Module 4 Electrons, Waves & Photons

Unit 2 Energy, Power & Resistance

4.2 Energy, power and resistance

This section provides knowledge and understanding of electrical symbols, electromotive force, potential difference, resistivity and power. The scientific vocabulary developed here is a prerequisite for understanding electrical circuits in 4.3.

There is a desire to use energy saving devices, such as LED lamps, in homes. Learners have the opportunity to understand the link between environmental damage from power stations and the impetus to use energy saving devices in the home (HSW10) and how customers can make informed decisions when buying domestic appliances (HSW12).

There are many opportunities for learners to use spreadsheets in the analysis and presentation of data (HSW3), to carry out practical activities to understand concepts (HSW4) and to analyse data to find relationships between physical quantities (HSW5).

Module 2 – Foundations of physics

- 2.1 Physical quantities and units
- 2.2 Making measurements and analysing data
- 2.3 Nature of quantities

Module 3 – Forces and motion

- 3.1 Motion
- 3.2 Forces in action
- 3.3 Work, energy and power
- 3.4 Materials
- 3.5 Newton's laws of motion and momentum

Module 4 – Electrons, waves and photons

- 4.1 Charge and current
- 4.2 Energy, power and resistance ← **You are here!**
- 4.3 Electrical circuits
- 4.4 Waves
- 4.5 Quantum physics

4.2 Energy, Power & Resistance

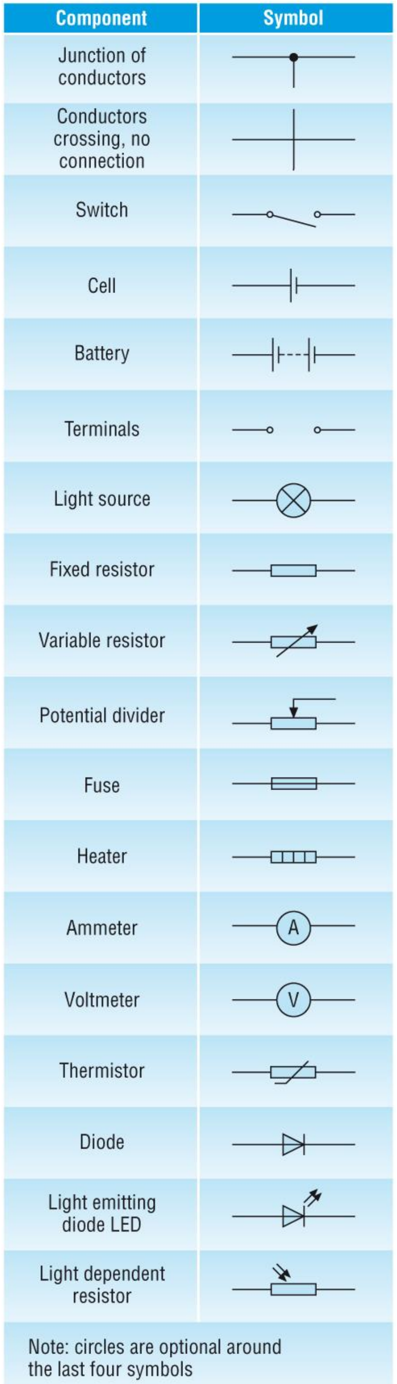
- 4.2.1 Circuit Symbols
- 4.2.2 EMF and PD
- 4.2.3 Resistance
- 4.2.4 Resistivity
- 4.2.5 Power

4.2.1 Circuit Symbols

4.2.1 Circuit symbols

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	circuit symbols
(b)	circuit diagrams using these symbols.

What circuit symbols do we need to know?



Circuit Symbols

- You do need to know these symbols.
- Produce a series of flashcards with a symbol on one side and the description on the other.
  - Then test a friend (if you have one).

How do we draw circuits?

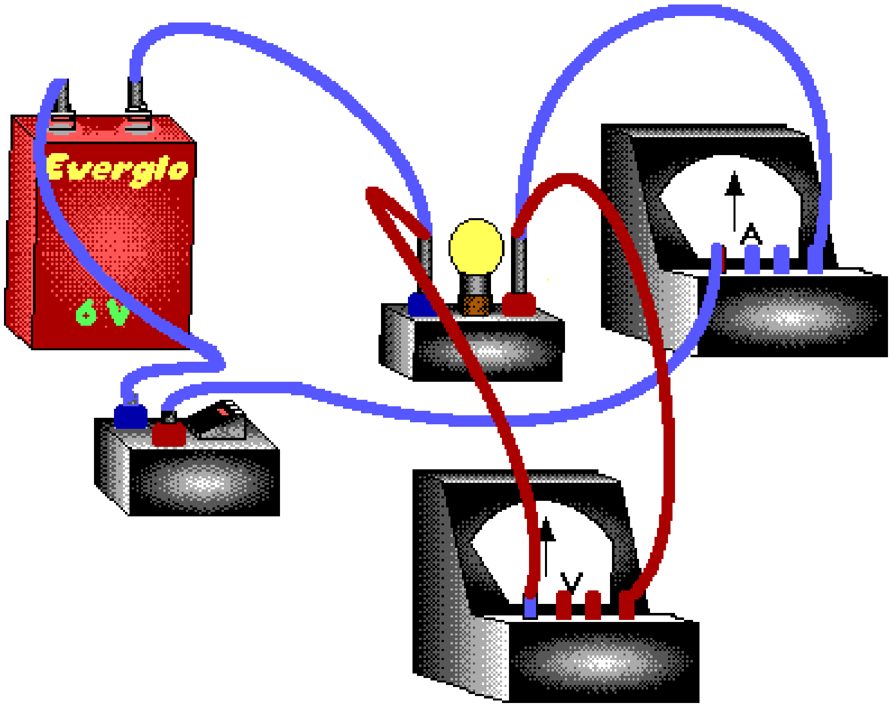
Draw a circuit…

- Which uses a 6v battery to light a lamp when a switch is pressed.

- Give yourself a point if:
  - You used only the symbols given on the previous slide in the correct place.
  - There are no gaps between any of the wires.
  - Only straight lines a used to represent wires.
  - It is correctly wired.

Draw a circuit…

- Which shows the following setup:



- Give yourself a point if:
  - You used only the symbols given on the previous slide in the correct place.
  - There are no gaps between any of the wires.
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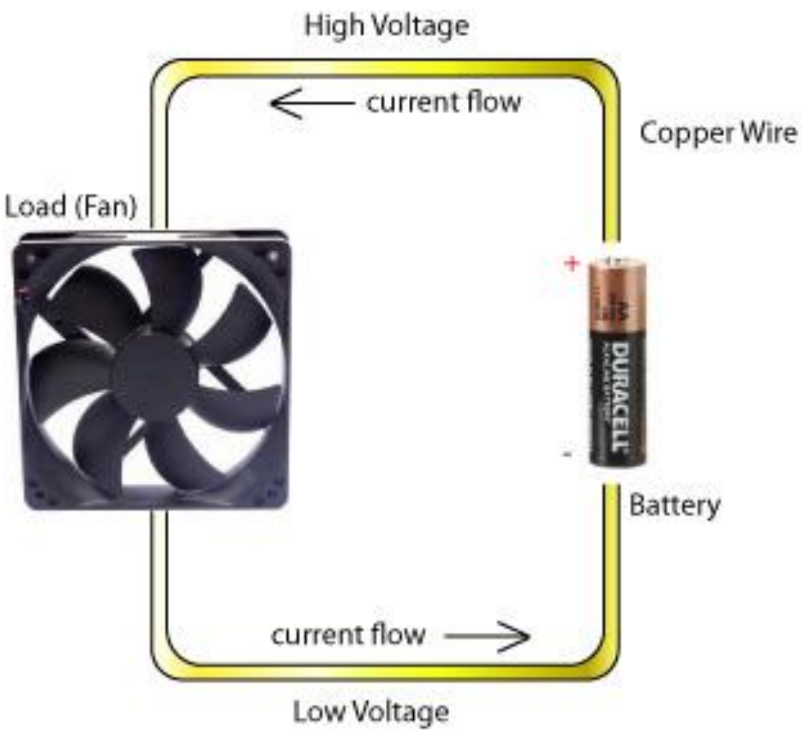
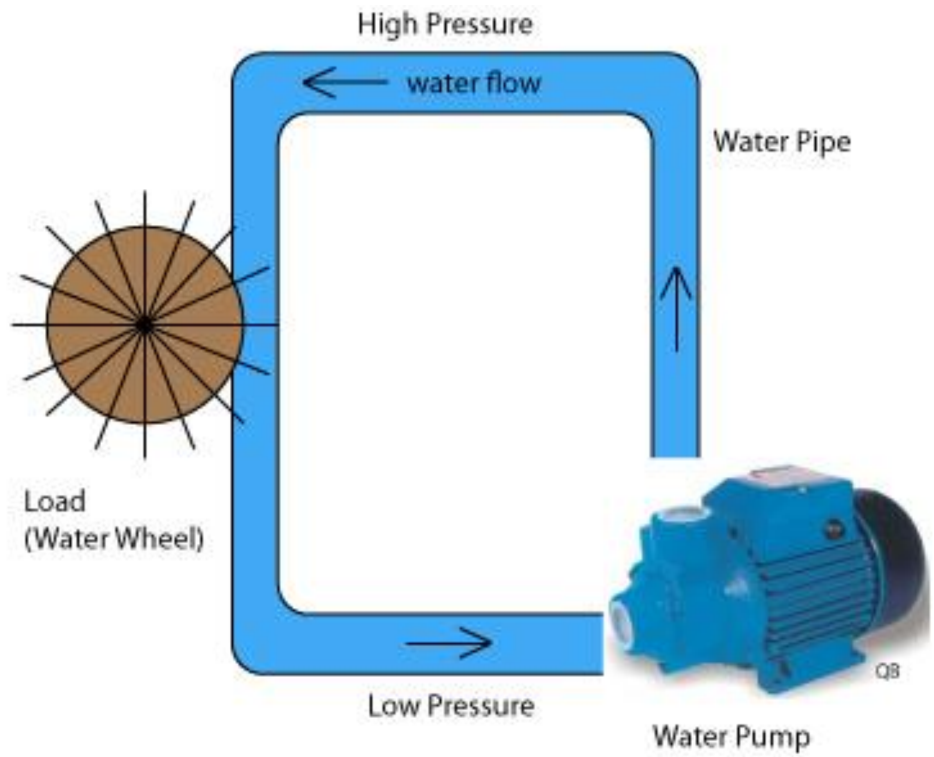
Models of Current





4.2.1 Circuit Symbols (review)

4.2.1 Circuit symbols

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	circuit symbols
(b)	circuit diagrams using these symbols.

4.2.2 EMF and PD

4.2.2 E.m.f. and p.d

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) potential difference (p.d.); the unit volt

(b) electromotive force (e.m.f.) of a source such as a cell or a power supply

(c) distinction between e.m.f. and p.d. in terms of energy transfer

(d) energy transfer; $W = VQ$; $W = \mathcal{E}Q$.

(e) energy transfer $eV = \frac{1}{2}mv^2$ for electrons and other charged particles.

What's the difference between emf and pd?

Electromotive Force, ε

- Electromotive force is the amount of energy which is transferred per unit of charge, when one other type of energy is converted to electrical energy.
  - Eg chemical energy in a cell converted to electrical energy
  - Imagine lifting the water to the top of a waterfall in order that it can fall down.

emf = electrical energy transferred, J / charge, C

- The unit of emf is JC^{-1}
- The SI unit for JC^{-1} is the Volt, V.

- So, $1V = 1JC^{-1}$

Using emf

- A single 1.5V cell,
  - total emf = 1.5V

- A battery of 4x1.5V cells,
  - total emf = 6V

Potential Difference, V

- Potential Difference is the electrical energy transferred per unit charge when electrical energy is converted to another form of energy.
  - Eg, electrical energy in a wire to heat in a resistor.
  - Imagine the water falling down a waterfall.

pd = electrical energy transferred, J / charge, C

- The unit of pd is JC^{-1}
- The SI unit for JC^{-1} is the Volt, V.

- So, $1V = 1JC^{-1}$

So what’s the difference between pd and emf?

- Not a lot really!

- Potential difference is used when discussing voltage (energy per charge) being supplied to a component.
  - (the energy given to components in a circuit)

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

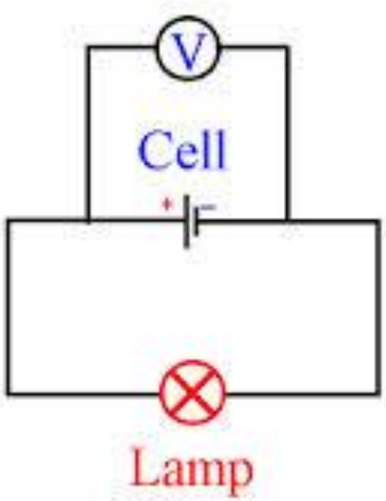
- Electromotive force is used when discussing voltage (energy per charge) being supplied by a cell/battery.
  - (the energy given to electrons to get them moving)

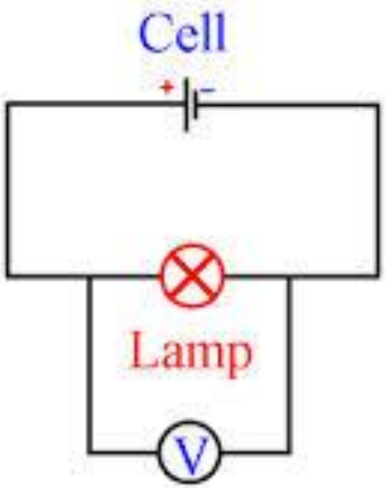
$$\varepsilon = \frac{W}{Q}$$

Measuring pd/emf

- A voltmeter is used in parallel with the component.

Measuring emf
(1.5V)





Measuring pd
(1.4V)

Where has the missing 0.1JC^{-1} gone?

Used to heat the wires

An equation dump for you...

- The number and type of exam questions relating to electricity are huge.
- Many can be solved by rearranging some basic equations:
  - One ampere (current) = one coulomb per second
  - One volt (pd or emf) = one joule per coulomb
  - One watt (power)= one joule per second

Physical quantity	Abbreviation	SI unit
time	t	second s
electric current	I	ampere A
electric charge	Q	coulomb C
potential difference	V	volt V
energy	W	joule J
power	P	watt W

$$I = \frac{Q}{t} \qquad V = \frac{W}{Q} \qquad P = \frac{W}{t}$$

...Or they can be rearranged

$$I = \frac{Q}{t} \qquad V = \frac{W}{Q} \qquad P = \frac{W}{t}$$

So,

$$Q = It \qquad W = VQ \qquad W = Pt$$

Or combined...

$$W = VQ = VIt \qquad P = \frac{W}{t} = \frac{VIt}{t} = VI$$

How many ways can you define the quantities: *t, I, Q, V, W* or *P? Include units!*

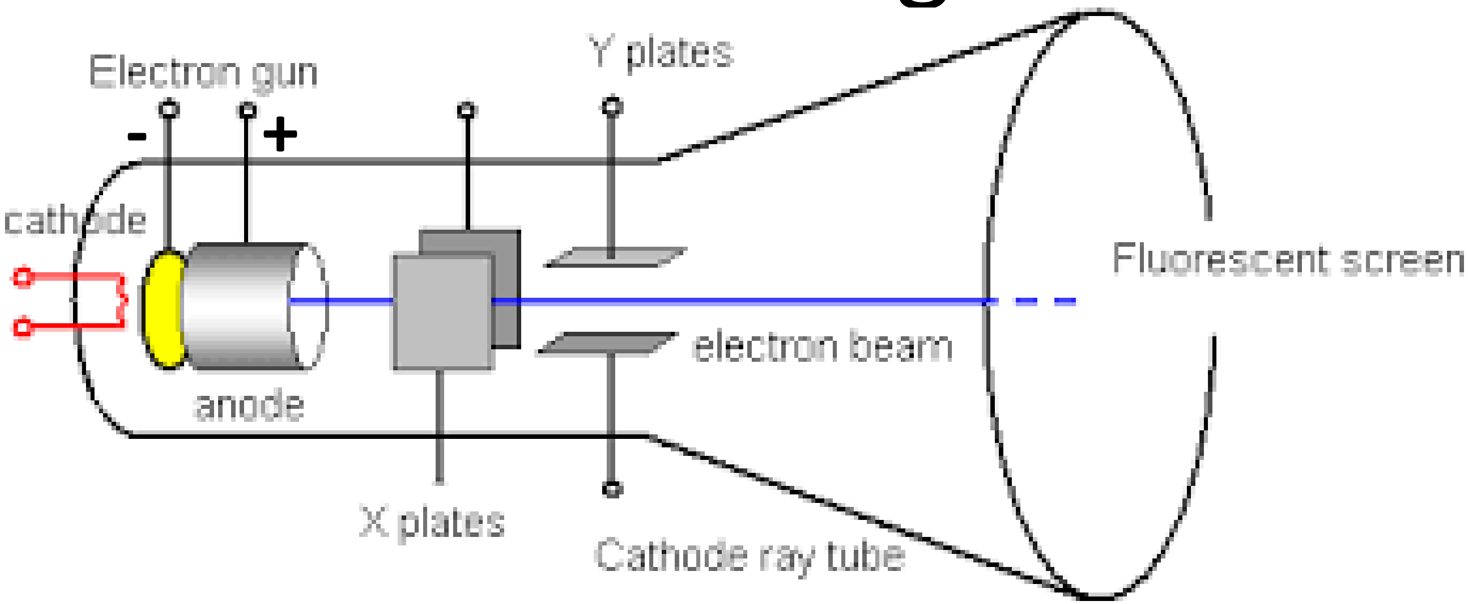
Did you spot this one?

$$pd = \frac{\text{Energy}}{\text{Charge}} = \frac{Power \times Time}{Current \times Time} = \frac{Power}{Current}$$

Or, in terms of units:

1 volt = 1 joule.coulomb^{-1} = 1 watt.ampere^{-1}

An electron gun



- The heating element heats the metal cathode.
- A pd between the cathode and the anode causes electrons to jump off the cathode and accelerate towards the anode.
- Some electrons pass through the hole in the anode and can be deflected using the X-Y plates.
- Electrons are detected as they hit the fluorescent screen.

Energy Transferred to the electrons

- As the electrons accelerate towards the anode they gain kinetic energy.
- We can calculate this energy using the equation which defines pd, $W = QV$.
  - Work done here is therefore *e*V where *e* is the elementary charge and V is the pd.
- By considering the law of conservation of energy, the work done on the electron will equal the gain in kinetic energy.

$W = eV = \frac{mv^2}{2}$ From here we could calculate v

What assumption has been made here?

That the electron had no or neligible energy at the cathode

4.2.2 EMF and PD (review)

4.2.2 E.m.f. and p.d

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	potential difference (p.d.); the unit volt
(b)	electromotive force (e.m.f.) of a source such as a cell or a power supply
(c)	distinction between e.m.f. and p.d. in terms of energy transfer
(d)	energy transfer; $W = VQ$; $W = \mathcal{E}Q$.
(e)	energy transfer $eV = \frac{1}{2}mv^2$ for electrons and other charged particles.

4.2.3 Resistance

4.2.3 Resistance

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) resistance; $R = \frac{V}{I}$; the unit ohm

(b) Ohm's law

(c) (i) I–V characteristics of resistor, filament lamp, thermistor, diode and light-emitting diode (LED)

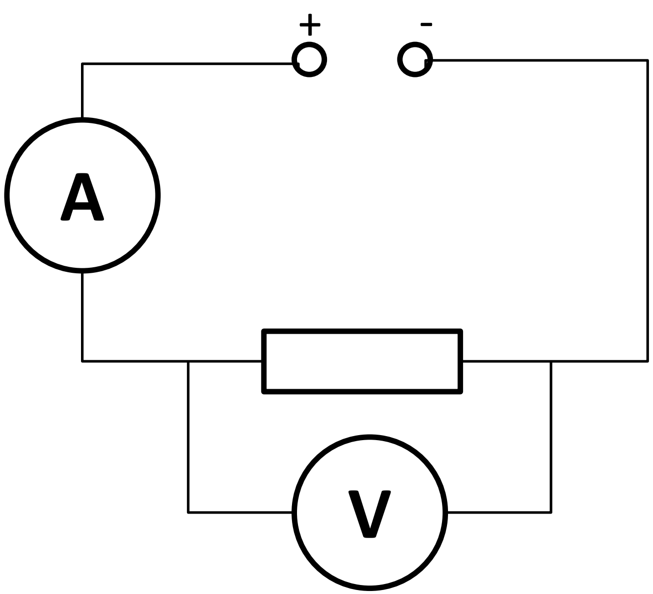
(ii) techniques and procedures used to investigate the electrical characteristics for a range of ohmic and non-ohmic components.

(d) light-dependent resistor (LDR); variation of resistance with light intensity.

What is resistance?

Ohm’s Law

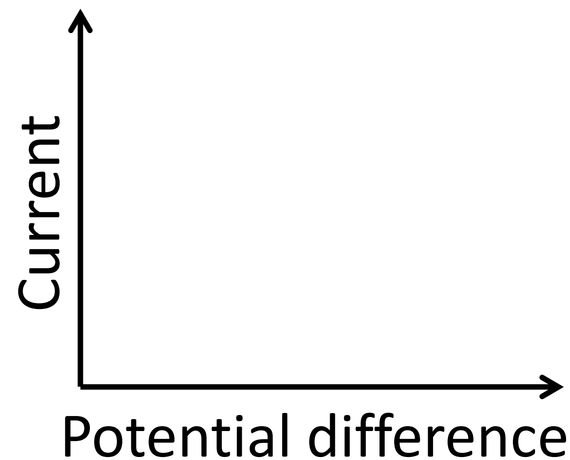
- In 1820s, Georg Ohm showed the relationship between potential difference and current in a circuit.
- Set up the following circuit and show it yourselves:



Collect data...

EMF	PD	Current

Then plot...



Ohm’s Law

The current through a conductor is proportional to the potential difference across it, provided physical conditions such as temperature remain constant.

- The graph you have plotted is called the I-V Characteristic of the component.

Resistance

$$\text{Resistance} = \frac{\text{Potential Difference}}{\text{Current}}$$

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

- The SI units of resistance are volts per ampere.
- This unit is also known as the Ohm, Ω.

Define resistance in base units

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

JC^{-1} → (W=Fd) → NmC^{-1} → (F=ma) → $Kgms^{-2}mC^{-1}$

↓ (Q=It)

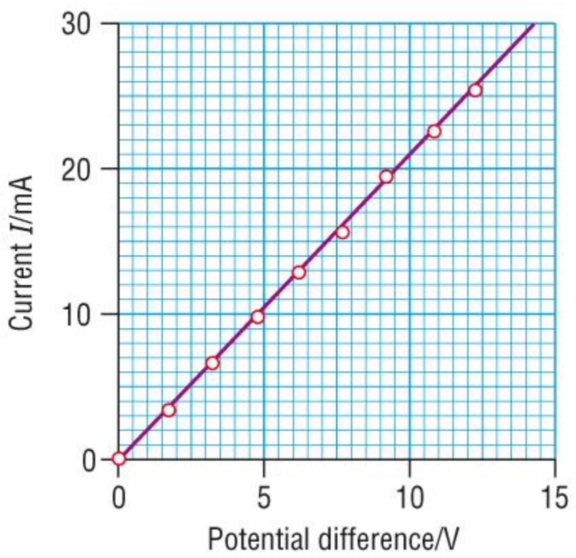
$Kgms^{-2}mA^{-1}s^{-1}$

A^{-1}

$Kgm^{2}s^{-3}A^{-2}$

What is Resistance?

- Electrical resistance is not the same as something being stopped or prevented from moving.
  - We've already seen how electrons actually move faster through a thin, high resistance wire compared to a thicker, low resistance one.
- To have a resistance of 2.5Ω just means that a pd of 2.5V is required to produce a current of 1 amp.
- Resistance of a component can be determined from its I-V Characteristic.



R = V/I

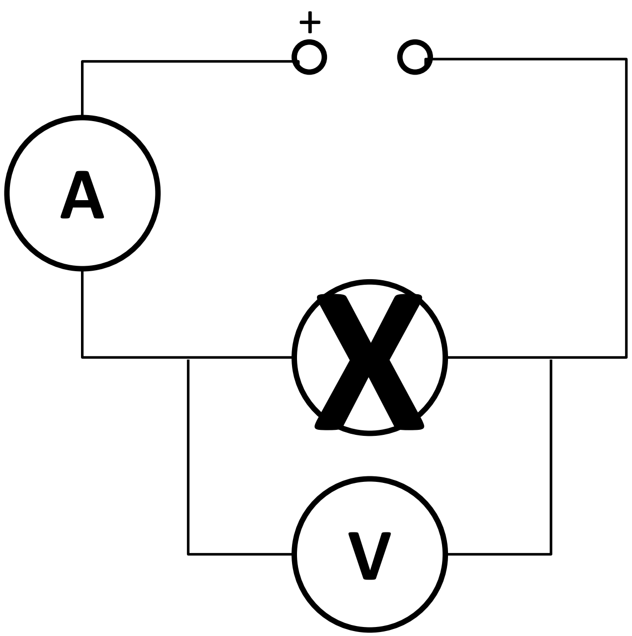
R = 14.2V/30mA

R = 14.2V/0.030A

R = 473Ω

The I-V Characteristic of a Filament Lamp

- Produce an I-V Characteristic graph for a filament lamp.



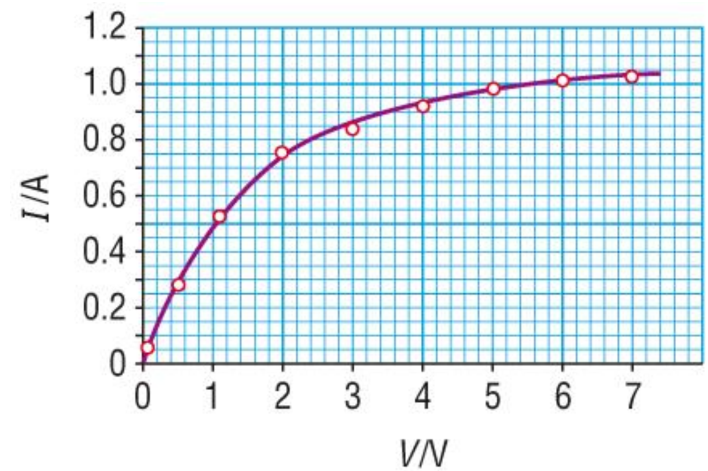
Produce a set of data like this...

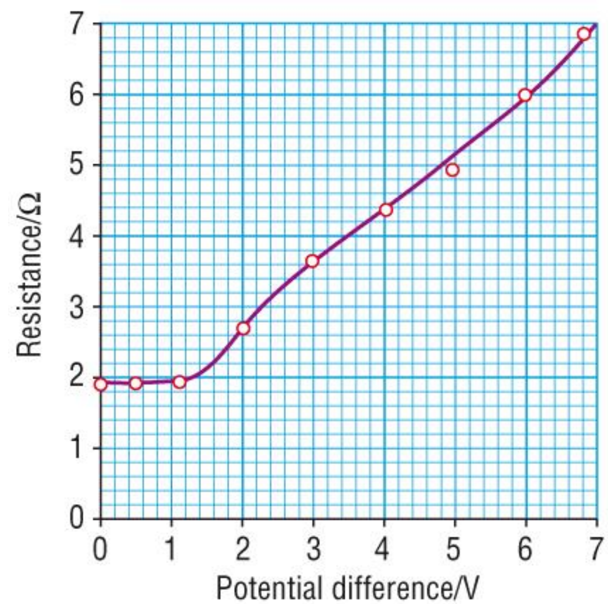
PD /V	I /A

Then calculate Resistance and Input Power...

What can you conclude?

- For a filament lamp:
  - Ohm's Law does not apply.
    - Since the temperature of the filament changes.
    - This increases the resistance of the filament.
  - Resistance is constant for low pd.
    - Then increases rapidly for increasing pd.

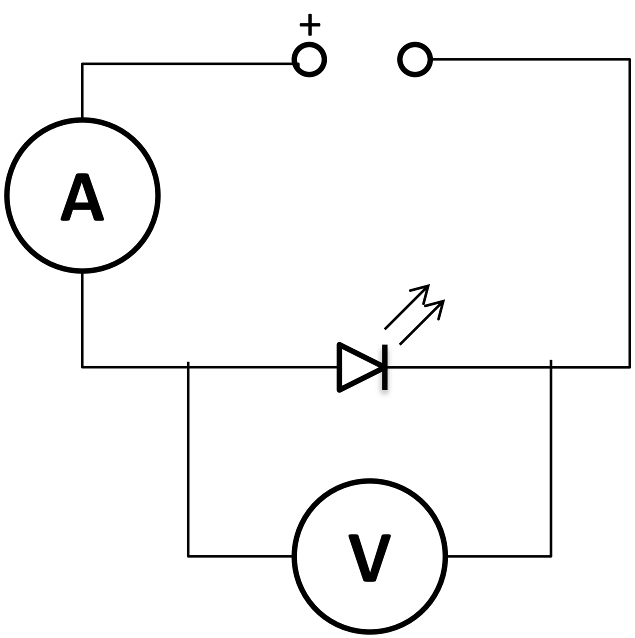


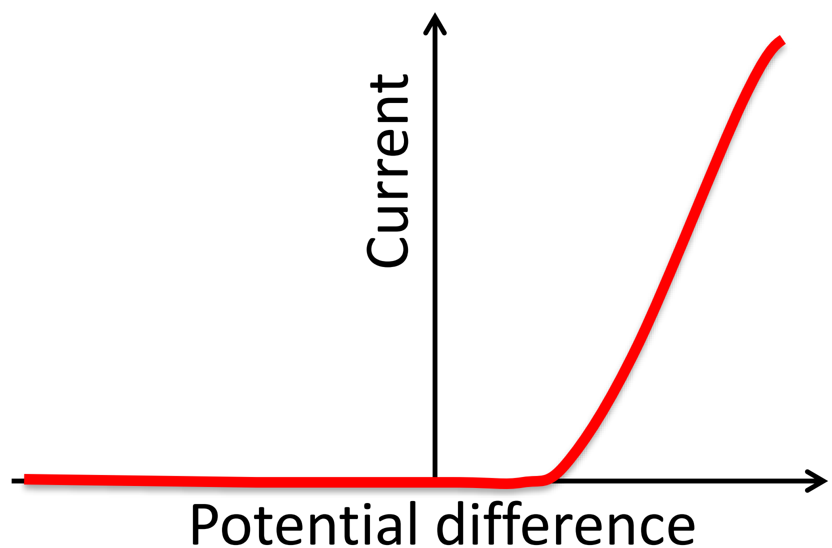


The I-V Characteristic of an LED

- What would an I-V Characteristic graph for a Light Emitting Diode look like?

- A diode allows current to pass only in one direction.
- An LED emits light as current flows through them.





Uses & Benefits of LEDs

- Benefits:
  - Switch on instantly
  - Very robust
  - Operate at low pd, low current
  - Long working life
  - Very versatile
- Uses:
  - Cycle/car lights
  - Road traffic lights
  - Appliance warning lights

What are the IV Characteristics of an LDR at various light intensities?

IV Characteristics of an LDR

- Plot the IV Characteristics of an LDR for three different, measured light intensities.
- What can you conclude about how the its resistance is determined by light intensity?

4.2.3 Resistance (review)

4.2.3 Resistance

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) resistance; $R = \frac{V}{I}$; the unit ohm

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4.2.4 Resistivity

4.2.4 Resistivity

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) (i) resistivity of a material; the equation $R = \frac{\rho L}{A}$

(ii) techniques and procedures used to determine the resistivity of a metal.

(b) the variation of resistivity of metals and semiconductors with temperature

(c) negative temperature coefficient (NTC) thermistor; variation of resistance with temperature.

Resistance v Resistivity: are they the same thing?

Resistivity

- Not to be confused with resistance.
- Resistivity is a property of a material.
  - As is Colour, Density and Young Modulus.

Resistivity v Resistance

- Resistance of a wire is proportional to its length and inversely proportional to cross sectional area.

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

- We need to multiply by a constant to turn this expression into an equation.

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

- **This constant (rho) is the resistivity.**

Rho

- Resistivity is therefore defined as:

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

- What are its units?
  - **Ωm**

Resistivity and Temperature

- Temperature has an effect on the resistivity of materials.

- Here we look at how temperature affects the resistivity of metals and semiconductors.

Metals

- As temperature increases:
  - Atoms in the metal lattice gain kinetic energy and vibrate faster/further.
  - Conduction electrons now need to pass through a more turbulent mass of atoms.
  - So a wire's resistance increases.
  - For many metals, resistance is proportional to temperature, RαT.
  - **So, resistivity of the metal will increase with increasing temperature:**

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

  - Expansion also causes an increase in length and cross sectional area (with area increasing as a square).
    - However, since these changes are small this has very little effect on resistivity.

Semiconductors

- Semiconductors (eg silicon) can be doped with metal atoms to reduce resistance.
- As temperature increases, the increased kinetic energy (vibration) of these atoms actually reduces the resistance further.
- Thermal expansion is less than in metals also.

- **Resistivity of a semiconductor is therefore reduced as temperature increases.**

Thermistors

- A thermistor is a component which alters its resistance with temperature changes.
  - They are made from doped semiconductors.

- Since the resistance will decrease with an increase in temperature:

  They are often referred to as **Negative Temperature Coefficient (NTC) Thermistors**

- These thermistors can have a resistance of 9000Ω at 0^{o}C and 240Ω at 100^{o}C.

4.2.4 Resistivity (review)

4.2.4 Resistivity

	Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) (i) resistivity of a material; the equation

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(ii) techniques and procedures used to determine the resistivity of a metal.

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4.2.5 Power

4.2.5 Power

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) the equations $P = VI$, $P = I^2R$ and $P = \frac{V^2}{R}$

(b) energy transfer; $W = VIt$

(c) the kilowatt-hour (kW h) as a unit of energy; calculating the cost of energy.

What is the unit of Power!?

Electrical Power

- What is the unit of Power?
  - Or rather, Watt is the unit of power!
- Power is the rate at which work is done, or the rate at which energy is transferred.
  - It's unit is Js^{-1}, or W.
- Remember the equation dump from a few lessons ago?
  - You may have produced some of your own...

You've seen this slide before

An equation dump for you...

- The number and type of exam questions relating to electricity are huge.
- Many can be solved by rearranging some basic equations:
  - One ampere (current) = one coulomb per second
  - One volt (pd or emf) = one joule per coulomb
  - One watt (power)= one joule per second

Physical quantity	Abbreviation	SI unit
time	t	second s
electric current	I	ampere A
electric charge	Q	coulomb C
potential difference	V	volt V
energy	W	joule J
power	P	watt W

$$I = \frac{Q}{t} \qquad V = \frac{W}{Q} \qquad P = \frac{W}{t}$$

You've seen this slide before

...Or they can be rearranged

$$I = \frac{Q}{t} \qquad V = \frac{W}{Q} \qquad P = \frac{W}{t}$$

So,

$$Q = It \qquad W = VQ \qquad W = Pt$$

Or combined...

$$W = VQ = VIt \qquad P = \frac{W}{t} = \frac{VIt}{t} = VI$$

How many ways can you define the quantities: *t, I, Q, V, W* or *P? Include units!*

You've seen this slide before

Did you spot this one?

$$pd = \frac{Energy}{Charge} = \frac{Power \times Time}{Current \times Time} = \frac{Power}{Current}$$

So, $$V = \frac{W}{Q} = \frac{Pt}{It} = \frac{P}{I}$$

Or, in terms of units:

1 volt = 1 joule.coulomb^{-1} = 1 watt.ampere^{-1}

Add V = IR to the pot...

- Combining V=IR with P=VI we can get:

$$P = VI = IRI = I^2R$$

and

$$P = VI = V\frac{V}{R} = \frac{V^2}{R}$$

Four Quantities, Four Equations

- Just like the SUVAT series of equations we now have 4 quantities:
  - Power, P
  - Current, I
  - Resistance, R
  - Potential Difference, V

- We can create four equations, each with one of these terms omitted...

Four Quantities, Four Equations

$$P = VI$$

$$V = IR$$

$$P = I^2R$$

$$P = \frac{V^2}{R}$$

TAKE CARE:

These terms MUST apply to the same part of a circuit at any one time.

If we need to calculate energy (or work) we just multiply the power by time

So we also get the following equations...

$$W = Pt = VIt = I^2Rt = \frac{V^2}{R}t$$

Domestic Electricity

- What is the kilowatt hour and how do electric companies charge us for what we use?

The kilowatt-hour

- A kWh is a unit of power x time.
  - Therefore it is a unit of energy – electrical energy.
- The kWh is used to measure the energy of household electricity because to use the joule would involve huge numbers.
  - $1kWh = 1000Js^{-1} \times 3600s = 3600000J$
- Note: a kWh is not kW per hour, it is the supply of 1kW for an hour (Power x Time)

Charging for electrical energy

- The kWh is also called a “unit” of electricity by the electricity company (EON, N-Power, etc).
- Electricity is charged by the kWh, with each “unit” having a set price (roughly 15p).
- If you used a 65W laptop for 8 hours, how much would this cost?
  - **0.065kW x 8h = 0.52units = 7.8p**

4.2.5 Power (review)

4.2.5 Power

Learning outcomes

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Module 4 – Electrons, waves and photons

4.1 Charge and current
4.2 Energy, power and resistance ← **Complete!**
4.3 Electrical circuits
4.4 Waves
4.5 Quantum physics