Electricity Basics

12th Dec

Power supplies, when connected, creates an electric field through the conductors and components in a circuit. This causes charges in the circuit to drift and move around the circuit. The power supply is DOING WORK on the charges. The charges then DO WORK on the components.

Charges flow from POSITIVE to NEGATIVE

Charge is measured in COULOUMBS, C.
The 'fundamental charge' is the charge on an electron (or proton) which has a magnitude of 1.6×10^{-19} C.

The CURRENT is the RATE OF FLOW of electric CHARGE.

$$I = Q/t$$

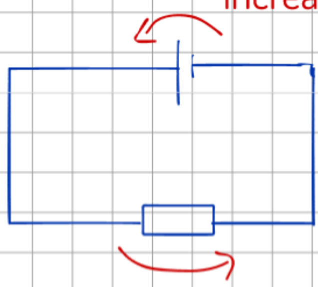
in $C\,s^{-1}$ or A (short for ampere)

The chemical energy transferred to electrical energy per unit of charge is called the ELECTROMOTIVE FORCE (emf).

$$\varepsilon = E/Q \quad \text{in } J\,C^{-1} \text{ or } V$$

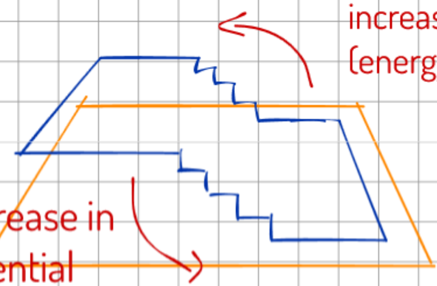
We often call this the VOLTAGE of the cell.

increase in potential

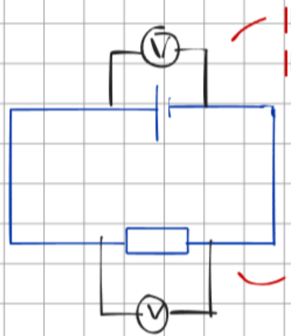


decrease in potential

increase in potential (energy of each unit charge)



decrease in potential



Tells us the potential difference across the cell.
It tells us the work done on each coulomb of charge.
It tells us the 'voltage' of the cell

Tells us the potential difference across a component. It is the work done by each coulomb of charge

$$V = \frac{E}{Q} \quad \text{in } J\,C^{-1} \text{ or } V$$

The electrical RESISTANCE tells us the ratio between applied potential difference and the current produced.

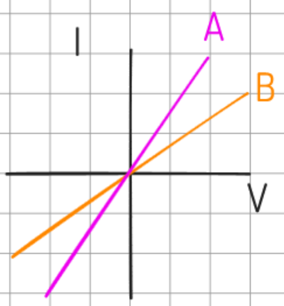
$$\boxed{R = \frac{V}{I} \quad \text{in ohms, } \Omega}$$

IV Characteristics

9th Jan

These are graphs that tell us how the current through a component varies when the potential difference across it is changed.

Ohmic conductor (i.e. resistor at constant temp)



Ohm's law: the current through a component is directly proportional to the potential difference across it at a constant temperature

A conductor that obey's Ohm's law is 'ohmic'.

$$I \propto V$$

We can use V = IR to calculate the RESISTANCE of a component providing we know the current through it and the potential difference across it.

For an ohmic conductor: $\text{gradient} = \frac{\Delta y}{\Delta x} = \frac{I}{V}$

Hence we can find the resistance: $R = \frac{1}{\text{gradient}} = \frac{V}{I}$

Note: this only applies to ohmic components

Bulb/Filament Lamp

To find the resistance at a particular p.d. we can read off the corresponding current and use R = V/I.

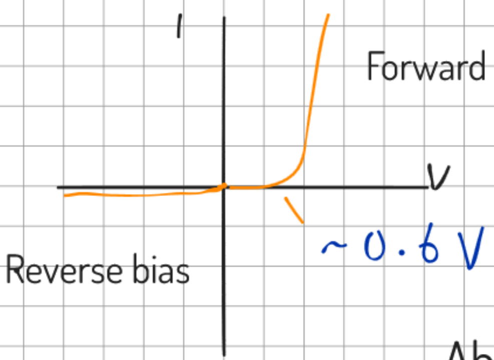
As the p.d. increases, so does the current through the bulb.

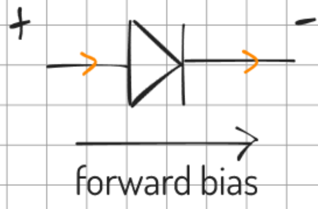
Electrons collide with ions in the filament, transferring energy to the ions and causing them to vibrate.

Increasing the current increases the rate of collisions and the rate of energy transfer.
The temperature of the filament increases. This increases the resistance of the filament.

The bulb behaves the same way when current is reversed.

Diode





In the forward bias no current flows until a threshold p.d. is across the diode.
Above this threshold voltage the diode has a very low resistance.

In the reverse bias the resistance is very high, so almost no current flows.

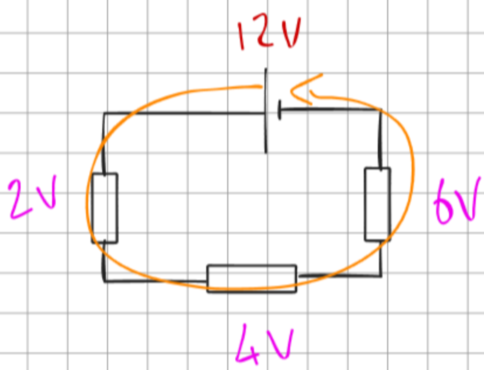
Unless told otherwise we assume AMMETERS and VOLTMETERS are 'ideal'. An ideal ammeter has no resistance, and an ideal voltmeter has infinite resistance.

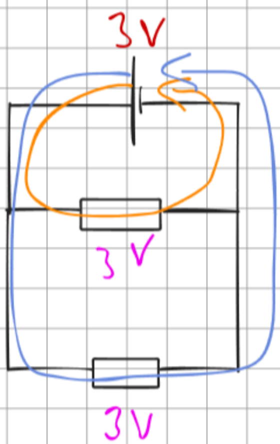
Conservation of Energy and Charge

13th Jan

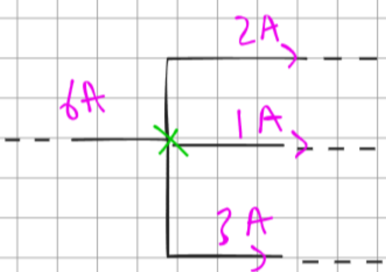
The energy supplied to charges in a circuit is typically transferred to the components in a circuit. The electric potential of the charges is INCREASED by a power source, and then DECREASES as the charges do work on components.

Kirchhoff's voltage law: the SUM of the POTENTIAL DIFFERENCE across all components in a CLOSED LOOP is equal to the POTENTIAL DIFFERENCE of the power supply

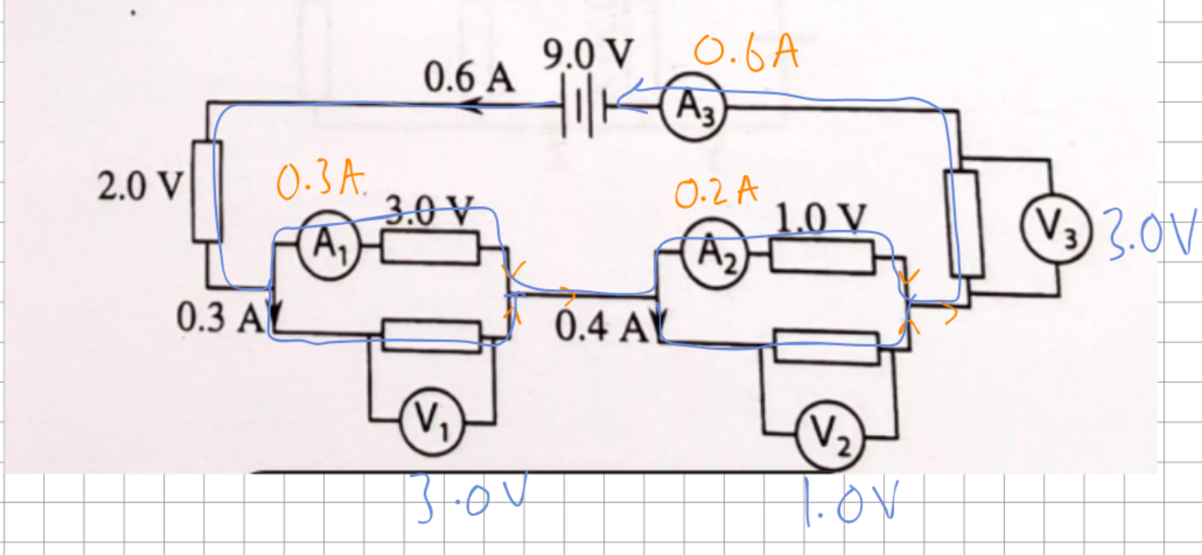




Kirchhoff's current law: the SUM of all currents into a point is equal to the SUM of the currents that flow out of the point.

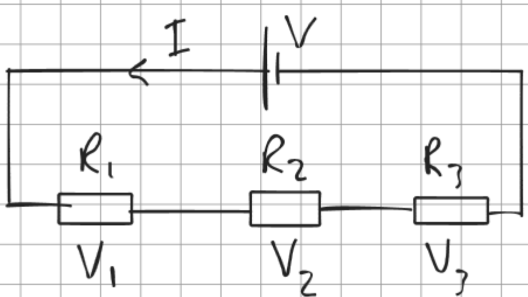


23.10 What are the readings on A_1, A_2 and A_3, and on V_1, V_2 and V_3 below?



Resistor Combinations and Total Resistance

13th Jan



We know that:

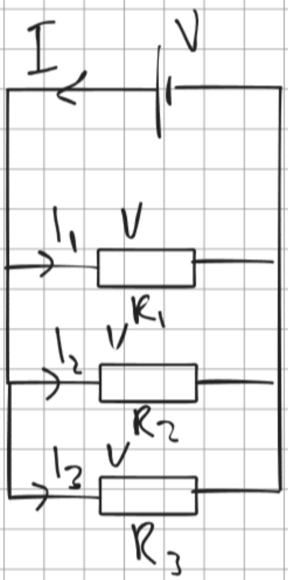
$$V = V_1 + V_2 + V_3$$

From ohm's law: $V = IR$

$$\cancel{I} R_T = \cancel{I} R_1 + \cancel{I} R_2 + \cancel{I} R_3$$

$$\boxed{R_T = R_1 + R_2 + R_3}$$

The total resistance of components in series is just the sum of their resistances.

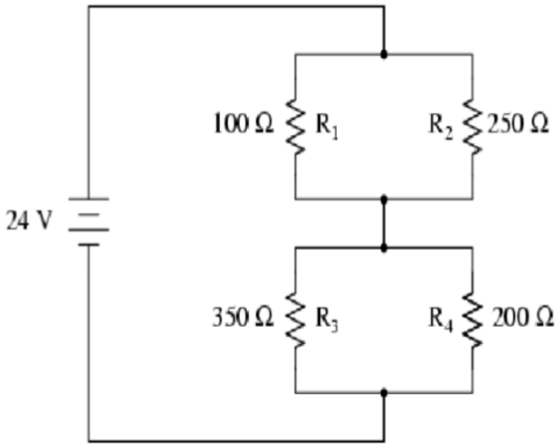


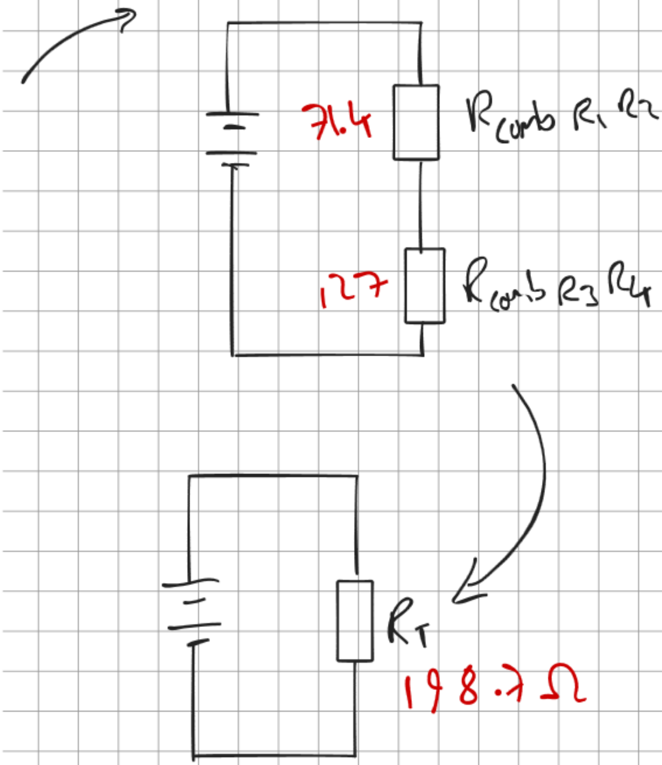
$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

We can use this expression to calculate the equivalent resistance of multiple resistors in parallel with each other.





1. Calculate the total resistance of the circuit.
2. Calculate the current through the cell
3. Calculate the potential difference across the R_1 and R_2 combination.
4. Hence, calculate the current through R_1 and R_2
5. Calculate the potential difference across the R_3 and R_4 combination.
6. Hence, calculate the current through R_3 and R_4

1. $\frac{1}{R_{comb_{12}}} = \frac{1}{100} + \frac{1}{250}$ so $R_{comb_{12}} = 71.4\ \Omega$

$\frac{1}{R_{comb_{34}}} = \frac{1}{350} + \frac{1}{200}$ so $R_{comb_{34}} = 127\ \Omega$

$R_T = 71.4 + 127 = 198.7\ \Omega$

2. $I = \frac{24}{198.7} = 0.121\ A.$

3. $V = IR = 0.121 \times 71.4 = 8.63\ V$

4. $I_1 = \frac{8.63}{100} = 0.0863\ A$ $\quad I_2 = \frac{8.63}{250} = 0.0345\ A.$

5. $V = 24 - 8.63 = 15.4\ V$

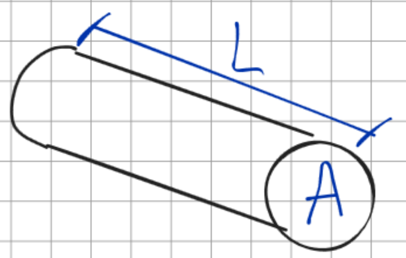
6. $I_3 = \frac{15.4}{350} = 0.0439\ A$ $\quad I_4 = \frac{15.4}{200} = 0.0770\ A.$

Resistivity

20th Jan

The resistance of a conductor can depend on the physical properties it has, such as:

- Its length
- Its cross sectional area
- The material it is made from



The resistance of a conductor is directly proportional to its length.

The resistance is also inversely proportional to the cross-sectional area.

$$\left.\begin{array}{l} R \propto L \\ R \propto \frac{1}{A} \end{array}\right\} \quad R \propto \frac{L}{A} \qquad R = \rho\frac{L}{A}$$

The resistivity, ρ, is a property of the material the conductor is made from.

$$\rho = \frac{RA}{L}$$

ρ has units of $\Omega\,m$.

Note: you will often be given a measurement of p.d. and current rather than resistance

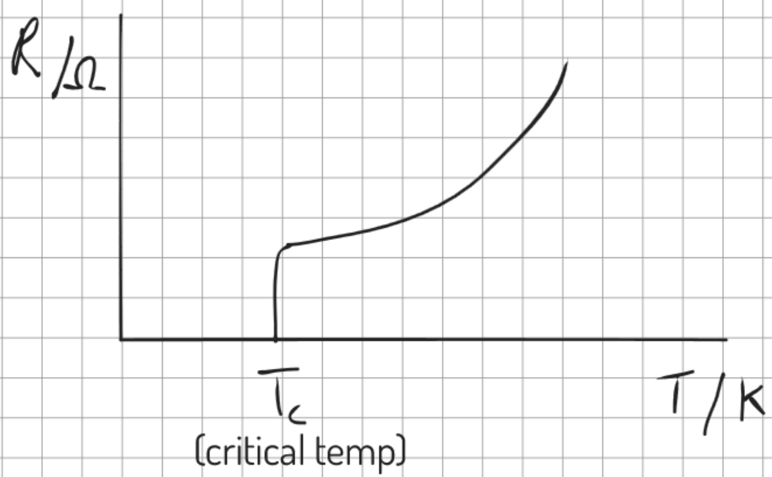
$$R = \frac{V}{I} \longrightarrow \rho = \frac{VA}{IL}$$

Superconductors

6th Feb

When some materials are cooled to extremely low temperatures, specifically below what is known as the CRITICAL TEMPERATURE, they become SUPERCONDUCTIVE.

This means they have NO ELECTRICAL RESISTANCE at all.



No resistance means we can have high currents with no energy dissipation.

We use superconductive materials wherever we wish to generate strong magnetic fields e.g. MRI, particle accelerators, maglev trains.

If we were able to use superconductive materials for power transmission, we could do so with no loss of energy.

Internal Resistance

6th Feb

The ELECTROMOTIVE FORCE (or emf) is the energy transferred from the chemical store of a cell to the electrical store of a circuit when moving a unit of charge around the circuit.

$$\varepsilon = \frac{E}{Q} \qquad JC^{-1} \text{ or } V$$

In reality most cells have INTERNAL RESISTANCE meaning that not all of this energy is transferred to components in the circuit. When a current flows through a cell some energy is dissipated to the surroundings as work has to be done to move charge through this internal resistance.

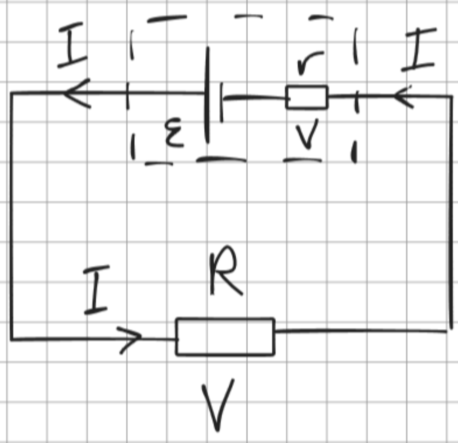
The work done per unit of charge in moving charge through the internal resistance is often called the LOST VOLTS.

$$\varepsilon = V + v$$

emf of the cell

lost volts

p.d across components in circuit or 'terminal p.d.' or 'load p.d.'



Terminal p.d. or load p.d.: $V = IR$

lost volts: $v = Ir$

Hence the following statements are true:

$$\varepsilon = IR + Ir \qquad \varepsilon = V + Ir$$

$$\varepsilon = I(R + r)$$

Energy is only dissipated across the internal resistance WHEN A CURRENT FLOWS.

When no current flows: $\varepsilon = V.$

Semiconductors

13th March

LDRs and Thermistors both contain semiconductor materials.

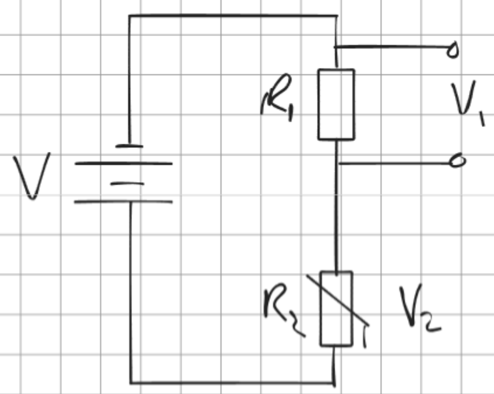
When a semiconductive material is provided with energy it is able to release MORE ELECTRONS into the circuit.

This effectively lowers the resistance of the component (as we get a greater current flow for the same potential difference).

With an LDR the energy comes from incoming photons; the greater the light intensity the lower the resistance.

With a thermistor increasing its temperature does increase the resistance due to increased oscillations/electron collisions etc. However, the release of extra electrons has a greater effect, so overall resistance lowers.

Sensor Circuits



In this circuit we know that:

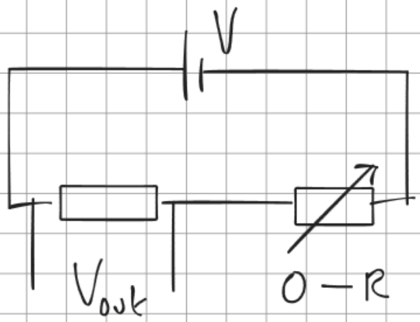
$$V_1 = \frac{R_1}{(R_1 + R_2)} \times V$$

As temp of circuit increases;

- Resistance of thermistor decreases
- Proportion of total resistance that R_1 has increases, therefore it receives a greater proportion of the supply p.d.

Potential Dividers - Rheostats/Potentiometers

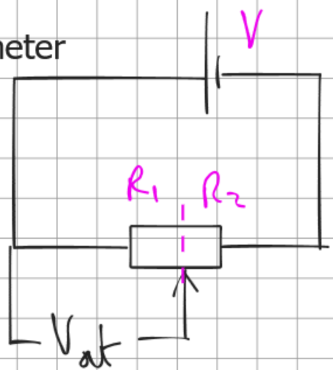
Rheostat



- When variable resistor is set to R;

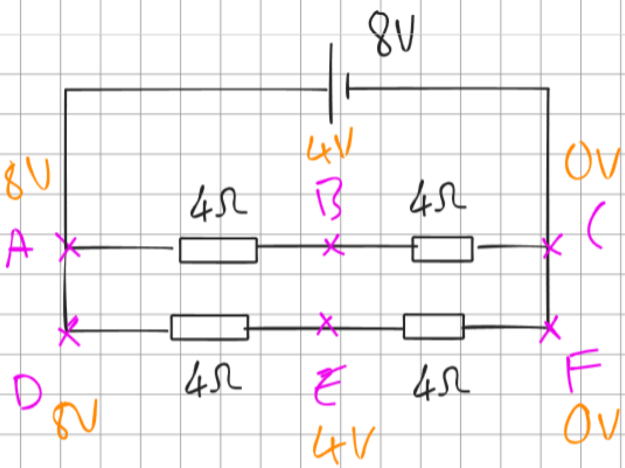
  V_{out} is a minimum, but not 0 V.

Potentiometer



- We change the proportion of the variable resistor our output is in parallel with.
- Full range from 0 to V for V_{out}
- Power dissipated by current flowing through variable resistor at all times

Potential Dividers in Parallel (Wheatstone bridges)



- A voltmeter would read 8 V if it was connected between:

  A & F
  D & C
  A & C
  D & F

It would read 4 V between: A & E, B & C, D & E, E & F, E & C, B & F etc

We would get 0 V between any two points that are at the same potential.

Uncertainty in Measurements

There are two types of uncertainty:

Absolute uncertainty: limits of the range above and below our measured/calculated value.

E.g. if our measured value of time was 2.56 s, and its absolute uncertainty was 0.01 s, then in reality our time measurement lies in the range 2.55 to 2.57 s.

$$t = 2.56 \pm 0.01 \text{ s}$$

Finding absolute uncertainty:

For repeated measurements: absolute uncertainty = $\frac{\text{range}}{2}$

For single measurements:

If one judgement is made i.e. taking reading from digital device then the absolute uncertainty is HALF of the resolution.

If two judgements are made i.e. start and end point of a measured length then the absolute uncertainty is THE RESOLUTION of the apparatus used.

Finding percentage uncertainty:

If the absolute uncertainty in measurement a is Δa

The percentage uncertainty, εa, is found from:

$$\varepsilon a = \frac{\Delta a}{a} \times 100$$

The percentage uncertainty in a calculated value depends on the percentage uncertainty of everything we used in the calculation.

For example: using V = IR where $\varepsilon I = 0.2\%$ $\varepsilon R = 0.4\%$

$$\varepsilon V = \varepsilon I + \varepsilon R$$

(add the percentage uncerainties if the quantities are multiplied or divided)

When an equation has a power involved, we multiply percentage uncertainty by the power.

$$A = \frac{\pi d^2}{4} \quad \text{and} \quad \varepsilon d = 1\%$$

$$\varepsilon A = 2 \times \varepsilon d = 2\%$$