Basics of Electricity

the electron

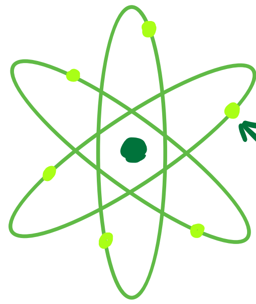
mass: 9.1×10^{-31} kg

charge: -1.6×10^{-19}

they repel each other
(because of the charge)

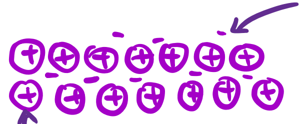
cya suckas

Normal:



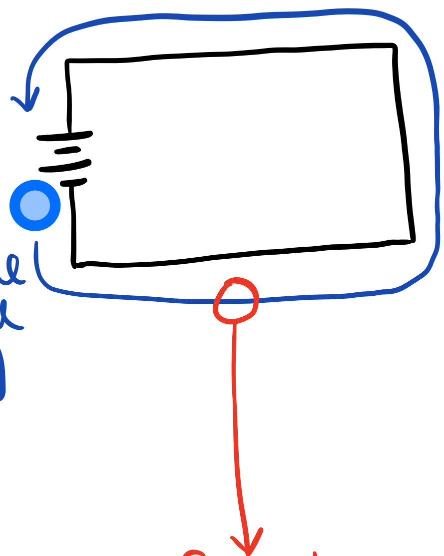
electrons
in orbit

Metal:



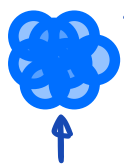
sea of
electrons

metal ions



high
electrical
potential
energy

The Coulomb



} 1 group of electrons

energy of 1 coulomb of e^- is 1 volt

voltage $V = \frac{E}{Q}$ energy / charge

Resistance

high voltage ⇒ high current

Ohm's law { current $I = \frac{V}{R}$ voltage / resistance

How easy is it for current to flow?

Current

How many coulombs of charge per second?

Current $I = \frac{Q}{t}$ charge / time

Sidenotes

- Voltage is AKA electrical potential
- Voltage is between 2 points (Like how GPE is relative to the floor)
- Voltage drop across a component is potential difference
- Voltage given in the battery is called electromotive force (EMF)

CONVENTIONAL current

+ve $\longrightarrow$ −ve

even though electrons flow from −ve → +ve

Exercise

1. Current = 0.40A charge in 15s = 0.40 × 15 = 6.0 C
2. 150C in 30s current = $\frac{150}{30}$ = 5A
3. 50C in 20s current = $\frac{50}{20}$ = 1.5 A
4. Car battery ⇒ 50 Ah
   a) 50 Ah = 50 × 60 × 60 = 180000 C
   Duration with 200A output = $\frac{180000}{200}$ = 900s
   b) charge in this time = 180000C
5. # of protons for 1C of charge = $\frac{1}{1.6\times10^{-19}}$ = 6.25×10^{18}
6. Car headlamp 16Ω, 12V battery
   Current = $\frac{12}{16}$ = 0.75 A

More on Ohm's Law

because V = IR,

$V \propto I$ when R is constant

6V 3A

12V 6A

POWER

$$V = \frac{E}{Q}$$

$$E = QV$$

$$\frac{E}{t} = \frac{Q}{t} V$$

Power $P = IV$ Current × Voltage

$$P = I(IR)$$

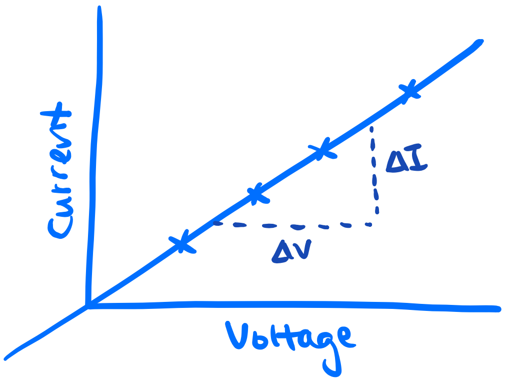
Power $P = I^2R$ Current² × Resistance

$$P = \left(\frac{V}{R}\right)V$$

Power $P = \frac{V^2}{R}$ $\frac{\text{voltage}^2}{\text{resistance}}$

GRAHPS: CURRENT AGAINST VOLTAGE

OHMIC CONDUCTORS

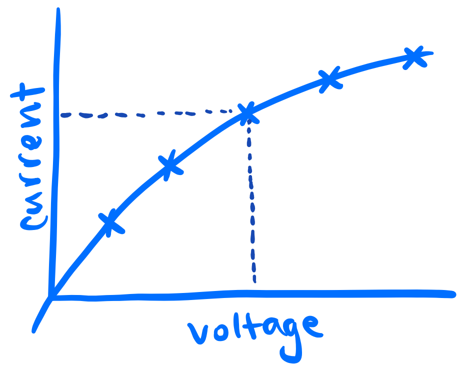


$V = IR$

$$\underbrace{\frac{1}{R} = \frac{I}{V} = \frac{\Delta I}{\Delta V}}$$

∴ Reciprocal of gradient = resistance

NON-OHMIC CONDUCTORS



DO NOT draw a tangent and treat it as the reciprocal of resistance!

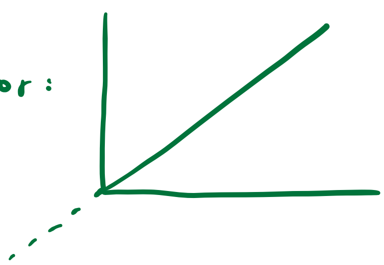
work out resistance using V and I values from graph

Electrical component: 2V → 10mA Resistance = 200 Ω

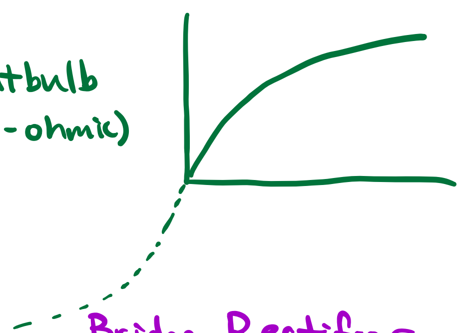
8V → 60mA Resistance = 133 Ω

∴ Doesn't obey ohm's law

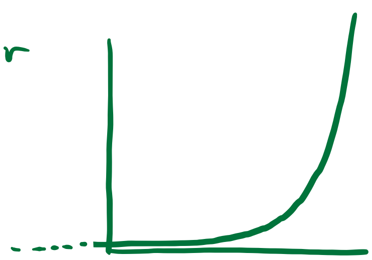
Ohmic resistor:

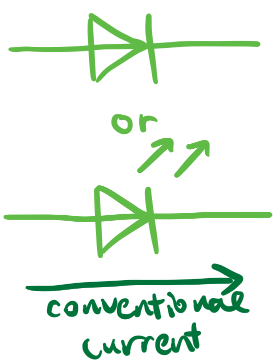


Lightbulb (non-ohmic)

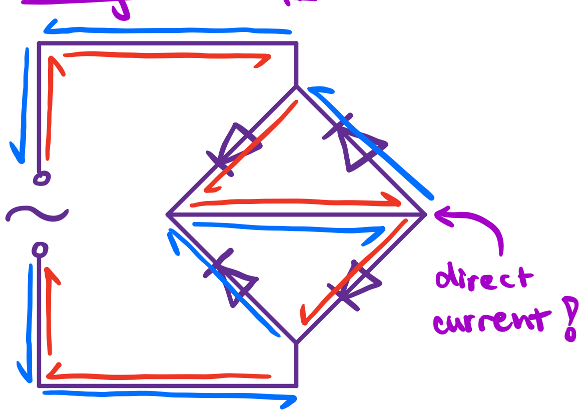


Semiconductor Diode (non-ohmic)





Bridge Rectifier



RESISTIVITY (ρ) [Ω m]

used to describe the resistance of a material

copper: 1.69×10^{-8} Ωm

quartz: 5×10^{16} Ωm

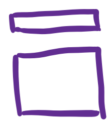
Length

$R \propto l$

increased chance of collision

Thickness (Cross sectional area)

$R \propto \frac{1}{A}$



more charge carriers (ie electrons)

$$R \propto \frac{l}{A} \Rightarrow R = \frac{\rho l}{A} \qquad [\Omega] = \frac{[\Omega m][m]}{[m^2]}$$

$\boxed{\text{0.50 mm diameter manganin}}$ ($\rho = 44 \times 10^{-8}$)

1Ω

$$R = \frac{\rho l}{A}$$

$$1 = \frac{44 \times 10^{-8} \times l}{(0.00025)^2 \pi}$$

$$l = \frac{(0.00025)^2 \pi}{44 \times 10^{-8}} = 0.45 \text{ m}$$

5Ω $0.45 \times 5 = 2.2$ m

10Ω $0.45 \times 10 = 4.5$ m

$\boxed{\text{1 cm}^3 \text{ Copper} \Rightarrow \text{Cross-sectional area} = 4 \times 10^{-7} \text{ m}^2}$ ($\rho = 1.69 \times 10^{-8}$)

$A = 4 \times 10^{-7} m^2 = 0.004 cm^2$

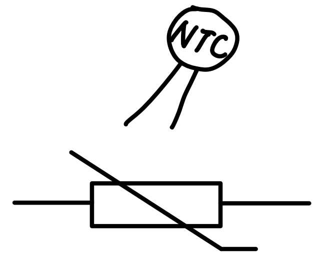
$V = Al$

$$l = \frac{V}{A} = \frac{1}{0.004} = 250 \text{cm}$$

$$R = \frac{\rho l}{A} = \frac{1.69 \times 10^{-8} \times 2.5}{4 \times 10^{-7}} = 0.11 \Omega$$

Temperature

In general: when temp ↑, resistance ↑

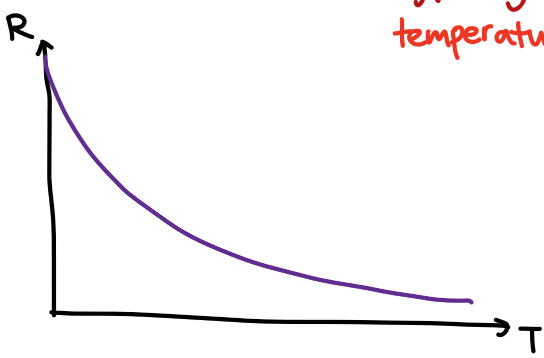


NTC Thermistor: when temp, resistance ↓

↓ negative temperature coefficient

Typically used for:
temperature sensors such as fire sensors

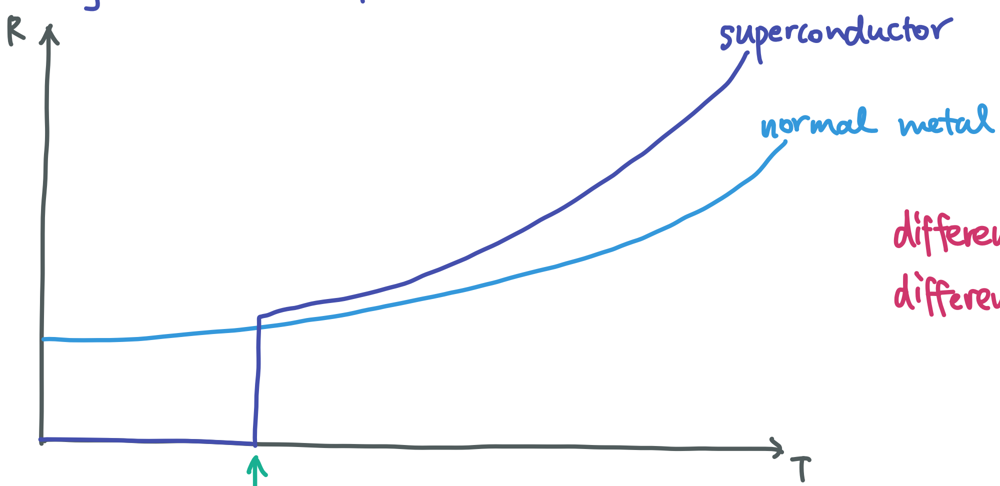
NTC Thermistor:



Superconductors

When metals are cooled, their resistance decreases.

Mercury: resistance drops to 0 at 4.1K



T_c (ie critical/transition temperature)

different materials have different T_c

Definition: a material that has 0 resistance when under its critical temp.

Applications: superconductive electromagnets are used in maglev trains & MRI machines

strong magnetic field

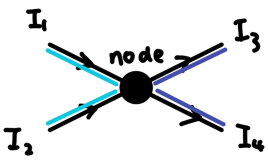
Circuits

Kirchoff's Current/First Law

$$\sum I_{in} = \sum I_{out} \quad \text{(of a node)}$$

sum of current in = sum of current out

Result of conservation of charge



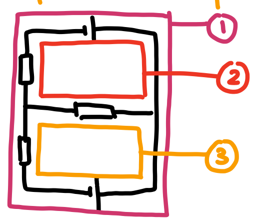
$$I_1 + I_2 = I_3 + I_4$$

Kirchoff's Voltage/Second Law

$$\sum EMF = \sum PD$$
$$\sum EMF = \sum IR$$

(In a loop)

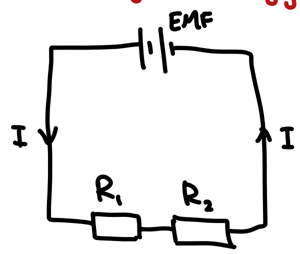
these loops can overlap!



Sum of emf = sum of p.d.

or

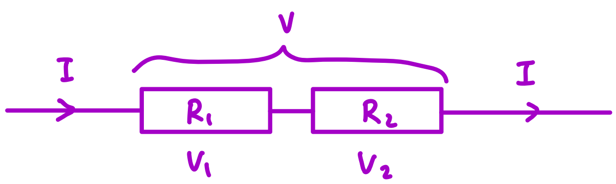
energy in = energy out



$EMF = IR_1 + IR_2$

Using these laws to derive expressions for combined resistance:

SERIES

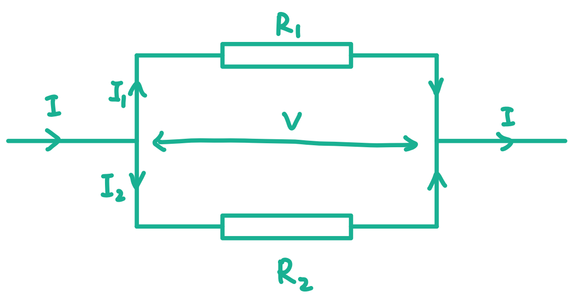


$$V = IR_{Total}$$

$$R_{Total} = \frac{V_1}{I} + \frac{V_2}{I} = R_1 + R_2$$

$$R_{Total} = \sum R$$

PARALLEL

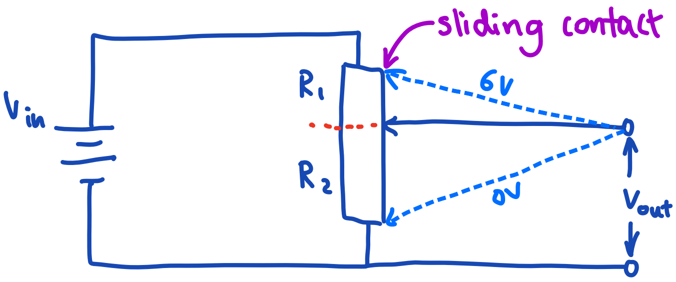


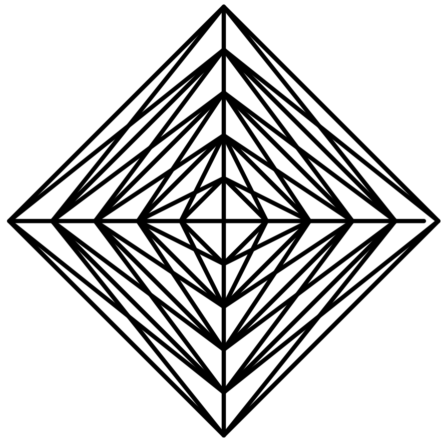
$$I_{1,2} = \frac{V}{R_{1,2}} \qquad I = \frac{V}{R_{Total}} \qquad I_1 + I_2 = I_3$$

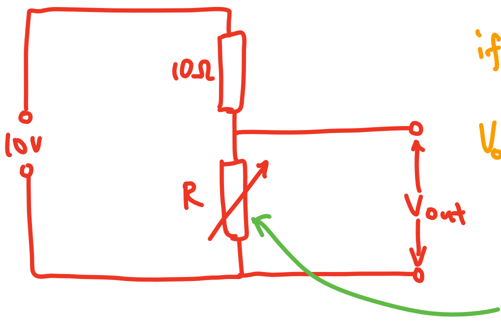
$$\frac{V}{R_1} + \frac{V}{R_2} = \frac{V}{R_{Total}} \quad , \quad \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_{Total}}$$

$$\frac{1}{R_{Total}} = \sum \frac{1}{R}$$

Potential Dividers





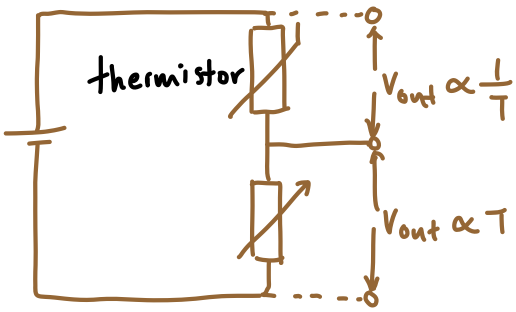


if R can be adjusted from 0Ω to 40Ω,

V_{out} can be adjusted from 0V to 8V

a variable resistor
AKA potentiometer

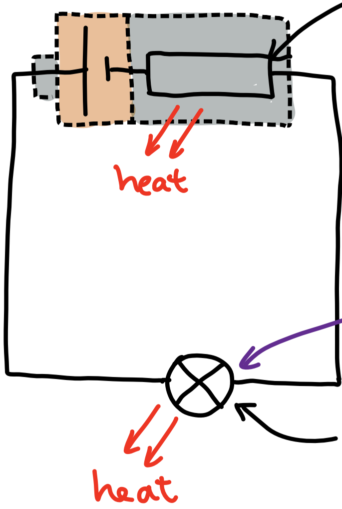
Using Thermistors:



Function: Heater

Function: Fire alarms

Internal Resistance

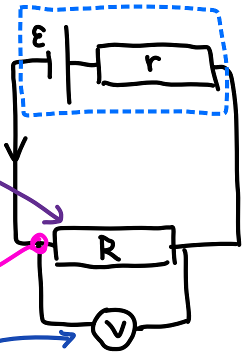


internal resistance (r)

(just draw a resistance next to battery)

Load Resistor

resistance (R)

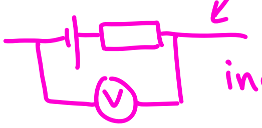


$\varepsilon = \Sigma pd = Ir + IR$

or $\varepsilon = V + Ir$

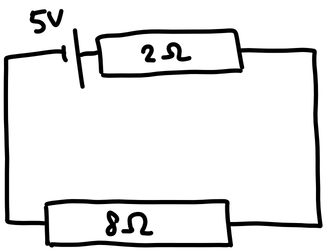
terminal PD

If we want accurate terminal PD,



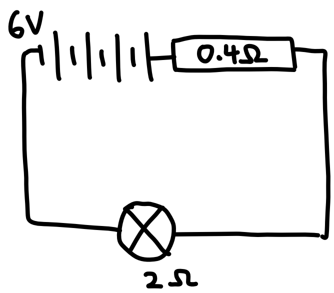
includes wire resistance

①



$I = \frac{V}{R} = \frac{5}{8+2} = 0.5A$

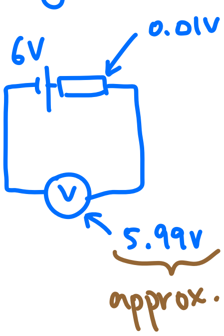
③



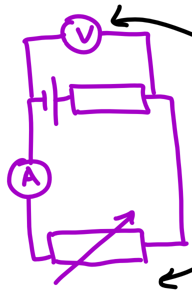
$I = \frac{V}{R} = \frac{6}{2.4} = 2.5A$

Measure EMF of power supply:

Easy:



Difficult:

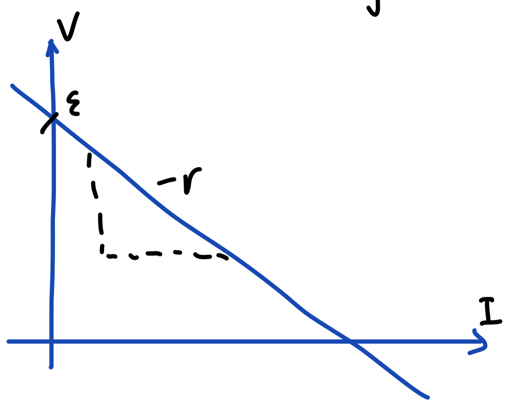


Change resistance, current changes (Independent variable)(x)

Terminal P.D. (Dependent Variable)(y)

$\varepsilon = V + Ir$

plot the graph $V = -rI + \varepsilon$ to find internal resistance and EMF of the battery



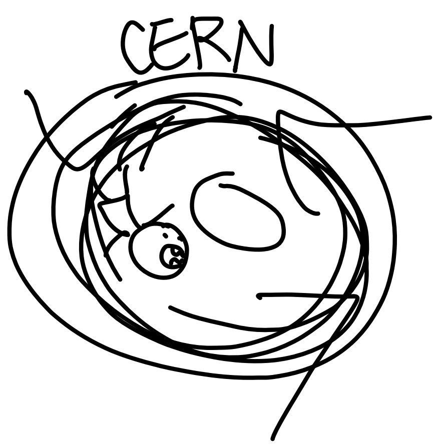
$\varepsilon = V + Ir$

a) $V = \varepsilon - Ir = 12 - 4 = 8V$

b) $P = IV = \frac{V^2}{R}$

$R = \frac{V^2}{P} = \frac{144}{36} = 4\Omega$

c) $P = \frac{V^2}{R} = \frac{64}{4} = 16W$



material of wire (copper-nickel alloy)

Experiment – Resistivity of Constantan

You will be assessed on:

- constructing a circuit from a circuit diagram.
- reading an ammeter and voltmeter, and using a micrometer screw gauge.
- safe use of the equipment.
- making precise measurements, obtaining sufficient data, demonstrating accuracy in your final results.

Theory

Resistivity is given by the equation:

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

Preliminary Questions

1. What does each letter in the equation represent?

   ρ = resistivity

   R = resistivity

   A = cross sectional area of wire

   l = wire length

2. What is the unit for resistivity?

   Ωm

3. By considering units in the equation above, prove that your answer is correct.

   $\Omega \times m^2 \times m^{-1} = \Omega m$

4. What is the definition of resistance?

   Voltage/current

5. How could you measure the resistance of a component?

   Connect to battery, then measure p.d & current.

6. For a given wire, predict the shape of a graph of R (y-axis) against length (x-axis). Justify your prediction.

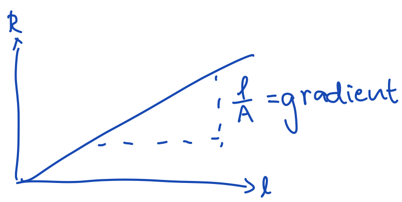
   Straight line with positive gradient & goes through origin

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

$R = \frac{\rho}{A} l + 0$

$y = mx + c$

Read the instructions through carefully before you begin.



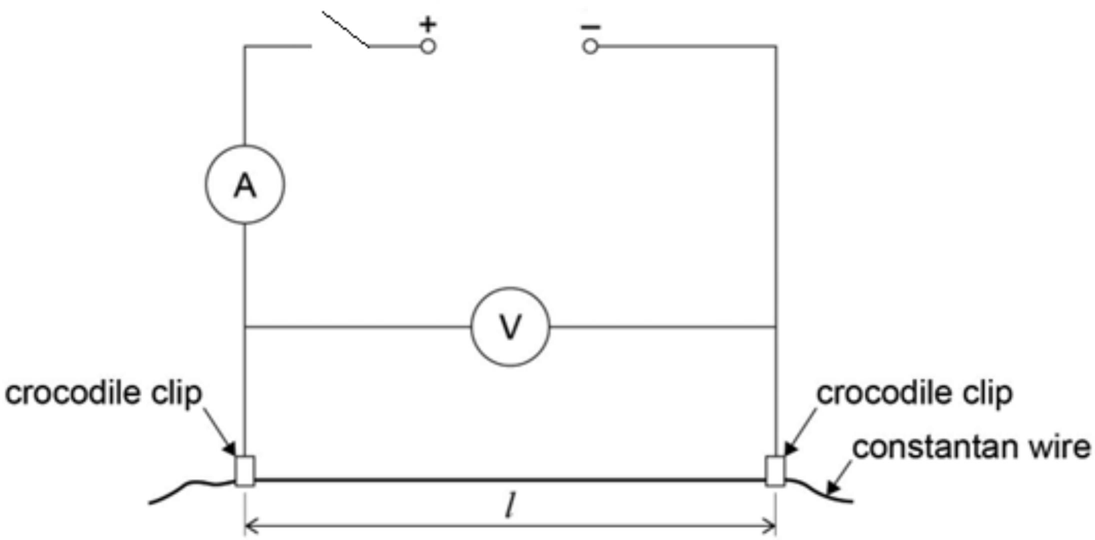
Preliminary Tasks

1. Read the method and data processing sections carefully.

2. Write a **risk assessment** for the experiment. This should include details of the **hazard** (thing that could cause injury), **risk** (injury or damage that could be caused) and **control measures** (how you will reduce the chance of injury).

3. Draw a **data table** including space for **repeats, averages and derived data**.

Method



1. Measure the thickness of the constantan wire using the micrometer in at least 3 places and find the mean diameter *d*. Convert this to metres.

2. Set up the circuit as shown in the diagram above.

3. Attach the crocodile clips so that l = 0.300m measured on the meter ruler.

4. **Make sure the ammeter is set to 10A scale.**

5. Close the switch and take the readings of pd, V, on the voltmeter and current, I, on the ammeter**. Open the switch between readings. Do not leave the switch closed when not taking a reading.**

6. Increase the length of wire to obtain pairs of readings of V and I. **You should collect at least 7 readings**.

7. Repeat all readings.

8. Calculate mean values of V and I for each length.

9. Calculate the mean resistance for each length.

Data Processing

1. Plot a graph of mean resistance against length.

2. Draw the best-fit line for your data.

3. Find the gradient of your line.

4. Use your gradient to determine the resistivity of the wire, showing all working.

Research Opportunity

1. Research the true value for the resistivity of constantan. Ensure you note the temperature for which this value is quoted. **Give full references for your source, including the date you accessed it.** hyperphysics.phy-astr.gsu.edu → Table of resistivity:
Constatan → 49×10^{-8} ie 4.9×10^{-7} (as of 10/11/2020)

2. Calculate the percentage uncertainty between your value for the resistivity of constantan and the value you have found by research.

3. Nichrome is another resistance wire. By researching the value of the resistivity of nichrome, evaluate whether this experiment would have yielded more accurate values, assuming all the physical conditions remained the same.

Length	Voltage	Current	Resistance	Resistivity (calculated without graph)
0.1	0.85	0.585	1.45299145	4.11965E-07
0.2	1.035	0.39	2.65384615	3.76221E-07
0.3	1.127	0.3	3.75666667	3.55041E-07
0.4	1.615	0.215	7.51162791	5.32441E-07
0.5	1.2145	0.165	7.36060606	4.17389E-07
0.6	1.225	0.155	7.90322581	3.73465E-07
Average	1.17775	0.301667	5.106494	4.11087E-07

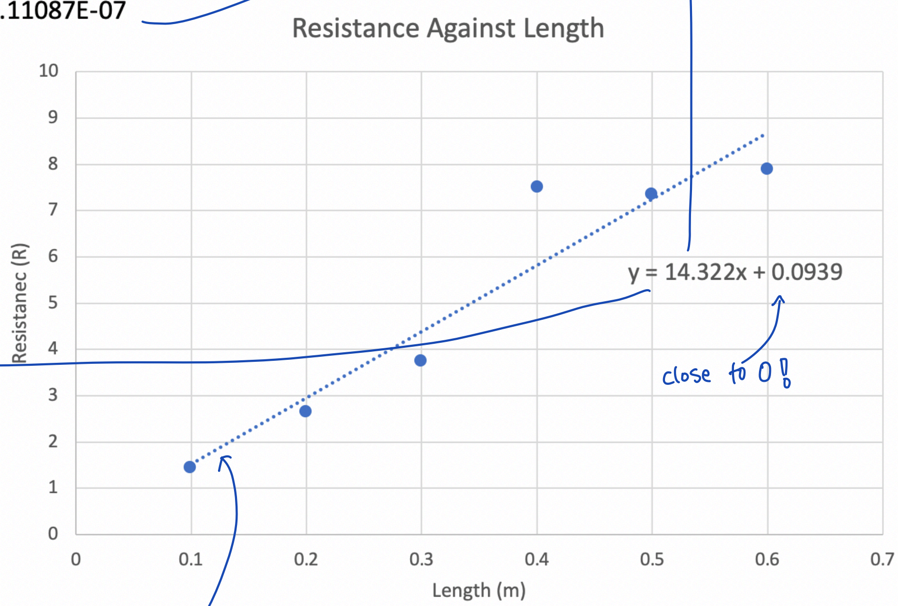
$$\text{Gradient} = \frac{\rho}{A} = \frac{4.11087 \times 10^{-7}}{0.000095^2 \pi} \approx 14.4989\ldots$$

Close enough!

Diameter of wire = 0.00019 m (Average of 3)
(0.19 mm)

Radius = 0.000095 m

Cross sectional area = $0.000095^2 \pi$ = A



close to 0!

ρ = Area × gradient
$= 0.000095^2 \pi \times 14.322$
$= 4.0607 \times 10^{-7}$
$\approx 4.1 \times 10^{-7}$

If we set intercept to (0,0), gradient = 14.538

My value:

±0.01 A (Current) $\Rightarrow \frac{0.01}{0.301667} = 3.3\%$

$3.3 + 0.085 = 3.4\%$ uncertainty (resistance)

±0.001 V (Voltage) $\Rightarrow \frac{0.001}{1.17775} = 0.085\%$

±0.001 m (Length) $\Rightarrow \frac{0.001}{0.35} = 0.29\%$ $\Rightarrow$ $3.4 + 0.29 = 3.7\%$ uncertainty (resistivity)

Researched value:

$\pm 0.1 \times 10^{-7}$ Ωm (Resistivity) $\Rightarrow \frac{0.1 \times 10^{-7}}{4.9 \times 10^{-7}} = 2.0\%$ uncertainty (resistivity)

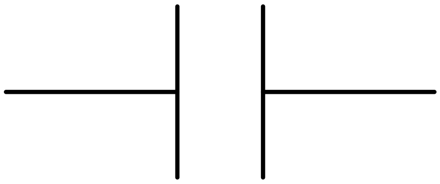
Nichrome Resistivity $= 100 \times 10^{-8}$ (according to hyperphysics on 10/11/2020)

Since resistivity is larger than constantan, % uncertainty is lower.

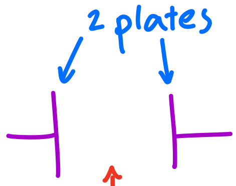
A-LEVEL CONTENT BELOW

↓

Capacitance

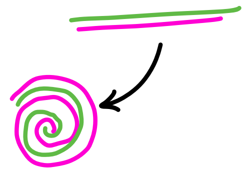


The capacitor
(NOT A CELL!)

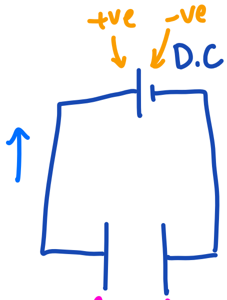


insulator/dielectric
(sometimes air, sometimes something else)
some capacitors have +ve and -ve terminals because of this material

usually rolled up into a cylindrical shape



Charging



D.C. power supply

e^- move this way

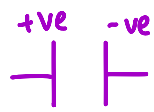
current drops when p.d. across plate = emf

e^- get repelled into +ve terminal of cell. (plate becomes +ve)

e^- stored on plate (plate becomes -ve)

e^- cannot pass through insulator

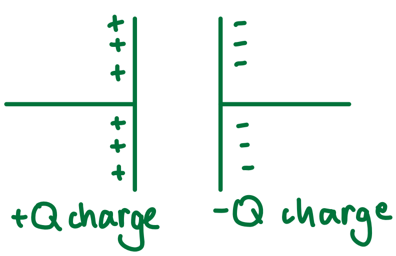
Now the capacitor has a p.d.



Exam answers: - e^- from -ve terminal of cell move onto one of the plates.

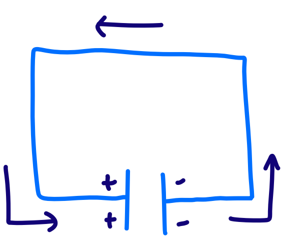
"explain how capacitors work" (≈ 4 marks)

- build up of -ve charge on one plate repels the -ve charges on the other plate.
- as the charge increases, it becomes more difficult for more e^- to move onto the plate
- current drops to 0 when p.d. across capacitor equals emf



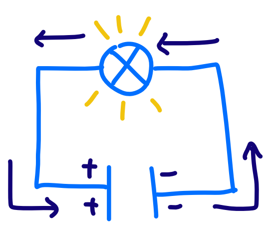
This has stored Q charge

Discharging



connect to itself

electrons flow the other way



connect to appliance

appliance turns on.

current drops when p.d. across plates becomes 0.

Capacitance, C

symbol, not unit (Coulomb is C)

Since the charge the capacitor stores depends on the voltage, capacitance is the amount of charge per volt that a capacitor can store

$$\boxed{C = \frac{Q}{V}}$$

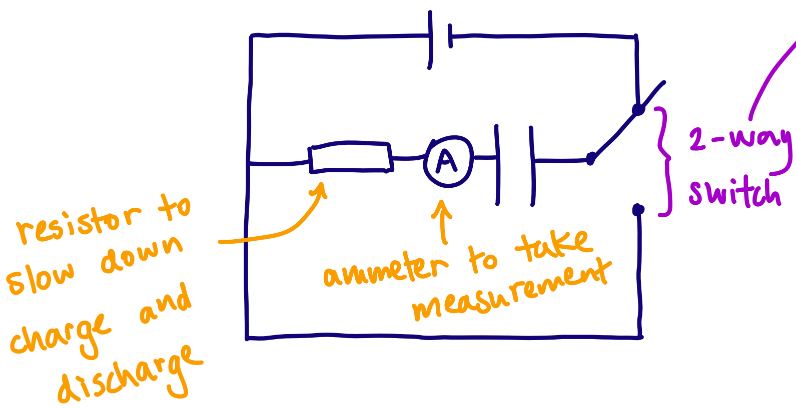
C = capacitance Q = charge V = p.d. across capacitor

or $Q = CV$

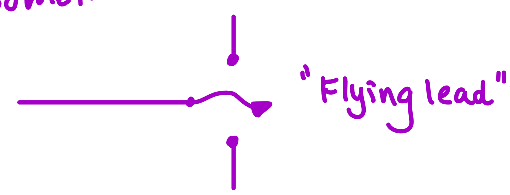
units: Farads, F $[F] = \frac{[C]}{[V]} = [CV^{-1}]$

<u>most capacitors have capacitance of μF</u>

Typical charge/discharge circuit

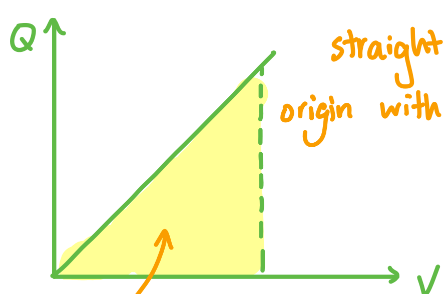


sometimes drawn like this



<u>Energy stored by capacitors</u>

$C = \frac{Q}{V}$



straight line through origin with +ve gradient (capacitance)

energy stored by capacitor $= \frac{1}{2}QV$

or

$\frac{1}{2}CV^2$

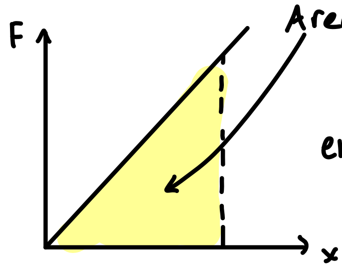
we know the capacitance!

Area = VQ = E

uncanny similarity

Sound familiar?

$F = kx$

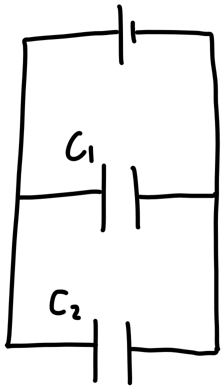


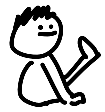
Area = Fx = Work / Energy

energy stored by spring $= \frac{1}{2}Fx$ or $\frac{1}{2}kx^2$

Combining Capacitors (making capacitors useful)

Parallel capacitors



& 

Same p.d. across C_1 & C_2 ($V_T = V_1 = V_2$)

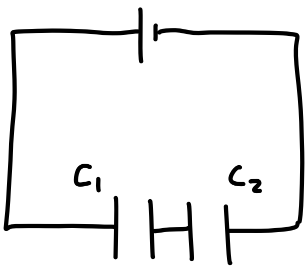
Total charge (Q_T) equals $Q_1 + Q_2$ ($Q_T = Q_1 + Q_2$)

$Q = CV$

$C_T V = C_1 V + C_2 V$

$\boxed{C_T = C_1 + C_2}$

Series Capacitors



$V_T = V_1 + V_2$

$Q_T = Q_1 = Q_2$

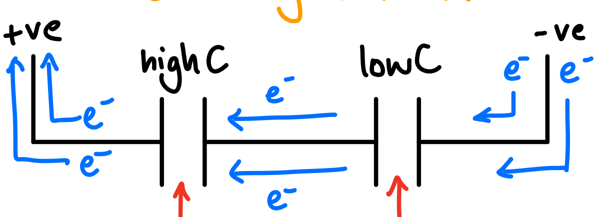
$V = \frac{Q}{C}$

$\frac{Q_T}{C_T} = \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$

$\boxed{\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}}$

opposite of resistance calculations!

But why is that?



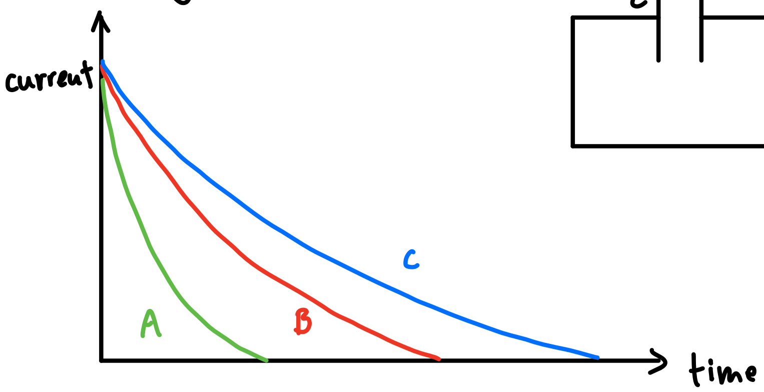
e⁻ are being repelled

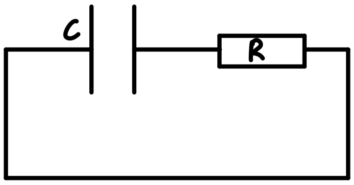
⚠ only $2e^-$ have moved through the cell

↳ total charge, Q_T, is $2e^-$, not $4e^-$

capacitors have the same charge always! even when they have different capacitance

Discharge Curves





C = 1000μF R = 100 kΩ

C = 1000μF R = 50 kΩ

C = 500μF R = 50 kΩ

Both C and R dictate rate of discharge