# Electricity

2015 EdExcel A-Level Physics

*Topic 3*

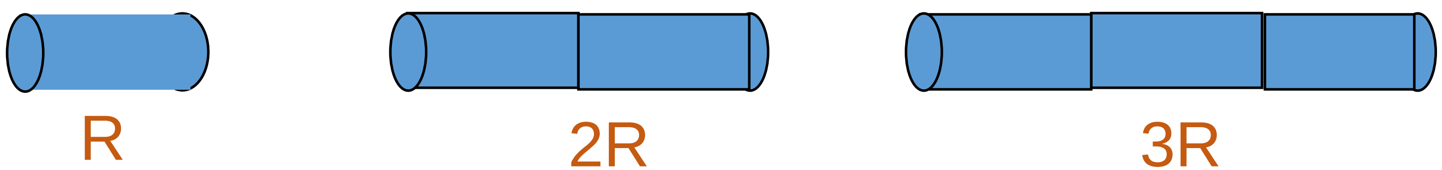
## Resistivity and I=nAqv

Physics Tutor Online

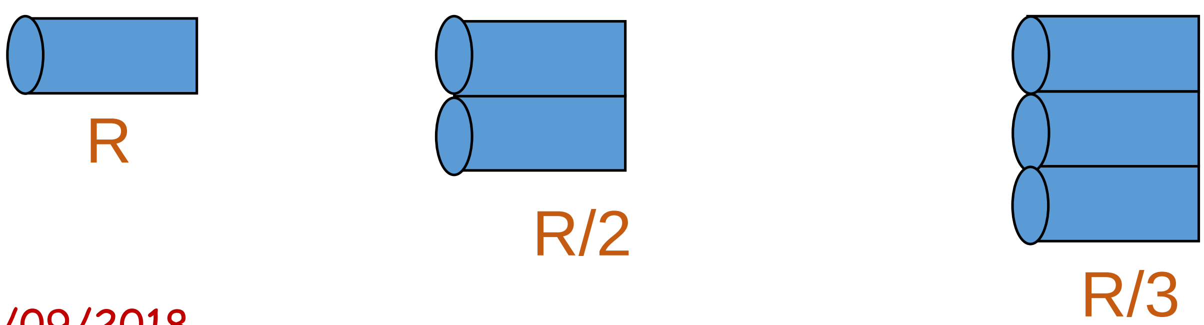
# Factors affecting the resistance of a wire

The resistance of a wire depends on 3 things: the length of the wire, the width of the wire and what the wire is made of:

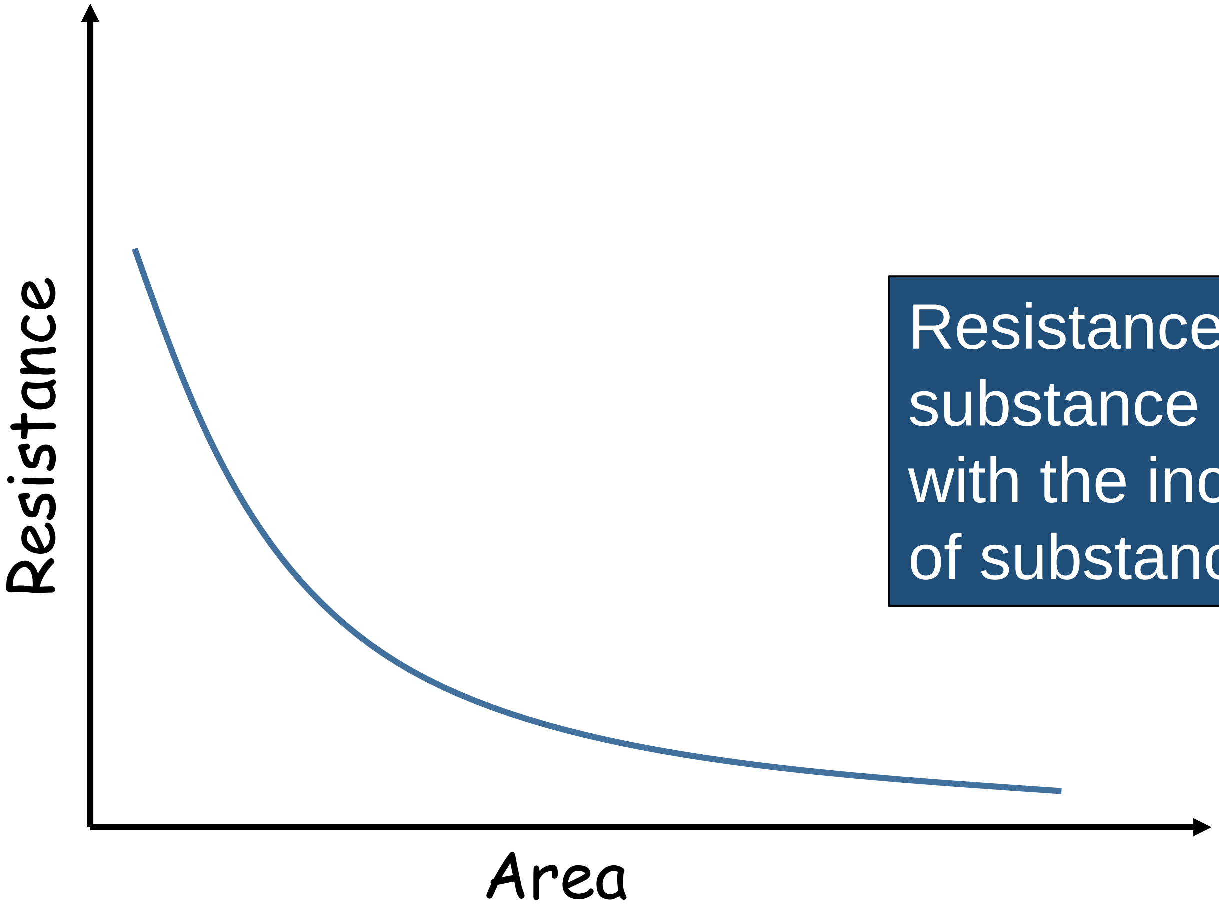
1) Length – Resistance is proportional to length




2) Area – Resistance is inversely proportional to area

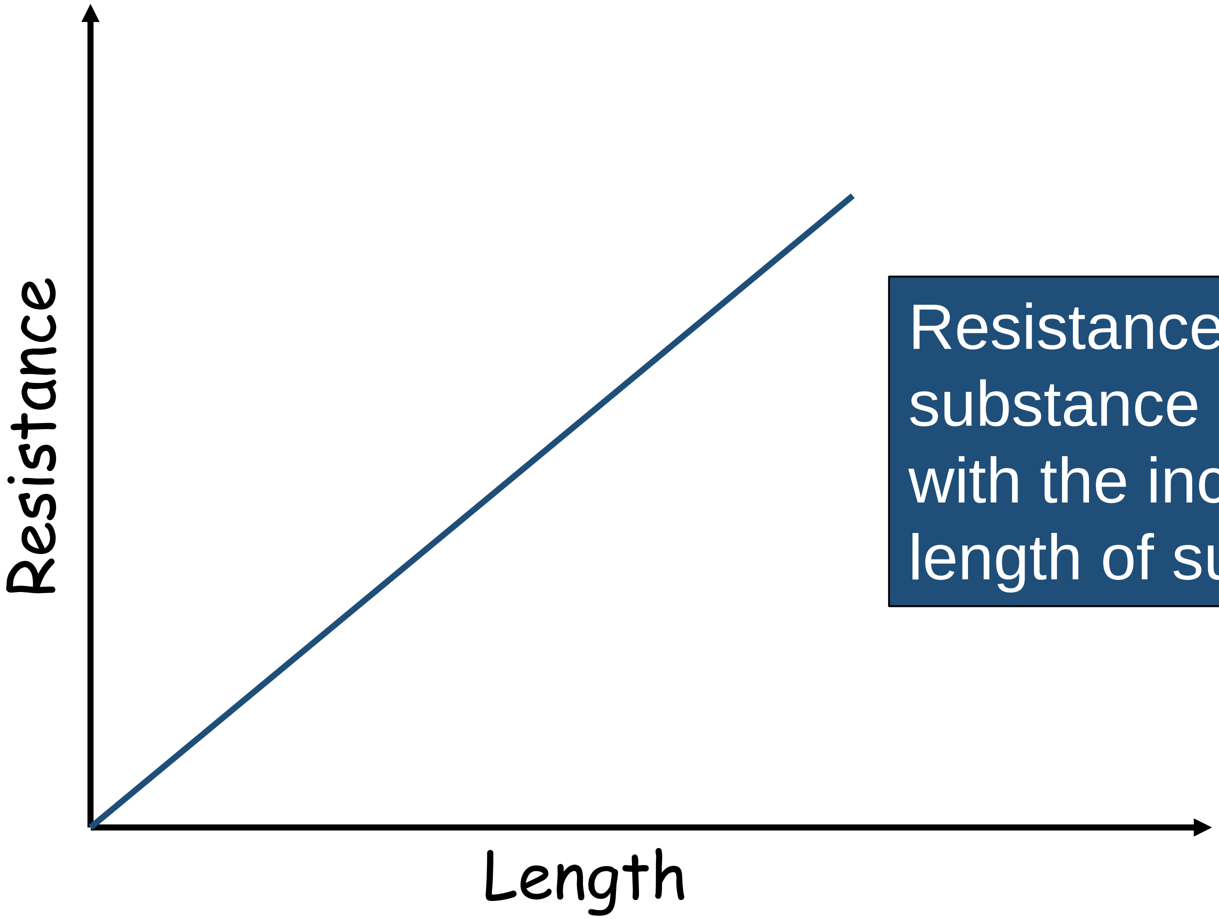


# Resistance vs area graph




Resistance of a substance decreases with the increase in area of substance.

# Resistance vs length graph




Resistance of a substance increases with the increase in length of substance.

# Resistivity

The resistance of a wire depends on 3 things: the length of the wire, the width of the wire and what the wire is made of:

$$\text{Resistance} = \frac{\text{resistivity} \times \text{length}}{\text{area}} \qquad R = \frac{\rho L}{A}$$

Units of resistivity:

$$\rho = \frac{R\,A}{L}$$

$$= \frac{\Omega \times m^2}{m}$$

$$= \Omega m$$

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# Resistivity

The resistance of a wire depends on 3 things: the length of the wire, the width of the wire and what the wire is made of:

$$\text{Resistance} = \frac{\text{resistivity x length}}{\text{area}} \qquad R = \frac{\rho L}{A}$$

Calculate the following:

1) The resistance of a wire of length 150cm, area 3.0mm$^2$ and resistivity 1.7x10$^{-8}$ Ωm

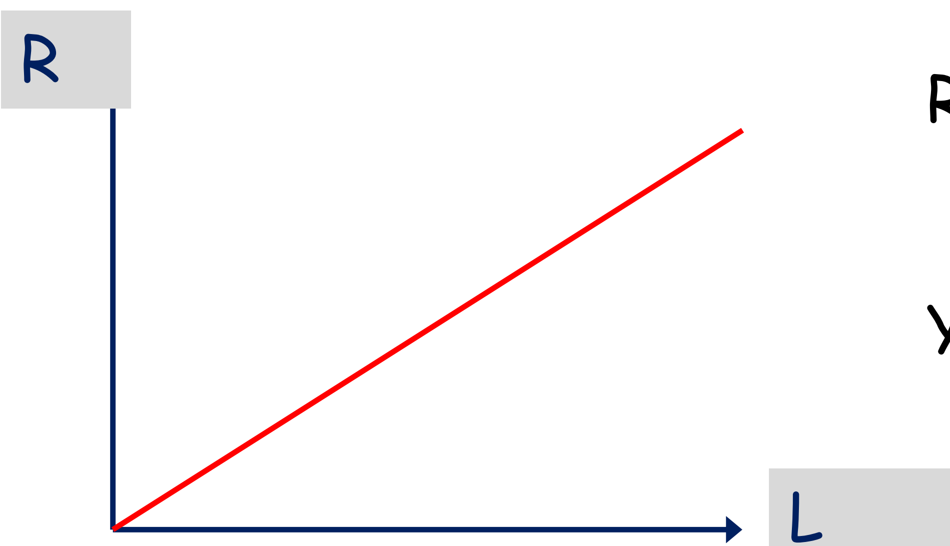
2) The length of an iron wire of resistance 80 Ohm, area 4mm$^2$ and resistivity 1x10$^{-7}$ Ωm

3) A wire has a resistance of 6Ω. If the wire is 15m long and area 6mm$^2$ what is the resistivity of the wire?

# Core Practical 2: Determining Resistivity

| Length/m | Resistance/Ω |
|---|---|
| | |

| Diameter of wire/m | |
|---|---|
| 1 | |
| 2 | |
| 3 | |
| Ave | |



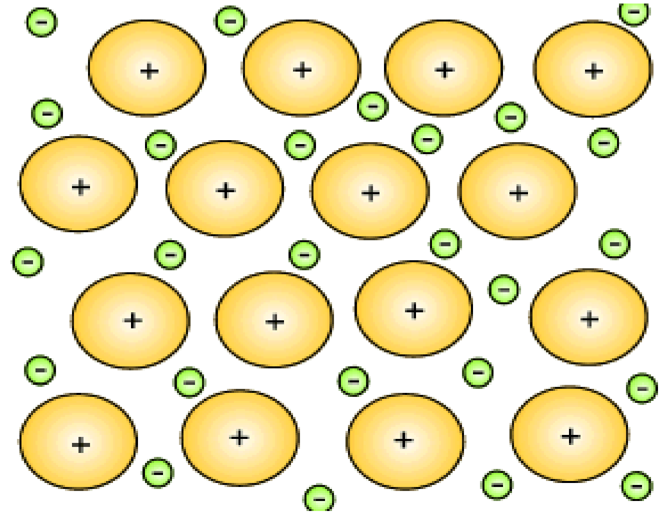

$$R = \frac{\rho L}{A}$$

$$y = mx + c$$

$$\text{gradient} = \frac{\rho}{A}$$

# Inside a metal

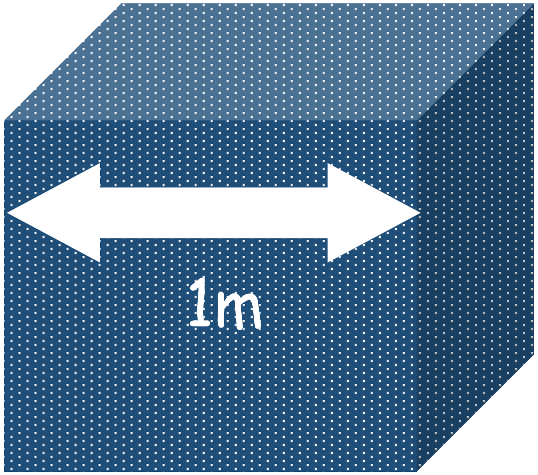
Inside a metal there is a 'sea of electrons' free to move through the material. Their movement is hindered by collisions with the ions in the lattice structure




At normal temperatures, with no current flowing, electrons hurtle around continuously.  They collide with ions but because their movement is random there is no net energy transfer. Their average positions do not change.

# Carrier Density

*Consider a cube of a metal sides 1m:*




*The "charge carrier density" (n) is the number of free electrons within the metre cube*

The charge carrier density can be calculated from the atomic radius of the metal atom.

The diameter of a copper atom is about 0.25nm, so there are $(1m/0.25nm)^3$ atoms in 1 $m^3$ = 6.4 x $10^{28}$

If each atom has 1 free electron, then n= 6.4 x $10^{28}$ $m^{-3}$

# Example

Calculate how much free charge is contained within 1 cubic metre of copper ($n = 6.4 \times 10^{28}$ and each electron has a charge of $1.6 \times 10^{-19}$C)

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Solution:

Charge carrier density = $n = 6.4 \times 10^{28}$

Charge of electron = $1.6 \times 10^{-19}C$

Total free charge = $6.4 \times 10^{28} \times 1.6 \times 10^{-19}C$

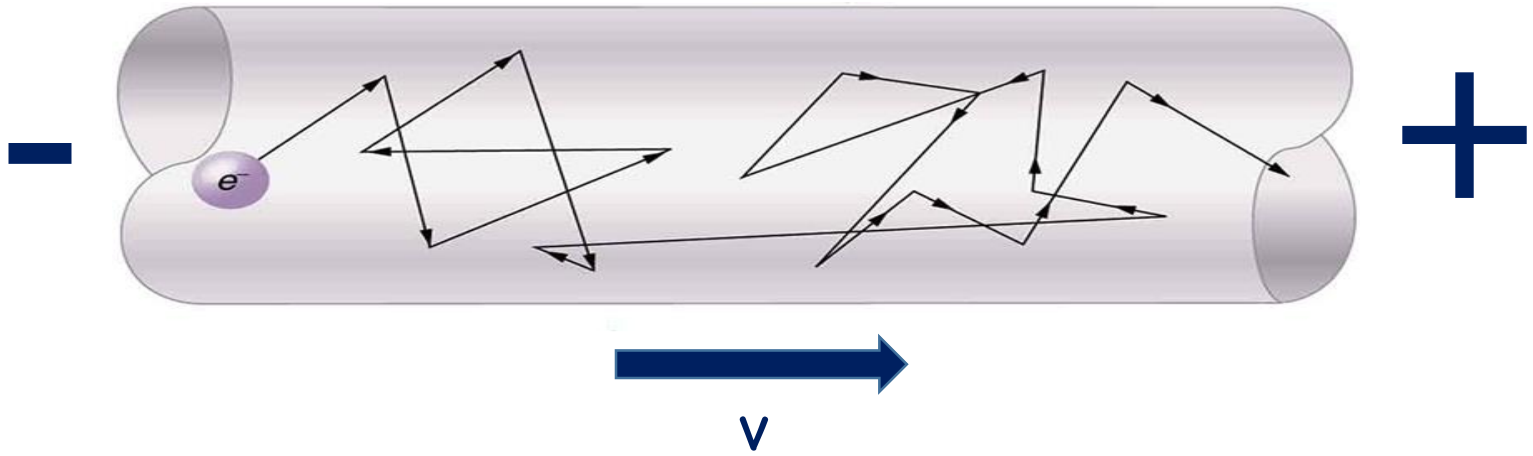
$= 1.024 \times 10^{10}C$

# Practice questions

1) If $n = 4 \times 10^9$ and each electron has a charge of $1.6 \times 10^{-19}$C how much free charge is in the cubic metre?
2) How much free charge would be in $1mm^3$ instead?
3) Calculate the carrier density for a cubic metre of another atom with diameter 0.5nm. Assume each atom has one free electron again.

# Drift velocity

When a current is flowing, the power source provides an EMF which will tend to push the electrons towards to + side of the electric field.



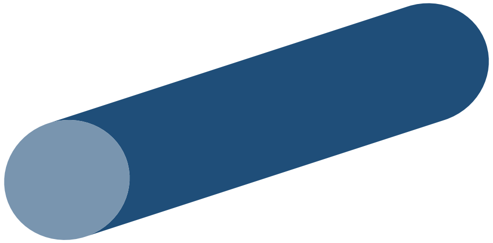

The drift velocity, v,  is the average velocity that the electrons gain in a material due to an electric field.

# The transport equation

Definition: The drift velocity, v, is the average velocity that the electrons gain in a material due to an electric field.

Consider a wire of cross sectional area A and charge carrier density n, where each carrier has the charge q and they are moving with a drift speed of v.

How can we calculate the electric current from this?



1) Every second the volume of charge carriers that pass a point will be Av
2) Therefore the number of charge carriers that pass by every second is given by nAv
3) Therefore the charge that passes by every second will be nAvq
4) But charge per second IS current, so…

$$I = nAqv$$

# Example

Calculate the current down a $0.1mm^2$ wire where the drift speed is $2mms^{-1}$ and the carrier density is $6.4 \times 10^{28}m^{-3}$ (remember that the charge on an electron is $1.6 \times 10^{-19}C$)

# Example

Calculate the current down a 0.1mm$^2$ wire where the drift speed is 2mms$^{-1}$ and the carrier density is 6.4 x 10$^{28}$m$^{-3}$ (remember that the charge on an electron is 1.6 x 10$^{-19}$C)

Solution:

$A = 0.1mm^2$; $v = 2mms^{-1}$

$n = 6.4 \times 10^{28}m^{-3}$; $q = 1.6 \times 10^{-19}C$

$I = ?$

According to drift speed equation

$$I = nAqv$$

$$I = 6.4 \times 10^{28} \times 1 \times 10^{-7} \times 1.6 \times 10^{-19} \times 2 \times 10^{-3}$$

$$I = 2.048A$$

# Practice questions

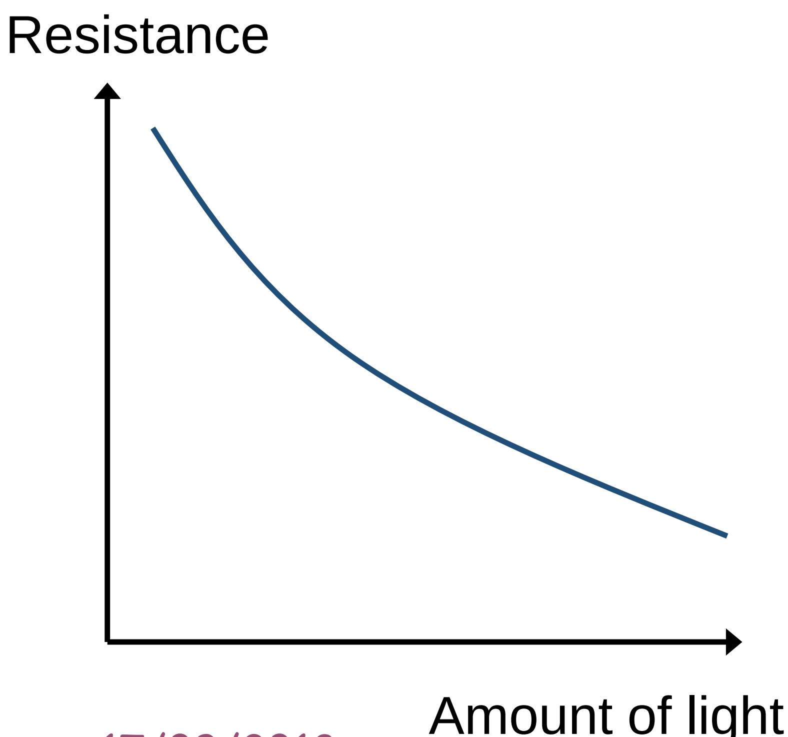
1) Calculate the carrier density down a 1.4mm$^2$ wire where the drift speed is 1.2mms$^{-1}$ and the current is 1.2A.(remember that the charge on an electron is 1.6 x 10$^{-19}$C)

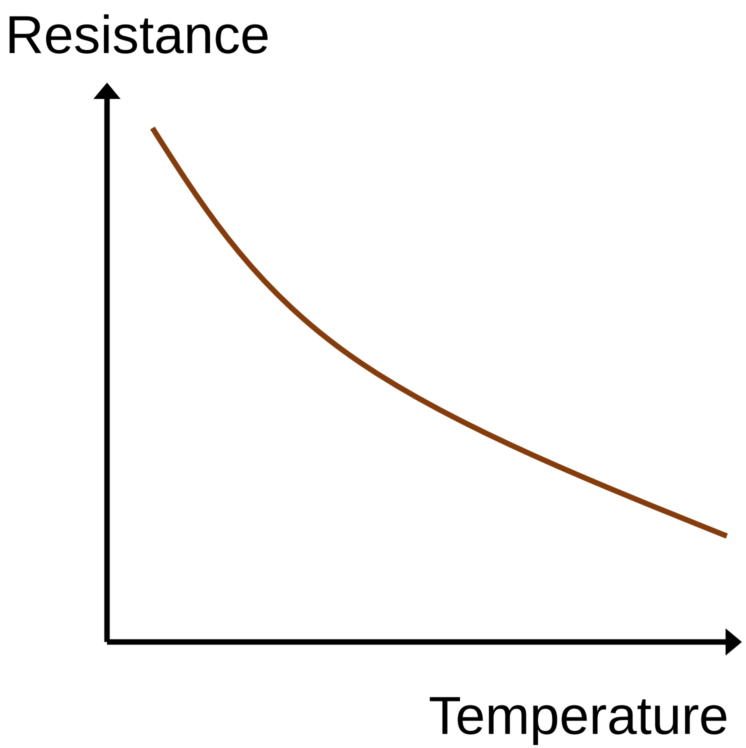
2) Calculate the area of wire with drift speed 1.5mms$^{-1}$ wire which has a current of 0.6A passing through it and a carrier density of 6.4 x 10$^{28}$m$^{-3}$.

# Thermistors and LDRs:

1. Light dependant resistor – resistance DECREASES when light intensity INCREASES

2. Thermistor – resistance DECREASES when temperature INCREASES



# Understanding Current

*Recall the equation:*

$$I = n A q v$$

Increasing the temperature of a metal will increase the _____________ of the ions.  This will increase the _________ of the metal and decrease the current because it lowers the _____ ______.

In a thermistor, the carrier density is small but __________ with temperature. Increasing the temperature of the thermistor lowers the ________ and _____________ the current

**Words** – thermistor, resistivity, vibrations, drift speed, increases