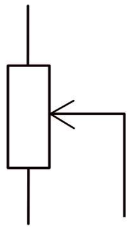
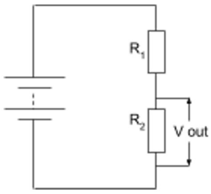
- Total voltage of a parallel circuit has the same value as the voltage across each branch
  - 

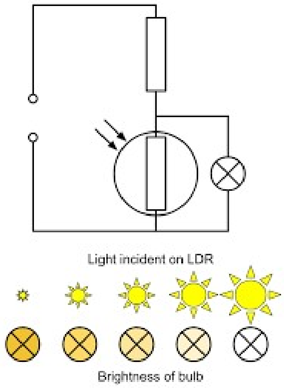
  - ① = ② = ③ + ④

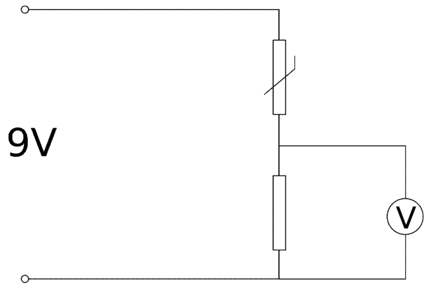
- Total voltage of cells
  - Cells joined in series
    - $V_T = V_1 + V_2 + V_3 + \cdots$
  - Identical cells joined in parallel
    - Total voltage = voltage of one cell as current is split equally between branches so overall pd is the same as if the total current was flowing through a single cell
    - $V_T = V_1 = V_2 = V_3 = \cdots = \varepsilon - \frac{Ir}{n}$
      $= \text{emf} - \frac{\text{total current of the circuit} \times \text{internal resistance of each cell}}{\text{number of cells}}$
    - Total internal resistance = calculated in the same way as other parallel circuits
    - Act like one cell but with reduced internal resistance
- Total resistance calculation
  - In series
    - $R_T = R_1 + R_2 + R_3 + \cdots + R_n$
  - In parallel
    - $\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$
- Power (P) and energy (E)
  - $P = IV = \frac{V^2}{R} = I^2R$
  - $E = Pt = IVt$
- Kirchhoff's laws
  - In **DC circuits**
  - Kirchhoff's first law (conservation of charge)
    - The total current flowing into a junction is equal to the current flowing out of that junction
    - No charge is lost at any point in the circuit
  - Kirchhoff's second law (conservation of energy)
    - The sum of all the voltages in a series circuit is equal to the battery voltage
    - No energy is lost at any point in a circuit

3.5.1.5 Potential divider

- Potential divider

  - A circuit with several resistors in series connected across a voltage source
  - Used to supply constant or variable potential difference from a power supply
  - Symbol
    - 
- Using variable resistors
  - Potential divider supply a variable pd
  - Use variable resistor as one of the resistor in series
  - Vary the resistance across = vary pd output
  - 

- Using thermistor / LDR
  - Resistance decreases as temperature / light intensity increases
  - Used to trigger certain events
  - 

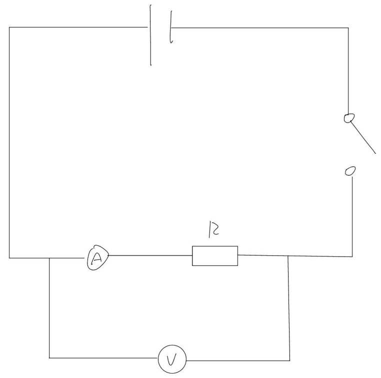


3.5.1.6 Electromotive force and internal resistance

- Internal resistance of batteries
  - The resistance of the materials within the battery
  - Caused by electrons colliding with atoms inside the battery so some energy is lost before electrons leave the battery
  - Represented as a small resistor inside the battery
- Terminal pd (V)
  - Pd across the resistor(s)
  - $V = \varepsilon - Ir$
- Lost volts (v)
  - Pd across the internal resistor in the battery
  - = energy wasted by the cell per coulomb of charge
- Electromotive force
  - The energy converted (from chemical) to electrical energy by a cell for per coulomb of charge that passes through it
  - Can be measured by measuring the voltage across a cell using a voltmeter when there is <u>no current</u> running through the cell
  - $\varepsilon = \frac{E}{Q} = \frac{\text{electrical energy transferred}}{\text{charge}}$
  - $\varepsilon = V + v = I(R + r) = \text{current} \times (\text{load resistance} + \text{internal resistance})$

Required practical 6 - finding the EMF and internal resistance of a cell

- Method
  - Set up the circuit as shown above with 2 (1.5V) cells connected in series



  - Connect a voltmeter across the resistor to measure the load voltage
  - Close the switch so that the current flows in the circuit
  - Record the ammeter and voltmeter readings
  - Open the switch to cut off the current and prevent heating in the circuit
  - Replace the resistor with a different resistor with a different resistance and repeat the measuring process
  - Use at least 5 different resistors with different resistances
  - Repeat the experiment 2 more times for each resistor and calculate the mean current and voltage
  - Plot a graph of load voltage against current
  - EMF of the cell is the y-intercept of the graph while the internal resistance of the cell is the magnitude of the gradient of the graph
- Safety
  - Another resistor can be included in series with the other to avoid high currents which could be dangerous and make the wires get hot
- Improvements / controls
  - Only close the switch for as long as it takes to read off each pair of readings
    - Prevent the internal resistance of the battery or cell from changing during the experiment due to heating
  - Use fairly new batteries/cells
    - The emf and internal resistance of run down batteries can vary during the experiment