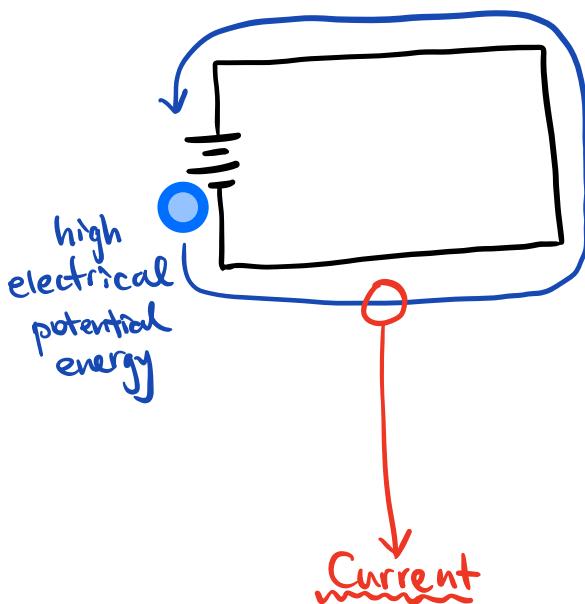


# Basics of Electricity

## the electron

mass:  $9.1 \times 10^{-31}$  kg  
charge:  $-1.6 \times 10^{-19}$

they repel each other  
(because of the charge)



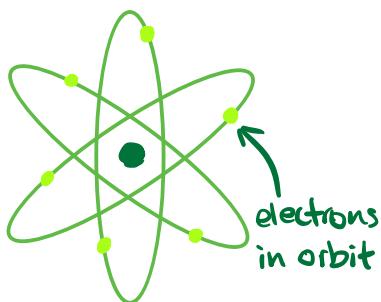
How many coulombs of charge per second?

$$\text{Current } I = \frac{Q}{t} \quad \begin{matrix} \text{charge} \\ \text{time} \end{matrix}$$

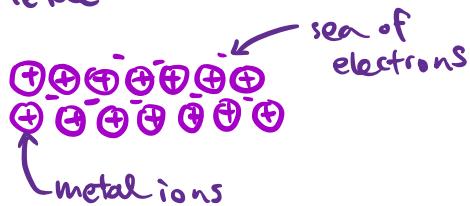
## Sidenotes

- 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)

## Normal:



## Metal:



## The Coulomb

A diagram showing a cluster of blue circles representing electrons, grouped together. An arrow points upwards from this cluster, labeled "energy of 1 coulomb of  $e^-$  is 1 volt". Below the cluster, the formula  $V = \frac{E}{Q}$  is written, with "voltage" under the "E" and "charge" under the "Q".

## Resistance

high voltage  $\Rightarrow$  high current

$$\text{Ohm's law } \left\{ \begin{matrix} \text{current } I = \frac{V}{R} \\ \text{voltage } V \\ \text{resistance } R \end{matrix} \right.$$

How easy is it for current to flow?

## CONVENTIONAL current

+ve  $\rightarrow$  -ve

even though electrons flow from -ve  $\rightarrow$  +ve

### Exercise

1. Current = 0.40A charge in 15s =  $0.40 \times 15 = 6.0 \text{ C}$

2. 150C in 30s current =  $\frac{150}{30} = 5 \text{ A}$

3. 50C in 20s current =  $\frac{50}{20} = 1.5 \text{ A}$

4. Car battery  $\Rightarrow 50 \text{ Ah}$

a)  $50 \text{ Ah} = 50 \times 60 \times 60 = 180000 \text{ C}$

Duration with 200A output =  $\frac{180000}{200} = 900 \text{ s}$

b) charge in this time = 180000C

5. # of protons for 1C of charge =  $\frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$

6. Car headlamp 16Ω, 12V battery

Current =  $\frac{12}{16} = 0.75 \text{ A}$

### More on Ohm's Law

because  $V = IR$ ,

$V \propto I$  when R is constant

6V  $\xrightarrow{3\text{A}}$

12V  $\xrightarrow{6\text{A}}$

## POWER

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

$$E = QV$$

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

Power  $P = IV$  Current  $\times$  Voltage

$$P = I(IR)$$

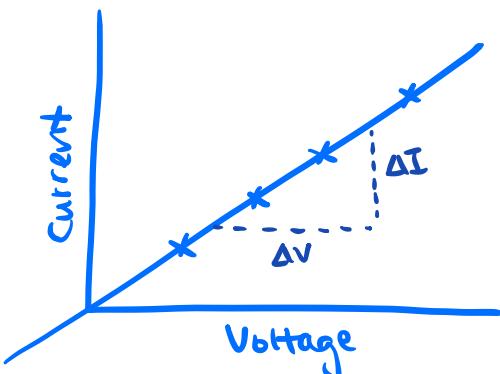
Power  $P = I^2R$  Current $^2 \times$  Resistance

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

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

# GRAPHS: CURRENT AGAINST VOLTAGE

## OHMIC CONDUCTORS

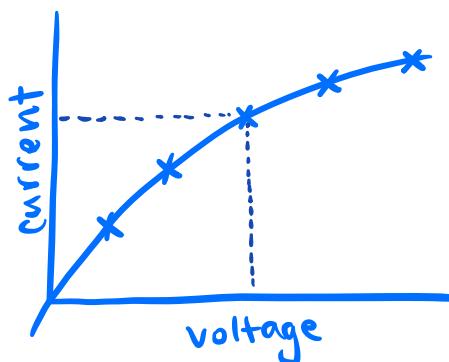


$$V = IR$$

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

$\therefore$  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

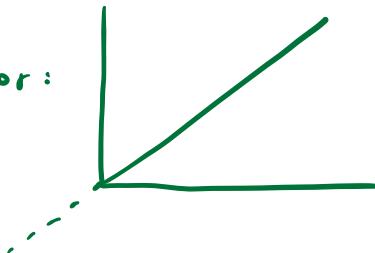
Electrical component:  $2V \rightarrow 10mA$   
 $8V \rightarrow 60mA$

$$\text{Resistance} = 200\ \Omega$$

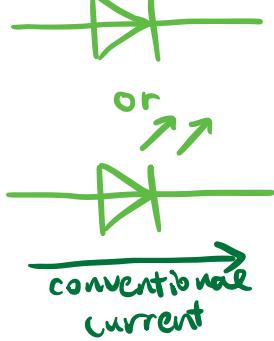
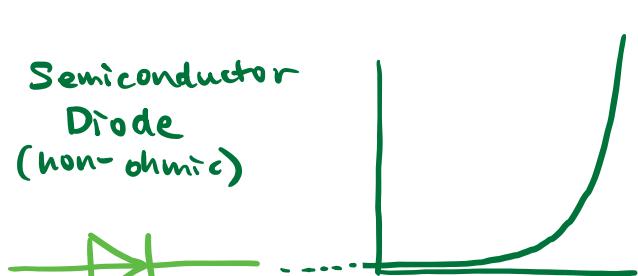
$$\text{Resistance} = 133\ \Omega$$

$\therefore$  Doesn't obey ohm's law

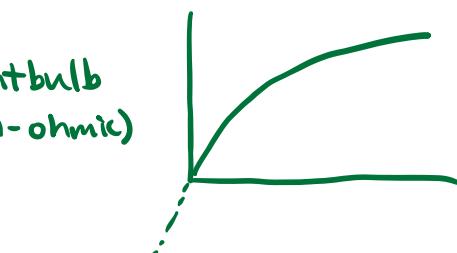
Ohmic resistor:



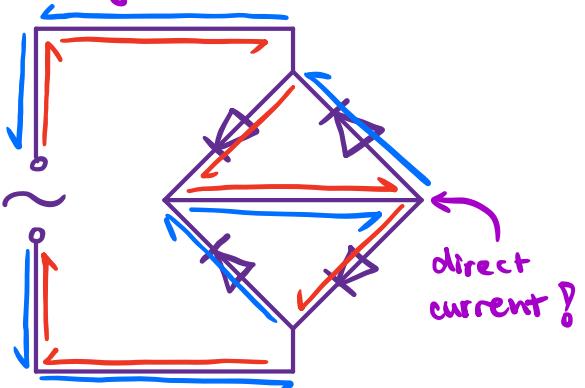
Semiconductor Diode (non-ohmic)



Lightbulb (non-ohmic)



Bridge Rectifier



# RESISTIVITY ( $\rho$ ) [ $\Omega \text{ m}$ ]

used to describe the resistance of a material

copper:  $1.69 \times 10^{-8} \Omega \text{ m}$

quartz:  $5 \times 10^{16} \Omega \text{ m}$

Length  
 $R \propto l$



Thickness (Cross sectional area)  
 $R \propto \frac{l}{A}$



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

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

<u>1 <math>\Omega</math></u> $R = \frac{\rho l}{A}$ $1 = \frac{44 \times 10^{-8} \times l}{(0.00025)^2 \pi}$ $l = \frac{(0.00025)^2 \pi}{44 \times 10^{-8}} = 0.45 \text{ m}$	<u>5 <math>\Omega</math></u> $0.45 \times 5 = 2.2 \text{ m}$
<u>10 <math>\Omega</math></u> $0.45 \times 10 = 4.5 \text{ m}$	

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

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

$$V = Al$$

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

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

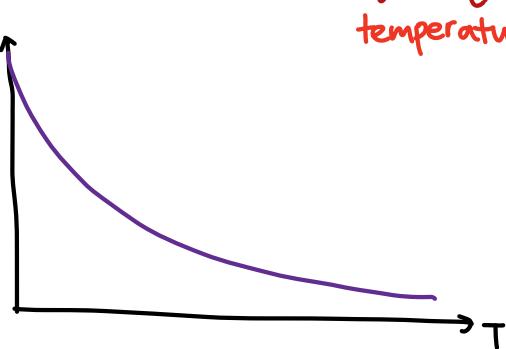
# Temperature

In general: When temp  $\uparrow$ , resistance  $\uparrow$

NTC Thermistor: When temp, resistance  $\downarrow$

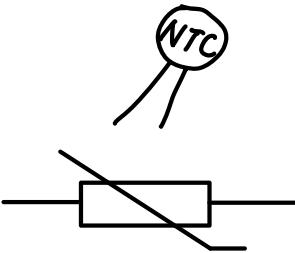
negative temperature coefficient

NTC Thermistor:



Typically used for:

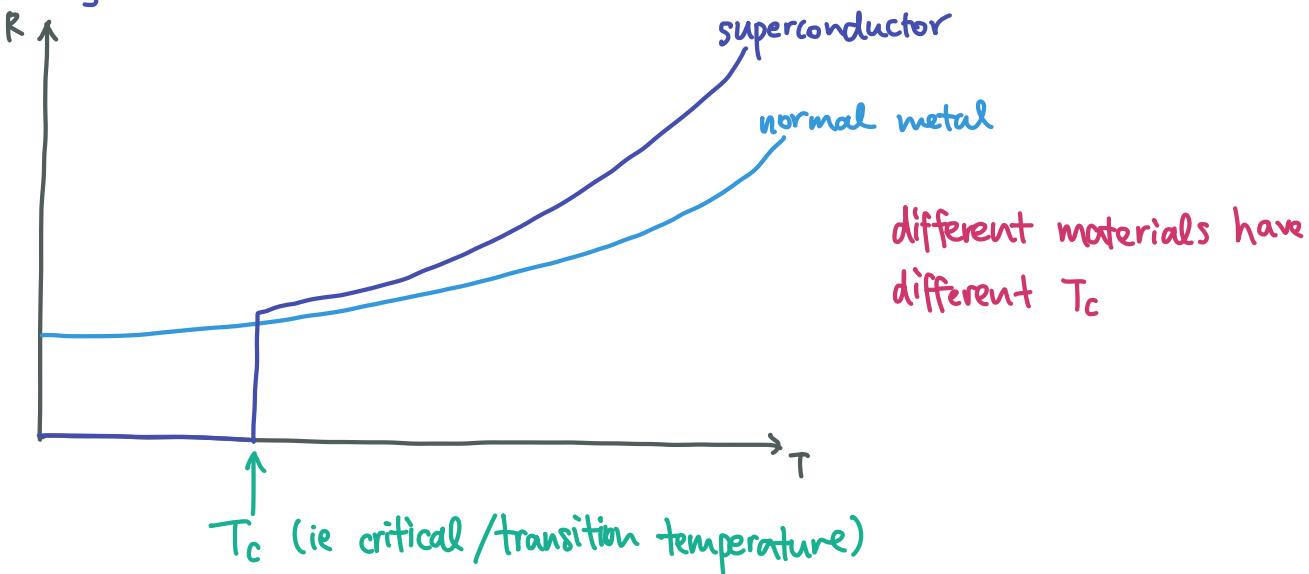
temperature sensors such as fire sensors.



# Superconductors

When metals are cooled, their resistance decreases.

Mercury: resistance drops to 0 at 4.1K



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

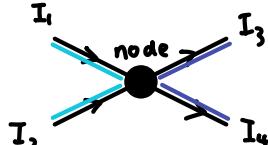
# Circuits

## Kirchoff's Current / First Law

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

sum of current in = sum of current out

Result of conservation of charge



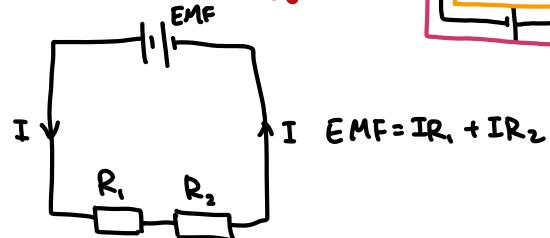
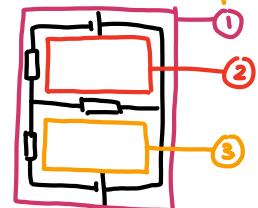
$$I_1 + I_2 = I_3 + I_4$$

## Kirchoff's Voltage / Second Law

$$\begin{aligned} \sum \text{EMF} &= \sum \text{PD} \\ \sum \text{EMF} &= \sum \text{IR} \end{aligned} \quad (\text{In a loop})$$

Sum of emf = sum of p.d.  
or

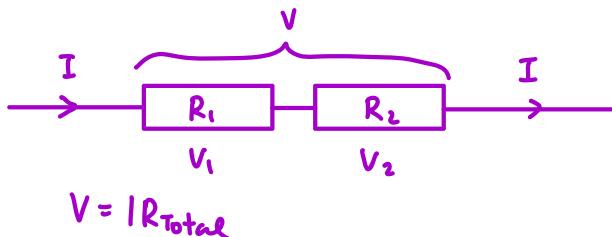
energy in = energy out



$$\text{EMF} = \text{IR}_1 + \text{IR}_2$$

Using these laws to derive  
expressions for combined resistance:

### SERIES

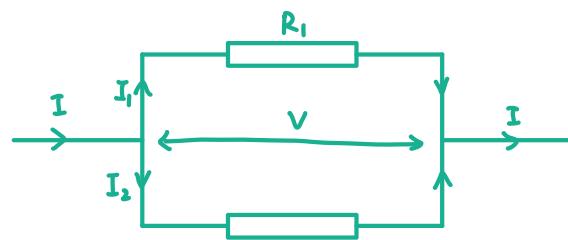


$$V = IR_{\text{Total}}$$

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

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

### PARALLEL

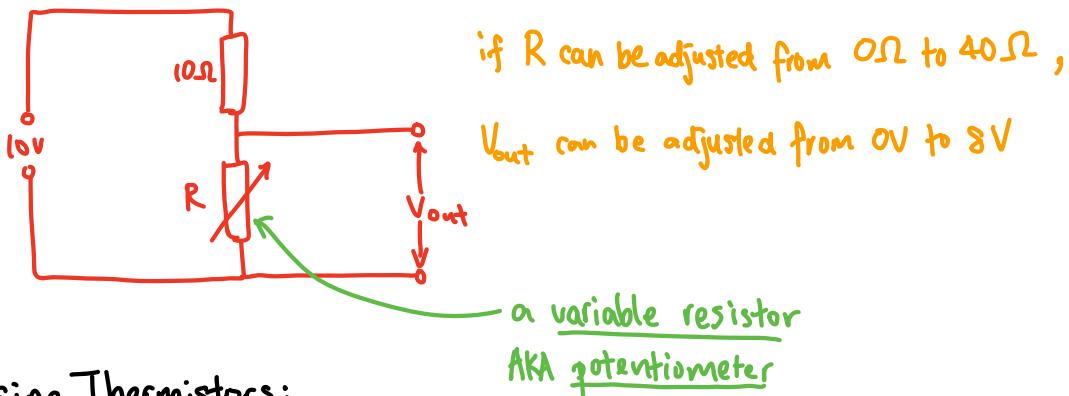
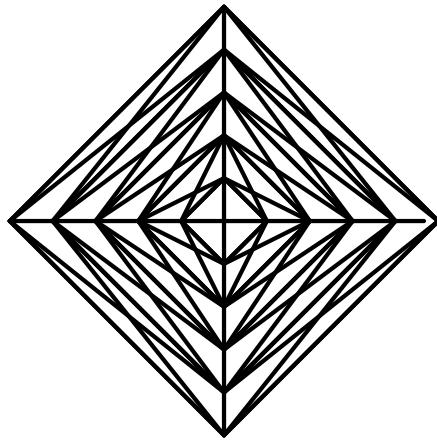
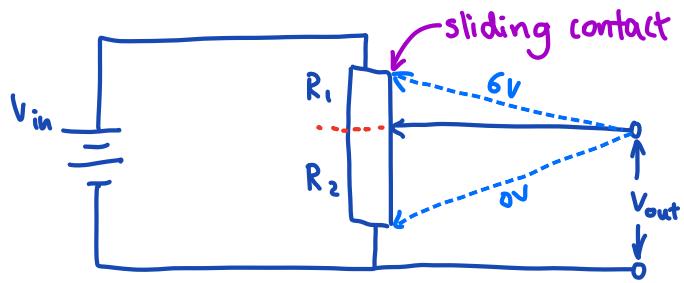


$$I_{1,2} = \frac{V}{R_{1,2}} \quad I = \frac{V}{R_{\text{Total}}} \quad I_1 + I_2 = I_3$$

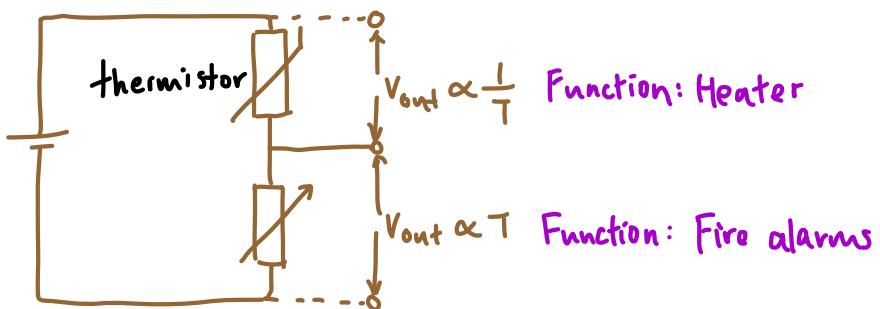
$$\frac{V}{R_1} + \frac{V}{R_2} = \frac{V}{R_{\text{Total}}} , \quad \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{R_{\text{Total}}}$$

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

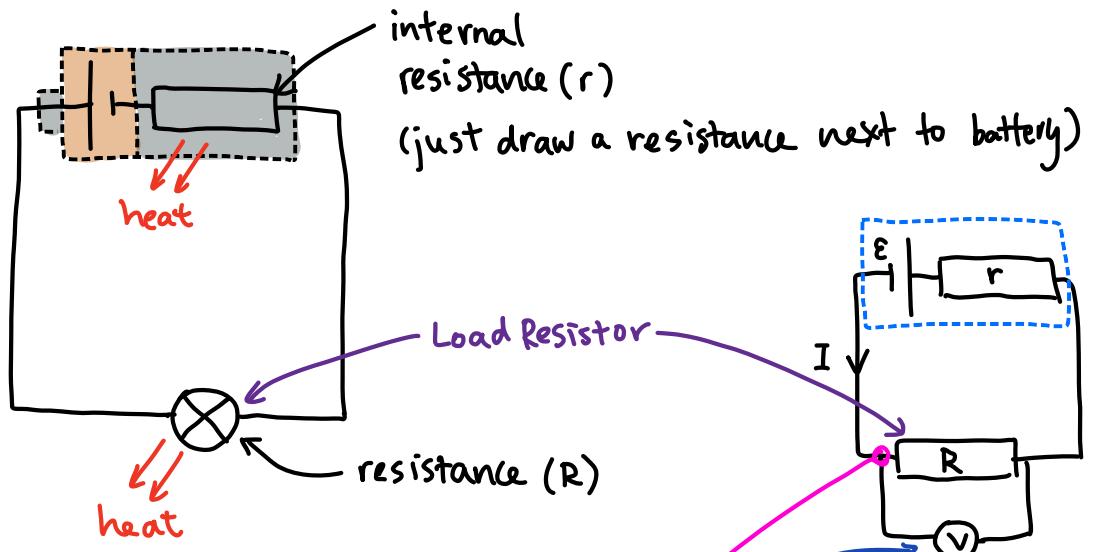
# Potential Dividers



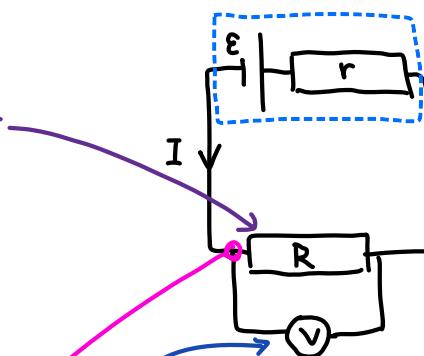
Using Thermistors:



# Internal Resistance



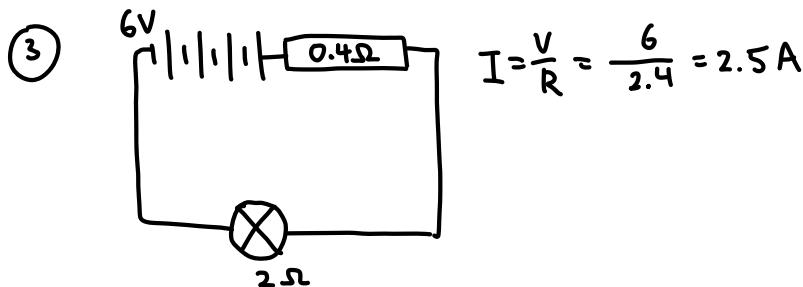
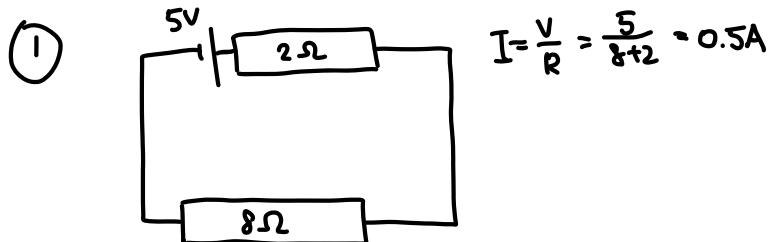
If we want accurate terminal PD,



$$E = \sum pd = Ir + IR$$

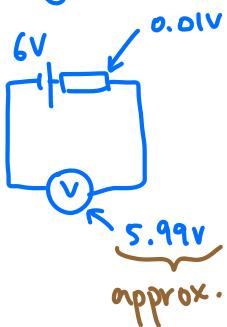
$$\text{or } E = V + Ir$$

terminal PD

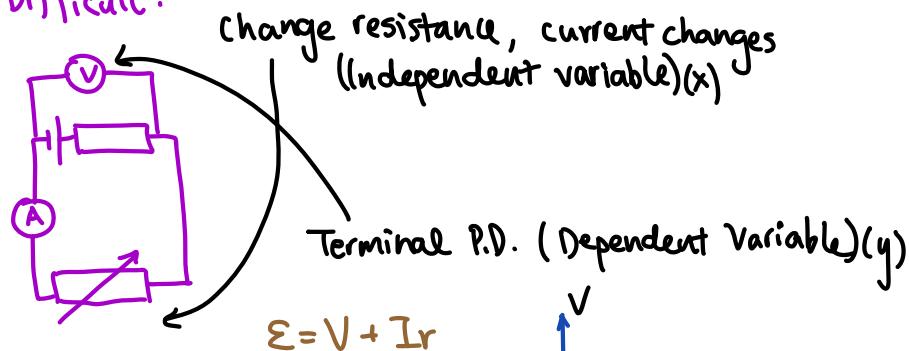


Measure EMF of power supply:

Easy:



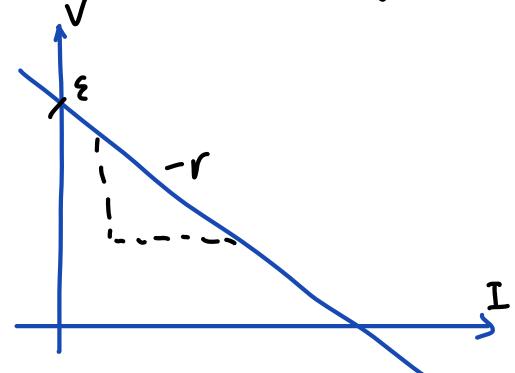
Difficult:



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

$$\Sigma = V + Ir$$

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

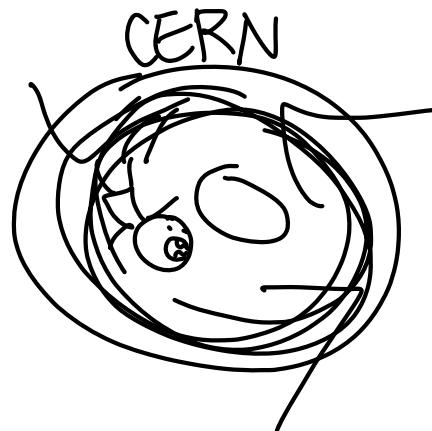


$$\Sigma = V + Ir$$

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

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

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



# Experiment – Resistivity of Constantan

material of wire  
(copper-nickel alloy)

## 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

- What does each letter in the equation represent?

$\rho$  = resistivity

$R$  = resistivity

$A$  = cross sectional area of wire

$l$  = wire length

- What is the unit for resistivity?

$\Omega \text{ m}$

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

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

- What is the definition of resistance?

Voltage/current

- How could you measure the resistance of a component?

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

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

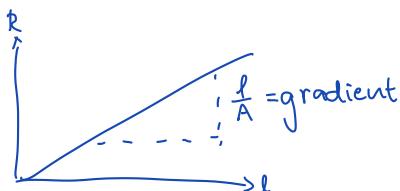
Justify your prediction.

Straight line with positive gradient & goes through origin

Read the instructions through carefully before you begin.

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

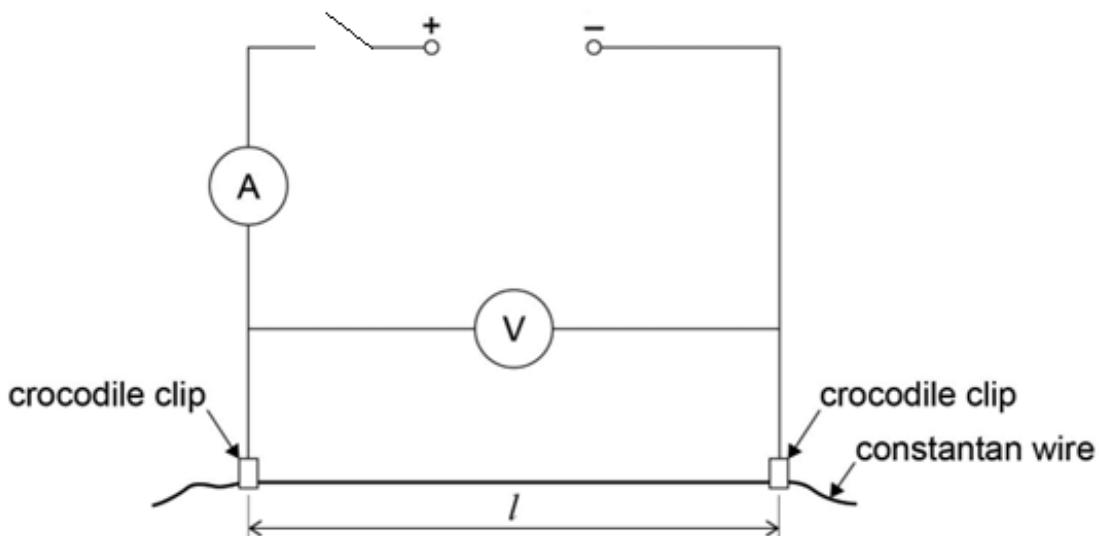
$$R = \frac{l}{A}$$
$$y = mx + c$$



## 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  $l = 0.300\text{m}$  measured on the meter ruler.
4. **Make sure the ammeter is set to 10A scale.**
5. Close the switch and take the readings of  $\text{pd}$ ,  $V$ , 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: Constantan →  $4.9 \times 10^{-8}$  ie  $4.9 \times 10^7$  (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	$4.11965 \times 10^{-7}$
0.2	1.035	0.39	2.65384615	$3.76221 \times 10^{-7}$
0.3	1.127	0.3	3.75666667	$3.55041 \times 10^{-7}$
0.4	1.615	0.215	7.51162791	$5.32441 \times 10^{-7}$
0.5	1.2145	0.165	7.36060606	$4.17389 \times 10^{-7}$
0.6	1.225	0.155	7.90322581	$3.73465 \times 10^{-7}$
Average	1.17775	0.301667	5.106494	$4.11087 \times 10^{-7}$

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

Radius =  $0.000095$  m

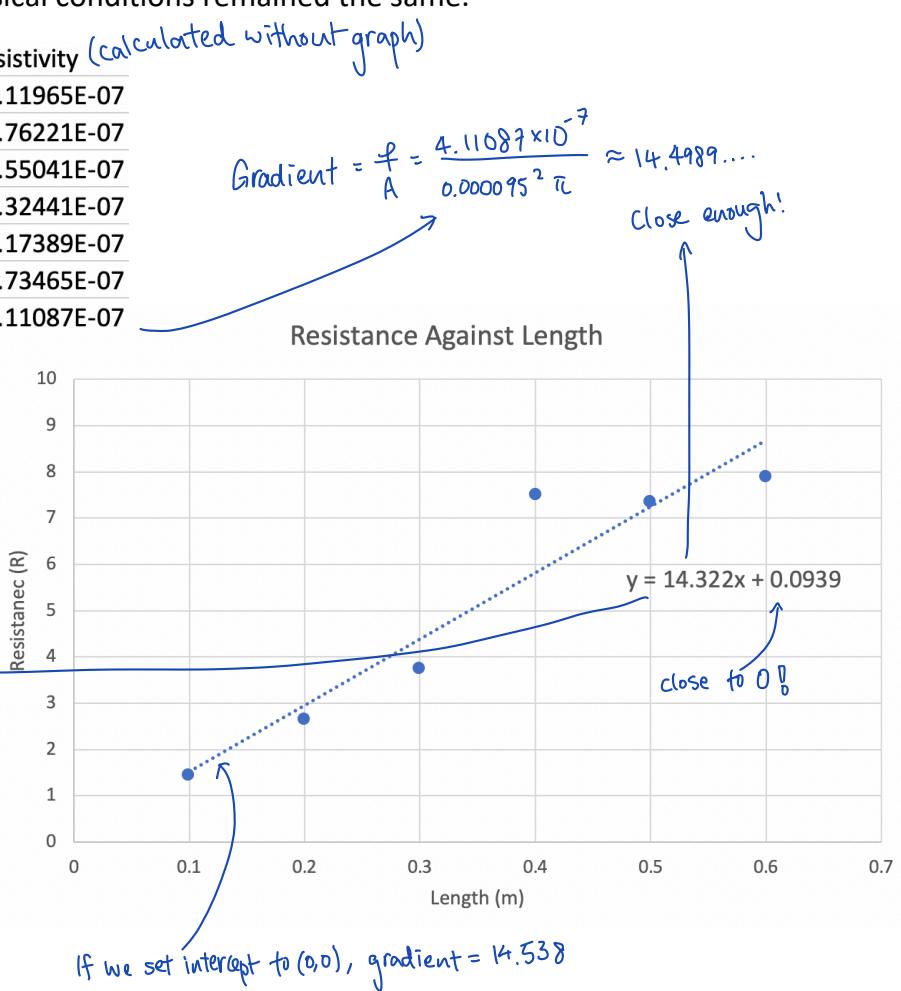
Cross sectional area =  $0.000095^2 \pi = A$

$$\rho = \text{Area} \times \text{gradient}$$

$$= 6.000095^2 \pi \times 14.322$$

$$= 4.0607 \times 10^{-7}$$

$$\approx 4.1 \times 10^{-7}$$



My value:

$$\pm 0.01 \text{ A (Current)} \Rightarrow \frac{0.01}{0.301667} = 3.3\% \Rightarrow 3.3 + 0.085 = 3.4\% \text{ uncertainty (resistance)}$$

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

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

Researched value:

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

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

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