PHYS1110 – Everyday Physics

TOPIC 1: HOW DOES A STREET LAMP WORK?

ELECTRIC CHARGES AND COULOMBS LAW
We will be considering static and stationary charges. There are two types of charges: positive and negative.

All the matter around us is made up of atoms. In the centre there is a nucleus and around it there is an electron cloud containing electrons. Electrons are negatively charged. Atoms become charged be gaining or losing these electrons. For matter to become charged we need to take electrons or add electrons to it. Electrons have a very small charge of:

$$1.602\times 10^{-19} \text{ coulombs}$$

Some materials such as metals only hold onto their electrons very loosely, so it is quiet easy to move the electrons away from the metal. Other materials such as plastic or wood, hold onto their electrons strongly and hence, it is hard to move these electrons away from them. When it is hard to remove electrons from a materials, it Is called a non-conductor. A non-conductor does not conduct an electric current. Whereas, materials that can easily lose electrons are called conductors, these conduct electric current.

Demonstrations where Materials are gaining and losing electrons
Demonstration 1: Plastic rod and a piece of fur
Fur gives up electrons very easily. So when you rub a plastic rod against the fur. Electrons should transfer from the fur to the rod, making it negatively charged. When the plastic rod touches the electroscope, electrons from the plastic rod are conducted to the metal of the electroscope. The metal arms have extra electrons. Since like charges repel. The two negatively charged metal sticks on the electroscope will move apart.

You can ground the electroscope by touching it and transferring the electrons through your hands and feet to the ground. This makes it neutral again. This happens to us on dry days. If you rub your feet on carpet and then touch someone or an object, you will feel an electric shock.

Demonstration 2: Van der graaf Generator
When the generator is turned on, electrons are moved away from the sphere at the top and so the sphere becomes positive. If we move a conductor (small metal sphere), the sphere on the generator will steal electrons from the conductor. The electrons are transferred very quickly causing a spark.

Coulombs Law

$$F = \frac{kq_1q_2}{r^2}$$

That is, force equals coulombs constant multiplied by the charges of the first and second charge. All divided by the square of coulomb's constant.

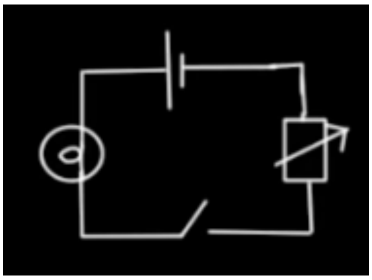
CURRENT FLOW AND OHMS' LAW

We are now going to be focusing on moving charges. Moving charges form an electric current. In metal wires it is the electrons that move conducting the current, as the electrons are only loosely bound to the wire. Often we refer to metals as a seas of electrons, as the electrons are really free to move.

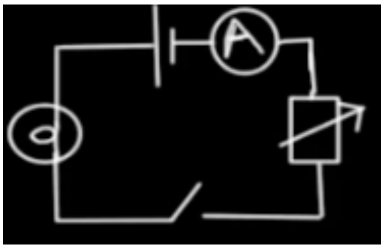
The electrons are moving to the right. Historically, it was not realised It was the electrons that moved. Instead it was thought the current was the result of moving positive charges. Convectional current is moving in the opposite direction to the flow of the electrons. To calculate current we can use the formula: **Current = Charge / Time (I=Q/t).**

Current flows through wire. Wires are often covered in an insulator to stop the electrons from escaping.

To start a simple circuit we need a power supply which supplies the electrons. If there is any break in the circuit, current will not flow through. Connect the power supply to the lightbulb, connect the lightbulb to the switch which is then connected to a rheostat (resistor). The resistor is then connected back to the power supply.



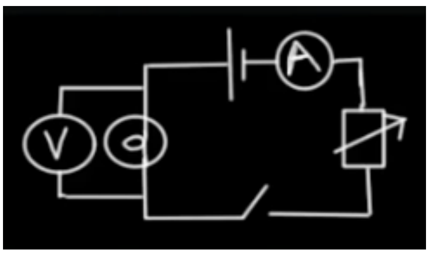
We can change resistance. When you close the switch, it allows the current to flow.



To measure the current, we us an ammeter. Current is measured in Amps. To get the current we have to put the ammeter in the circuit.

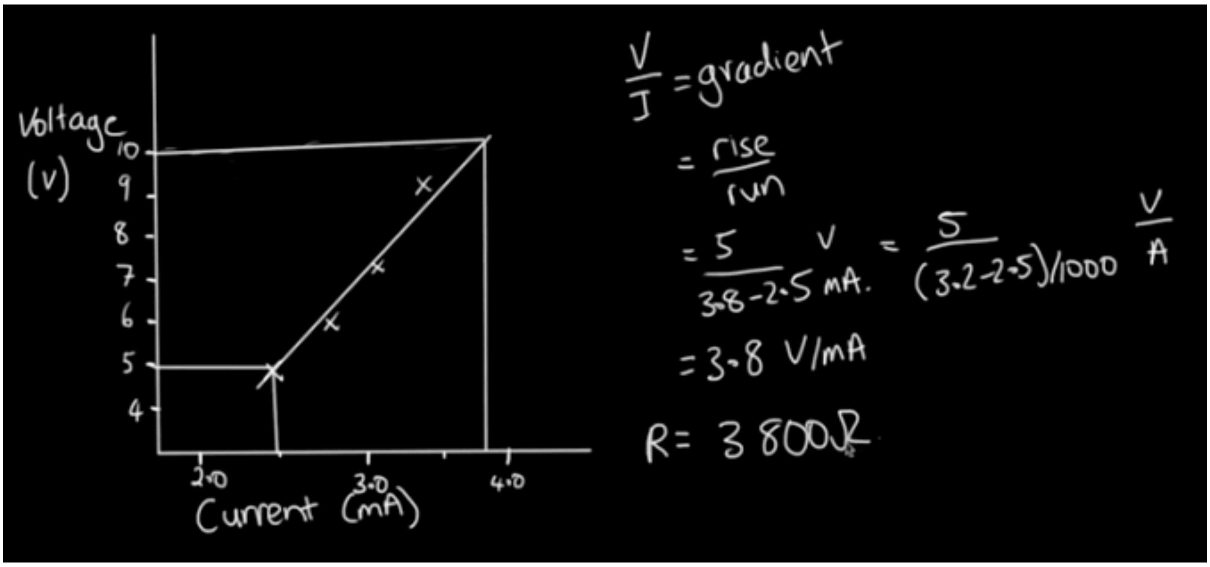
If we increase resistance, the light goes dimmer and the amps in the circuit decreases.

We can also measure voltage in a circuit. Voltage is the amount of potential energy that is available in the circuit, that is available to push the electrons. Each component in the circuit will use up some of this potential energy. There will be a voltage drop after each component in the circuit.



The voltage drop against the light globe is 4.8V. When we plug in a voltmeter in the circuit we plug it in parallel.

As we increase the current in the circuit (by reducing resistance), voltage increases. There is a linear relationship between these two properties. Ohm noticed the linear relationship and noticed that the gradient = resistance. Ohms is the unit of resistance.



The relationship between V and I is called ohms law. We can use this law to calculate the voltage, current or resistance in a circuit.

We are now going to put in a piece of paper in the circuit. Paper is a non-conductor. It is hard for a current to flow through paper. The globe no longer lights up. Electrons do not flow through the paper.

Electric current flows in the opposite direction of the flow of electrons.

SERIES AND PARALLEL CIRCUITS

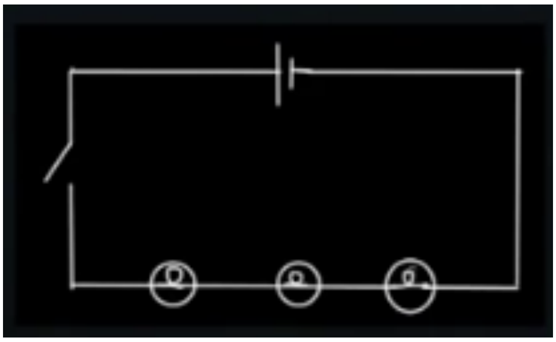
There are two ways a circuit can be wired: Series and Parallel

- In a series circuit the current flows sequentially through all components.
- In parallel circuits the current divides into two or more paths before recombining to complete the circuit

We can also have combination of these two circuits.

Series Circuit

The current goes out of the power supply to the switch to three light globe and back to the power supply.

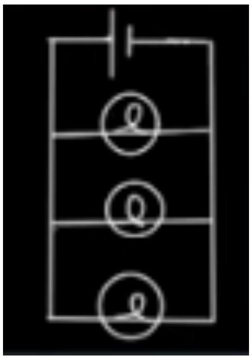


The current coming out of the power supply is 2.3A. the current between the first and second light globe is also 2.3A. ***THAT IS, the current remains the same throughout the circuit.***

The 12V provided by the power supply will be used up by the three components. If we add the voltage drop between each of the components it should add up to almost 12V. it won't be exact because the wires have some resistance.

The voltage across the first light lobe is approximately 4V. The voltage drop across the 2nd and 3rd lightbulb is just below 4V across each light globe.

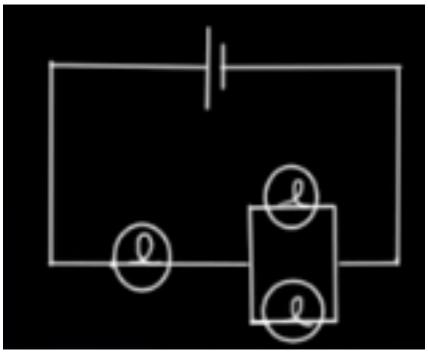
Parallel Circuit
In a parallel circuit, there are multiple ways in which a current can flow. It is like a river dividing into two or three streams and then combing back again to go to the sea.



To set up a parallel circuit we have a power supply to a light globe. Then a second and third globe is attached in branches.

The total current flowing through the circuit is 12.6mA. the current is split up between the light globes whereby 4.1mA flows through the first light globe. 4.2mA flowing through the second light globe and finally, 4.3mA flows through the third globe.

The voltage drop across the first light globe is 11.99V, the voltage drop across the second globe is 11.80V and the voltage drop across the third globe is 11.9V. they are slightly different because of the resistance in the wires.



Series and parallel are the simple building blocks of circuits. Not all circuits have to be one or the other. We can have circuits are a combination of the both.

The light globe in series is much brighter than the two in parallel.

The current flowing through the circuit is equal to 3.7mA. the voltage drop provided to the power supply is 12.33V.

The first globe is in series which means that all the current flows through the first globe and then the current splits into two. Whereby, half flows into the second and the other half flows through the third. 1.9mA and 1.8mA is flowing through the second and third globe.

We have twice as much current flowing through the first globe than the other two. This means we will expect it to have twice the voltage drop than the parallel part of the circuit. So, 2/3 of the total voltage will drop across the first globe and the other 1/3 of the voltage will drop in the 2nd and third globe.

Voltage drop of 9.7V across the first globe – slightly higher than the 8.2V predicted. A voltage drop of 2.8V between the other two globes.

ELECTRICAL ENERGY AND POWER
Flow of electricity delivers energy to street lights which use this energy to produce light. Electrical appliances need energy to work. Energy is *conserved* that is, it cannot be created or destroyed, only transformed. It can be transformed from one form to another or can be transferred from one body to another.

In electrical power plants, you burn coal to make chemical energy which is then converted into electrical energy which flows to homes, shops and street lights. When it flows to street lights, they convert that energy into light energy and some heat energy.

Power is a measure of how quickly energy is transferred. **Power = Energy/ time.** Power is measured in Watts, energy is measured in Joules and time in seconds.

Electricity bills charge for the amount of energy use not power. Because power is the rate of energy use, not the total amount of energy. Energy companies us a unit called kWh. We can rearrange out power equation to: **Energy = power x time.**

P=VI can be used to determine how much power components in a circuit use.

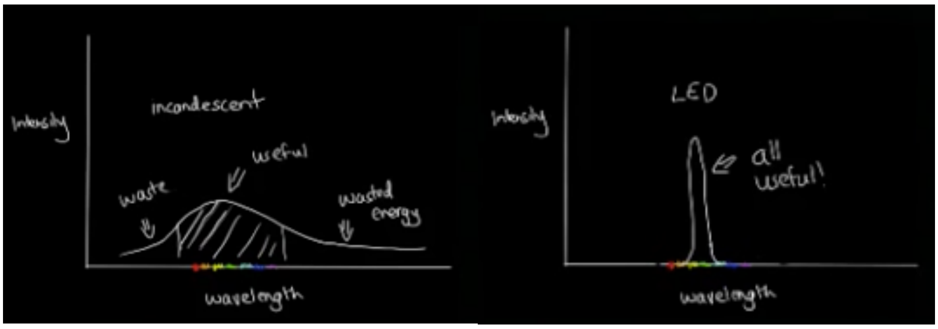
From previous topic, the light globes in the parallel circuit are much brighter than those in the series circuit. This can be explained according to how much power is used. When you use more power, you use more energy per second and therefore, the globes will be more brighter.

Governments use the most efficient method to have street lights. So they need to find globes that take less power. Also, since our eyes are accustomed to yellow lights these lights require less intensity. If they are to use blue or red lights.

Incandescent lights have a very narrow metal filament which current flows through. As the current flows through the wire it heats up. Hot things radiate light energy. This is called black body radiation. Imagine a coals mith, puts a cold lump of metal on the fire. As the fire heats up, the metal starts to get a bit red. As the fire get hotter, and the metal keeps getting hotter it will get orange, yellow, green and blue. This is because it is producing light at all different wavelengths. However, as it gets hotter the wavelengths of light get smaller causing it to emit different colours of light.

The incandescent light is working as the electrical energy is heating up the filament which then produces a little bit of light energy. This is a very inefficient way to produce light as lots of heat energy is produced. Supermarkets have now banned the sale of tungsten filament globes because of their inefficiency.

LED lights also use current, but they are much more efficient in converting electrical energy into light energy. LED only produce light with a very limited wavelength. Green LED emit light at around 459nm. A downside of these LED is that incandescent produces a spectrum of colours – we have evolved to like this spectrum. LED lights can seem cold and spark as they only produce a single wavelength.



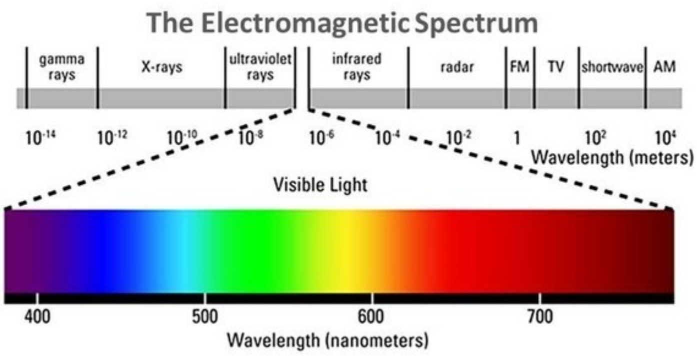
Since LED lights are more efficient compared to incandescent lights, traffic lights are being used to use LED lights.

Street lights are mainly Metal-halide lamp – these have a chamber filled with gas, current is sent into this chamber which create electrical arcs which lights up the gas. This causes a Tasma to form within the gas – electrons get enough energy to be disassociated and move around. And when the electrons come back and join back to their nucleus, they then produce light. *Mercury lamp* – green-blue. *Sodium gas* produces a more yellowy light – astronomers like to use this as they have a very specific wavelength 589nm.

Fluorescent lights work in very similar way to these gas discharge tubes except they have a fluorescent coating which interacts with UV light produced by the gas to produce light with a visible wavelength.

THE PHOTOELECTRIC EFFECT AND HOW STREET LAMPS KNOW WHEN TO TURN ON

The photoelectric effect as one of the first solid pieces of evidence for quantum mechanics. To understand the photoelectric effect, we have to know about electromagnetic radiation. At the beginning of the 20th century, it was understood that light comprised of waves which could travel through space – a vacuum. It was also known that the wavelengths gave light of different colours.



This was well understood at the beginning of the 20th century. We knew that these light waves travel through a vacuum at the speed of light – **3.00×10^8 m/s**. In other substances it travels at different speeds. We couldn't use this understanding of light to describe some of the phenomena that some people observed.

In 1887, *Heinrich Hertz* observed the ***photoelectric effect.*** He observed that when a light was shone onto a metal, electrons were released. It was *J. J. Thompson* who discovered that the released particles were electrons. It was then observed, that there was some problems with our understanding of light and what actually happens. It was observed that if you shone red light on some metals, no matter how intense the light got or how long red light was shone for, no electrons were released. But if you shone blue light that is, a light with greater frequency, then electrons were released.

This makes no sense if we take the classical model that light is made up of waves. As waves carry energy, that is, there should be enough energy in a piece of metal after shining a light for a long time, regardless of colour to allow the electrons to be released. This wasn't observed. *What was happening?*

It was *Einstein* that came up with an explanation of what was happening, and this was the basis of quantum mechanics. In 1921, Einstein received a Nobel Prize for services to theoretical physics and his discovery for the Law of the Photoelectric Effect. He said that light should be considered as a particle. That is, light should be instead considered as consisting of particles called ***photons***. Basically, we are shining photons at a metal. These photons should have enough energy to allow the electron to escape.

- If the photon didn't have enough energy, then overtime the electron will stay with its nucleus, and the energy was lost.
- If the photon did have enough energy then the atom will absorb the photon, the electron will get excited and mover away from the metal with energy in the form of kinetic energy – the energy of movement.

If you have a higher energy than some critical energy then the photons have enough energy for the electrons to escape. Vice versa.

Einstein said that the amount of energy a photon has: **E = *hf.*** Where, $h = 6.626 \times 10^{-34}$ Js and f is the frequency of the photon. Frequency is related to the wavelength ***c=fλ***

To cause the electron to escape, the photon has to give the atom a certain amount of energy. ***Work Function*** is the amount of energy an electron needs to escape an atom. This can be different for different types of metals.

$$hf = \Phi + KE$$

This explains why red light (low frequency) doesn't have enough photon energy to cause these electrons to escape. If you have shorter wavelength, higher frequency light such as blue light. The photons have enough energy to release the electron.

Street lights have a detector. When there is light shining on it through the day, electrons are released and flow forming a current. When the sun goes down, there is no more light hitting the photodetector, no more photoelectrons are produced. The photodetector notices this and tells the street light to turn on.

The intensity of the light hitting the photodetector is related to the number of photons hitting it. So during a cloudy day, the intensity of the light hitting a photodetector decreases, causing the lights to turn on during the day, if there is a storm on. The number of photoelectrons produces is proportional to the intensity of light as long as the light has enough energy to cause the photoelectrons to be produced.

Solar lamps works on similar technology to street lights. When light falls on the solar panel, electrons are released to produce a photocurrent which charges a battery. When the sun goes down, the photons stop falling on the solar panel, there is no current. So the light no knows to turn on.

<u>SUMMARY</u>

Static Charges

In nature there are two types of charge: positive and negative.

- The charge on an electron is 1.602 x 10^{19}C

Coulomb's law, there is a force between two charged particles. Like charges repel and unlike charges attract. This force is given by:

$$F = \frac{kq_1q_2}{r^2}$$

Moving Charges

- Current is made up of moving electrons
- The convectional current goes in the opposite direction to the electrons. Because, initially it was not understood that it was the electrons that were moing.
- The amount of current can be calculated using: I = Q/t
  - That is the amount of current that passes through a charge in a given amount of time.
- When a circuit is wired up a circuit, the voltage and current across a component were proportional to the resistance of the component: V =IR (Ohm's Law)

Parallel and Series Circuit

- Circuits can be wired up in two main ways: Series and Parallel.
- In series the current flows through each component sequentially. In parallel, the current branches through the components and comes back together again.
- Combination circuits include both.

Power

- The power flowing through a component in a circuit can be given by:

$$P = VI = \frac{Energy}{time}$$

- Power is also given by the rate of energy usage.
- Street lights are provided by electrical energy which is converted in the street lamp into light and heat energy.
- Incandescent lights are very inefficient. LED lights are very efficient but it is hard to get them with enough intensity. Street lights use LED.
- Street lamps use metal-halide lamps. This is an efficient way of lighting. It comes in good colours and is easy to get very intense.

The photoelectric Effect

Street lights know when to turn on because of the photoelectric effect. When light hits a piece of metal it can cause electrons to be ejected from the surface. This occurs if the photons, which light consists of have enough energy.

Photodetectors on street lamps detect these photons which release photoelectrons causing a photocurrent. While these electrons are detected the street lamps stay off. But once the intensity of the photons decreases such as, at dusk or on a stormy day, the street lamps don’t detect photoelectrons and know that they have to turn on.