

Electromotive force (e.m.f.):

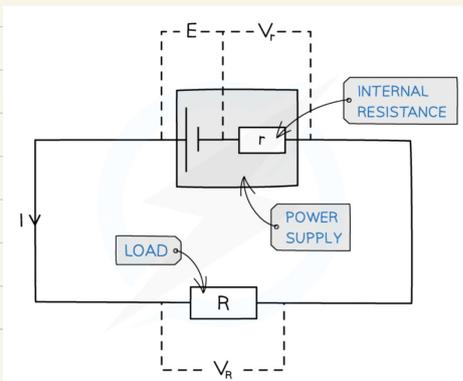
- e.m.f is the amount of chemical energy converted to electrical energy per coulomb of charge (C) when charge passing through a power supply
- e.m.f is measured in volts (V)
- e.m.f = potential difference across the cell when no current is flowing
- e.m.f can be measured by connecting a high-resistance voltmeter around the terminals of the cell in an open circuit

$$e.m.f = \frac{\text{energy transformed from chemical to electrical}}{\text{charge}}$$

the difference between potential difference (p.d.) and e.m.f is $p.d. = \frac{\text{energy transformed from electrical to thermal}}{\text{charge}}$

Internal Resistance:

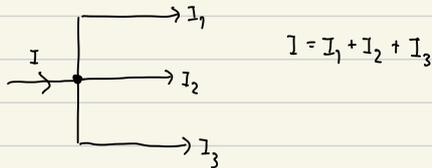
- all power supplies have some resistance between their terminals → this is called internal resistance
- this internal resistance causes the charge circulating to dissipate some electrical energy from the power supply itself
- ↳ this is why the cell becomes warm after a period of time
- the internal resistance therefore causes loss of voltage or energy loss in a power supply



- V_R = terminal potential differences
 - this is the voltage available in the circuit itself
 - terminal p.d = IR
 - V_r = lost volts
 - this is the voltage lost in the cell due to internal resistance, so, from conservation of energy
 - lost volts = e.m.f - terminal p.d.
 - lost volts = IR
 - e.m.f = the sum of these p.d., so $E = IR + I_r = I(R+r)$
- $E = \underbrace{IR}_{\text{terminal p.d. (V)}} + \underbrace{I_r}_{\text{lost volts across cell (V)}} = I(\underbrace{R}_{\text{resistance of load (Ω)}} + \underbrace{r}_{\text{internal resistance (Ω)}})$

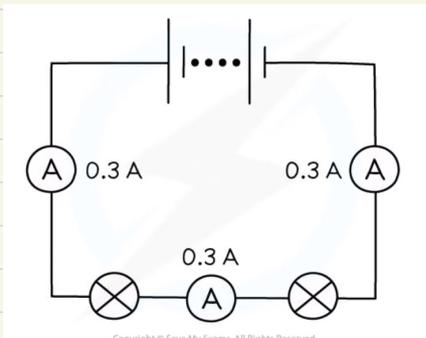
Kirchhoff's 1st Law

- Kirchhoff's 1st law states that: **the sum of the currents entering a junction always equal to the sum of currents out of the junction**
- this is the consequence of **conservation of charge** - current shouldn't increase/decrease in a circuit when it splits
- in a circuit:
 - Junction = point where at least 3 circuit paths meet
 - branch = path connecting 2 junctions



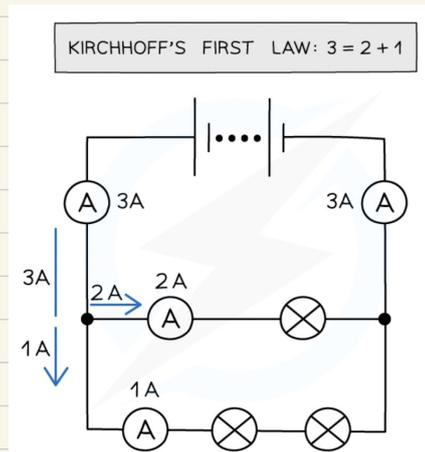
Series circuit:

- 1st law: current is the same through each component
- 2nd law:
 - the sum of the voltage is equal to the total e.m.f of the power supply *(voltage not con)*
 - the total resistance of the circuit is the sum of individual resistors



Parallel circuit:

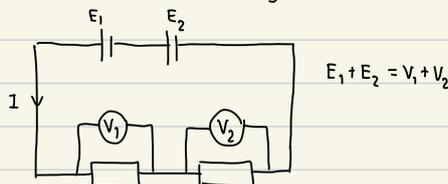
- the total current is divide at the junctions (each branch has a dif. value)
- the sum of the voltages in each closed circuit loop is equal to the e.m.f of the power supply *(voltage con)*
- the total resistance of the circuit is reduced as the current can follow multiple paths $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$



(junction only appear in parallel circuit)

Kirchhoff's 2nd Law:

- Kirchhoff's 2nd law states that: **the sum of the e.m.f's in a closed circuit equals the sum of the p.d.**
- this is the consequence of **conservation of energy**



Deriving the equation for resistor in series & parallel

CONSIDER TWO RESISTORS R_1 AND R_2 CONNECTED IN SERIES. A SINGLE RESISTOR R IS EQUIVALENT TO THEM. FROM KIRCHHOFF'S FIRST LAW: THE CURRENT I THROUGH EACH RESISTOR IS THE SAME SINCE THEY'RE CONNECTED IN SERIES (NO JUNCTIONS)

FROM KIRCHHOFF'S SECOND LAW: THE TOTAL p.d. OF BOTH RESISTORS IN A CLOSED CIRCUIT LOOP MUST EQUAL THE SUM OF THE p.d.s (THE p.d. ACROSS THE SINGLE RESISTOR) $V = V_1 + V_2$

FROM OHM'S LAW, POTENTIAL DIFFERENCE IS GIVEN BY THE PRODUCT OF CURRENT AND RESISTANCE $IR = IR_1 + IR_2$

SINCE CURRENT I IS THE SAME FOR ALL RESISTORS, DIVIDING BY I $R = R_1 + R_2$

THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN SERIES IS GIVEN BY $R = R_1 + R_2 + R_3 + R_4 \dots$

FROM KIRCHHOFF'S SECOND LAW, THE P.D. ACROSS EACH RESISTOR IN DIFFERENT BRANCHES IS THE SAME. THE RESISTOR R WILL HAVE THAT SAME p.d. ACROSS IT TOO $V = V_1 = V_2$

REARRANGING OHM'S LAW $V = IR$ FOR CURRENT I $I = \frac{V}{R}$ $\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$

SINCE POTENTIAL DIFFERENCE V IS THE SAME FOR ALL RESISTORS, DIVIDING BY V $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

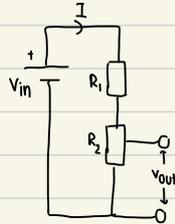
THIS EQUATION CAN BE EXTENDED SO THE EQUIVALENT RESISTOR R OF SEVERAL RESISTORS CONNECTED IN PARALLEL IS GIVEN BY $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \dots$

Potential Divider:

- when two resistors are connected in series, through Kirchoff's 2nd law, the p.d. across the power source is divided them
- potential dividers are circuits which produce an output voltage as a fraction of its input voltage

potential dividers have 2 main purposes:

- to provide a variable p.d.
- to enable a specific p.d. to be chosen
- to split the p.d. of a power source between 2 or more components



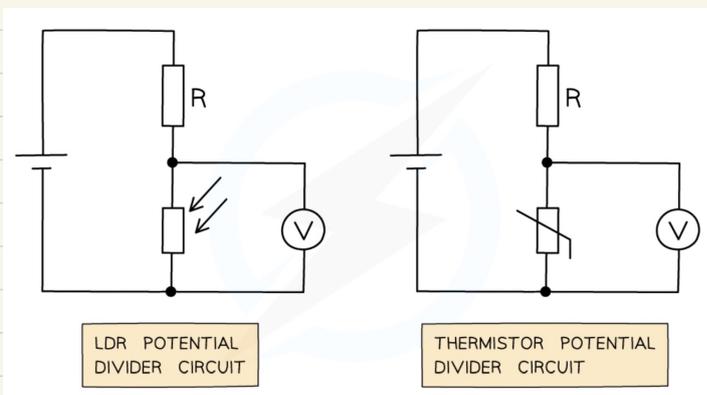
potential divider equation:

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

- the input voltage, V_{in} is applied to the top and bottom of the series resistor
- the output voltage, V_{out} is measured from the centre to the bottom of R_2
- the p.d. V across each resistor depends upon its resistance R
 - ↳ the resistor with the **largest resistance** will have a **greater p.d.** than the other one from $V=IR$
 - ↳ if the resistance of one of the resistor is increased, it will get a greater share of the p.d., whilst the other resistor will get a smaller share

Variable Resistance Components:

- Variable and sensory resistors are used in potential dividers to vary the output voltage
- sensory resistors used are LDRs and thermistors



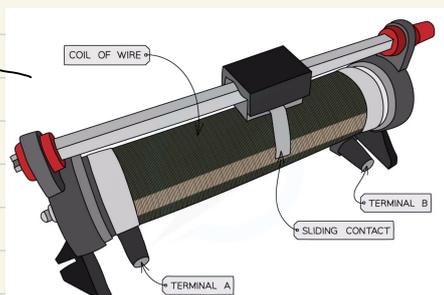
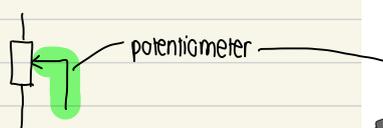
From $V=IR$: the p.d. V_{out} from a resistor in a potential divider circuit is proportional to its resistance

→ if an LDR/thermistor resistance increases, the p.d. also increases

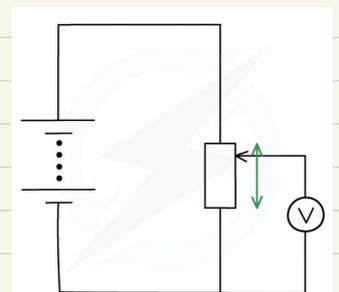
Since the total p.d. of the components must be equal to V_{in} , if the p.d. of the sensory resistor decreases then the p.d. of the other resistor in the circuit must increase and vice versa

Potentiometer:

- a potentiometer is similar to a variable resistor connected as a potential divider to give a continuously variable output voltage
- it can be used as a means of comparing p.d. in different parts of the circuit



- It is recognised on a circuit diagram with a resistor fitted with a sliding contact
- the sliding contact has the effect of separating the potentiometer into 2 parts (the upper and the lower part)
 - ↳ both of which have different resistances

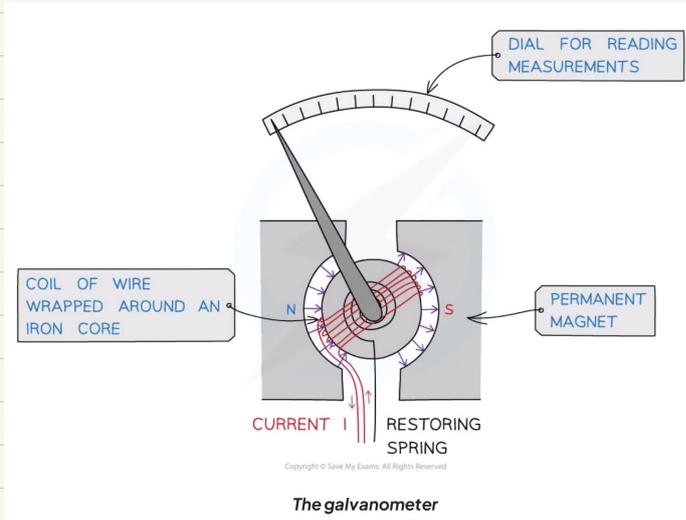


if the slider move upwards, the resistance of the lower part will increase and so the p.d. across it will also increase

Galvanometer

- a galvanometer is a type of sensitive ammeter used to detect electric current
- it is used in potentiometer to measure e.m.f. between two points in a circuit
- a galvanometer is made from a coil of wire wrapped around an iron core that rotates inside a magnetic field

Galvanometer



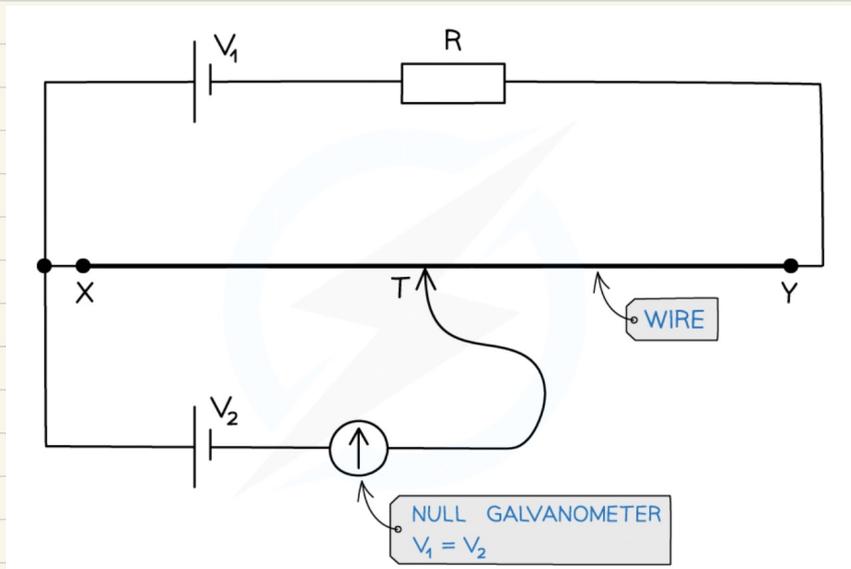
- the arrow represents a needle which deflects depending on the amount of current passing through
- when the arrow is facing directly upwards = no current
↳ this is called null deflection

• from Ohm's Law : current through a wire (conductor) is directly proportional to the p.d. through it

↳ i.e. no p.d. = no current flows through the current

→ a galvanometer has p.d. = 0 when the potential on one side is equal to the potential on the other side

★ This is at the position at which it is connected on the wire (which varies with the sliding contact) gives a p.d. equal to the e.m.f. of the cell connected to the galvanometer.



The cell should be connected such that its potential opposes the potential on the wire.