Electricity and Magnetism: Physics Narrative 01

Contents

- What happens in circuits? 2
- Electric Current: A flow of charges 4
- Two jobs for the battery 9
- Batteries, cells and energy stores 10
- Resistance and energy transfer 13
- A summary, so far 15
- Shifting energy from battery to surroundings via bulb 17
- The charges are always there…but something must get used up! 19
- Check your progress 20

This is the 'Physics Narrative' for this episode, that explains the physics for teachers. To develop your expertise in the episode, work with the 'Teaching and Learning Issues' and the 'Teaching Approaches'. Navigate to any part of the topic using the Topic Menu, or use the tabs below to stay within this episode..

What happens in circuits?

When a battery is connected to a bulb to make a complete circuit, the bulb lights up. If you are interested in understanding how electric circuits work, this familiar event raises a number of questions.

For example: When the bulb comes on energy is shifted or transferred (see the Energy topic), to the surroundings as the filament of the bulb heats up and light is emitted (see the Energy topic).

- Where does this energy come from in the first place?
- How is the energy transferred to the surroundings in the bulb?
- How can this happen so quickly?

You probably have some pretty good ideas about answers to these questions. What is needed is a way of thinking about electric circuits that allows us to "picture" what's going on inside them (inside the battery, wires and bulb). You can see the effect of what's going on (the bulb lighting up); what is needed is a model for the electric circuit to help you understand why that happens.

What happens in circuits?

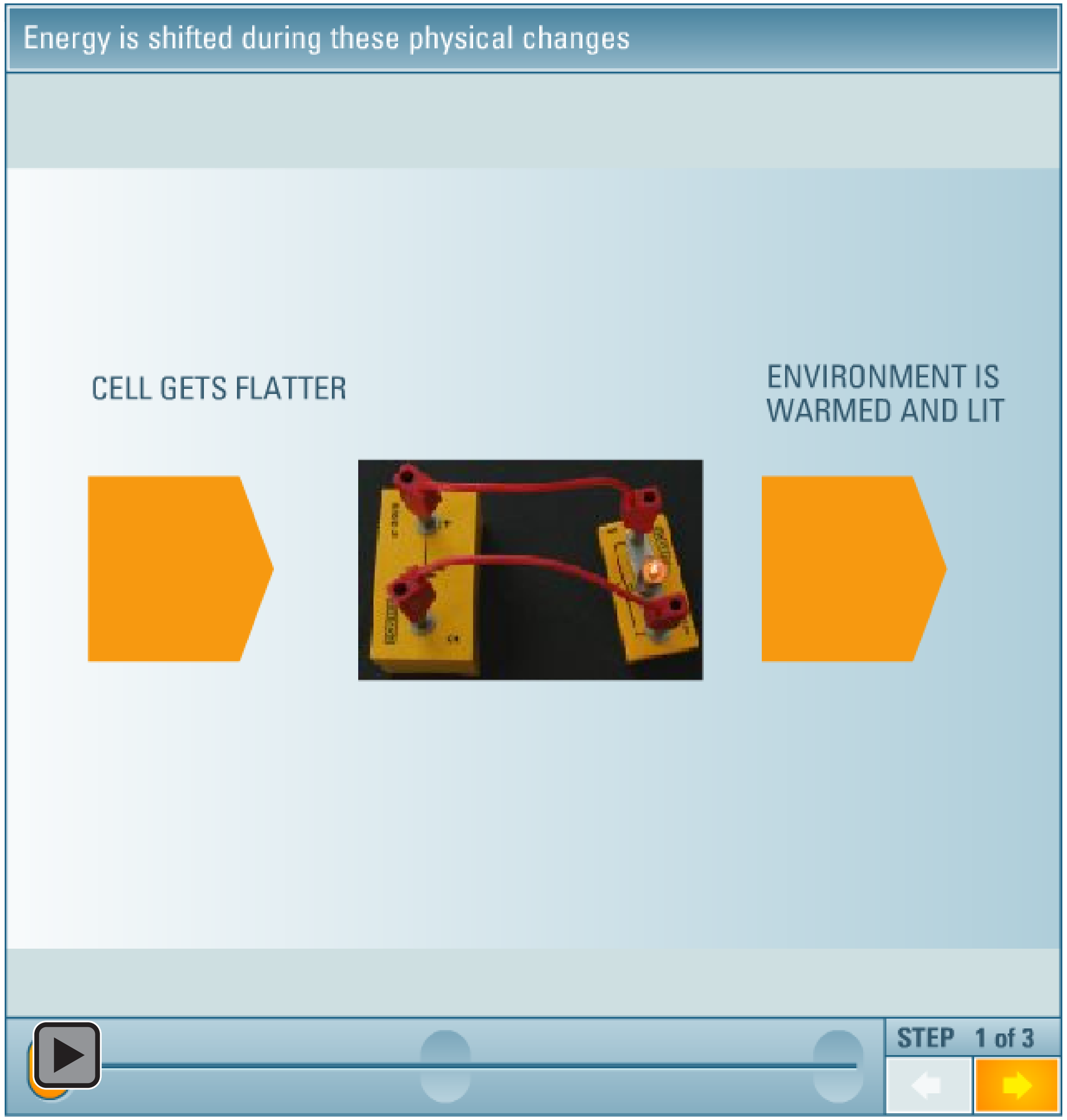
Starting point: So what actually happens?

What happens when a battery is connected to a bulb to make a circuit? The bulb lights up very quickly as the circuit is completed.

Where does the energy come from?

It is clear that the energy must come initially from the battery which acts as an energy store (see the Energy topic). This being the case, what happens in the circuit to enable the energy which originates in the battery to be shifted to the surroundings via the bulb? The energy story gives us an overall description of what happens but provides no details about the mechanism.

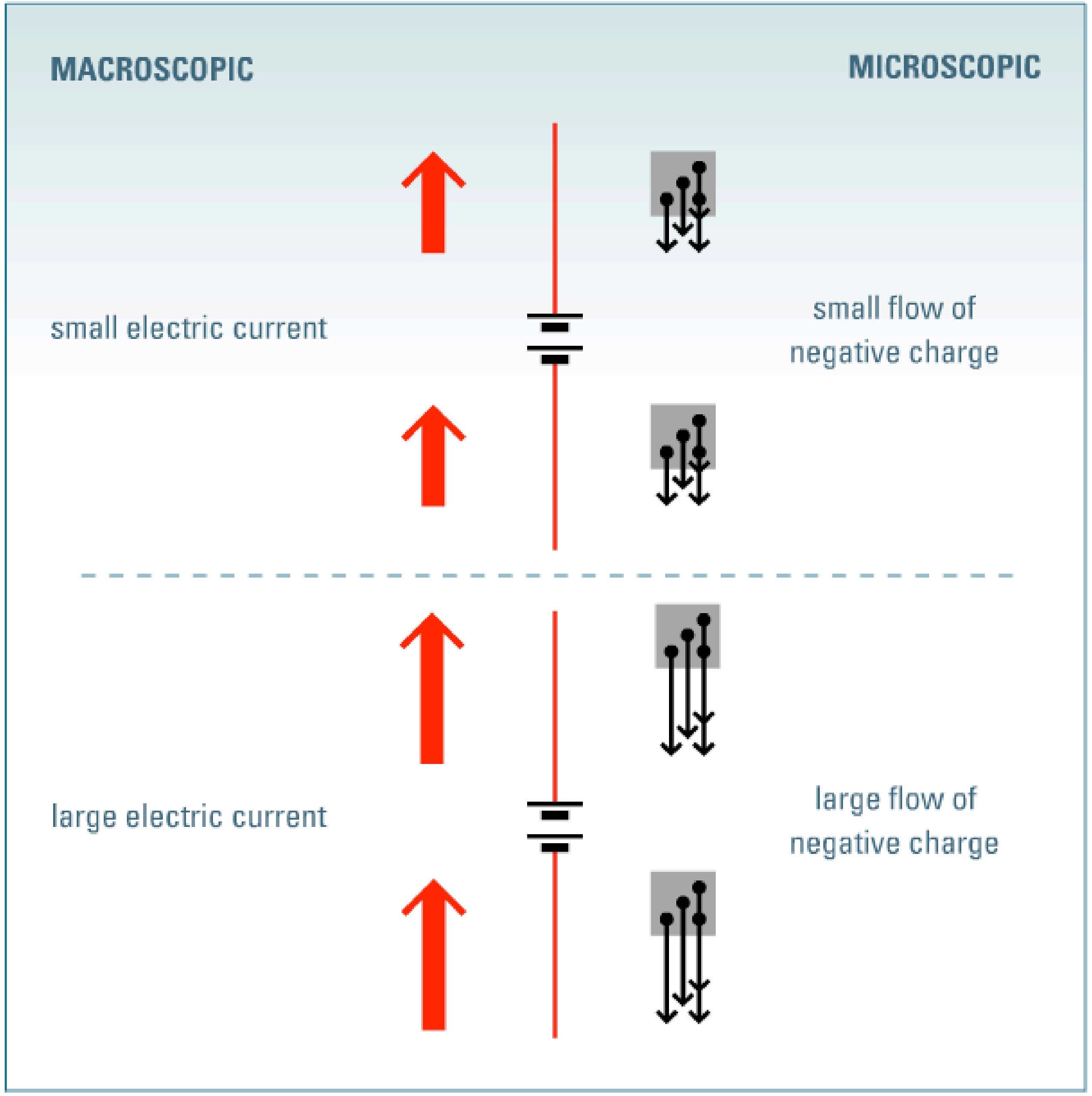
A helpful way to think about this follows.



Electric Current: A flow of charges

When the battery is connected up to the bulb to make a complete circuit, there is an electric current in the circuit. The electric current is made up from millions of minute, negatively charged particles called electrons, which pass around the circuit. The charge flows around the circuit.

Here are two representations of this movement. Current is always represented by an arrow which points away from the positive terminal of the battery and towards the negative. The current arrows point in the opposite direction to the charge flow because electrons are negative.



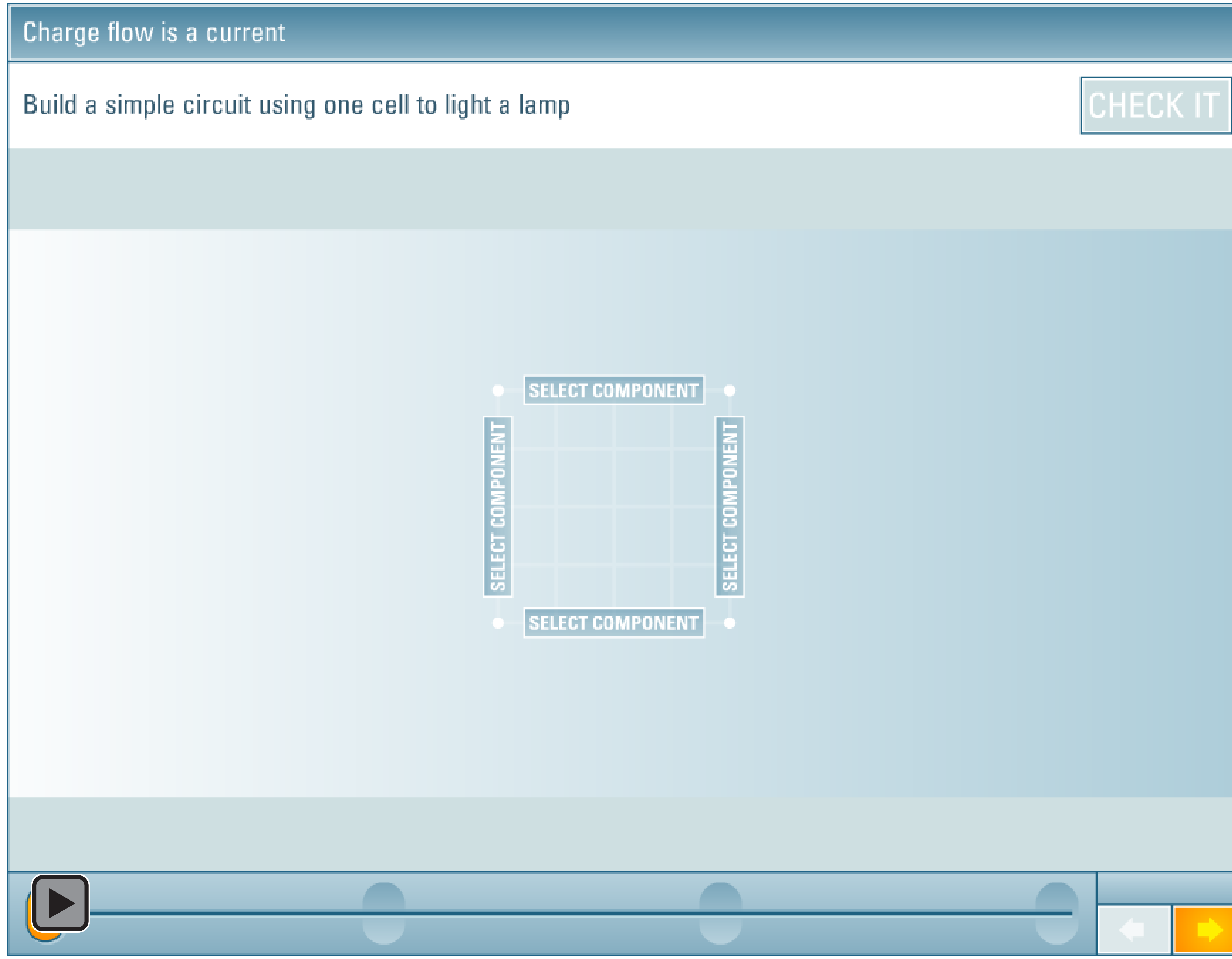
Electric Current: A flow of charges

Use this interactive to explore the relationship between current and charge flow.

Don’t forget that the current is the same all the way round the circuit - there are no leaks!

For now, don’t worry about electrons being negative. For early studies in electricity it turns out not to matter too much anyway. It is more important to be clear about the connection between the flow of charges and the current.

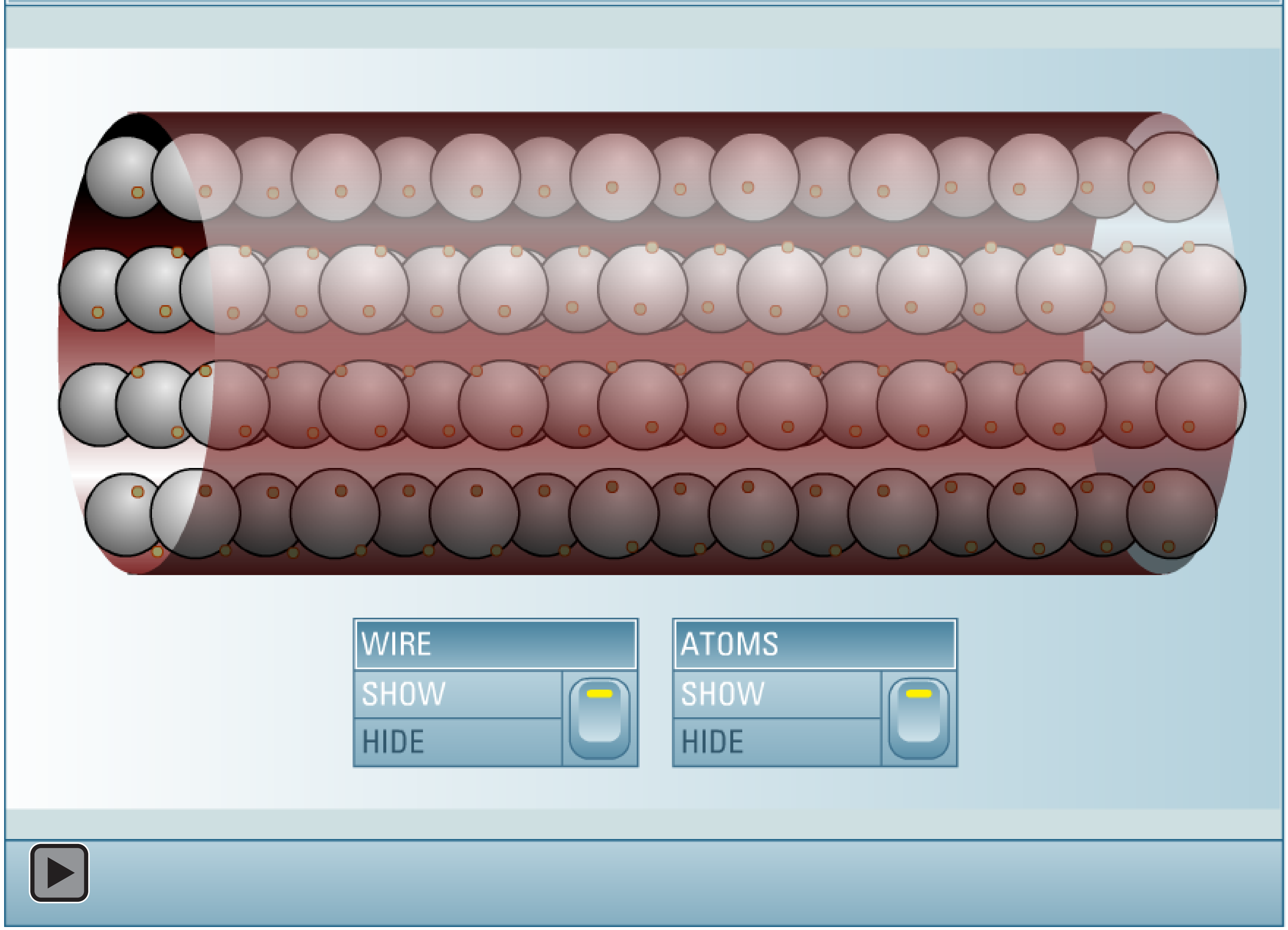
Where do these electrons come from?
This is a good question!



Electric Current: A flow of charges

The electrons originate in the circuit itself. They are simply part of the atoms that make up the battery, wires and bulb. When these components are not connected into a circuit, you might imagine a sea of free electrons buzzing around the fixed array of positive ions (rather like the molecules in a gas).

Inside a wire



Electric Current: A flow of charges

When the components are connected up to form a circuit, the negatively charged electrons in the circuit are attracted towards the positive terminal of the battery. You can imagine the electrons still buzzing around but, in addition, drifting through the fixed array of ions towards the positive terminal.

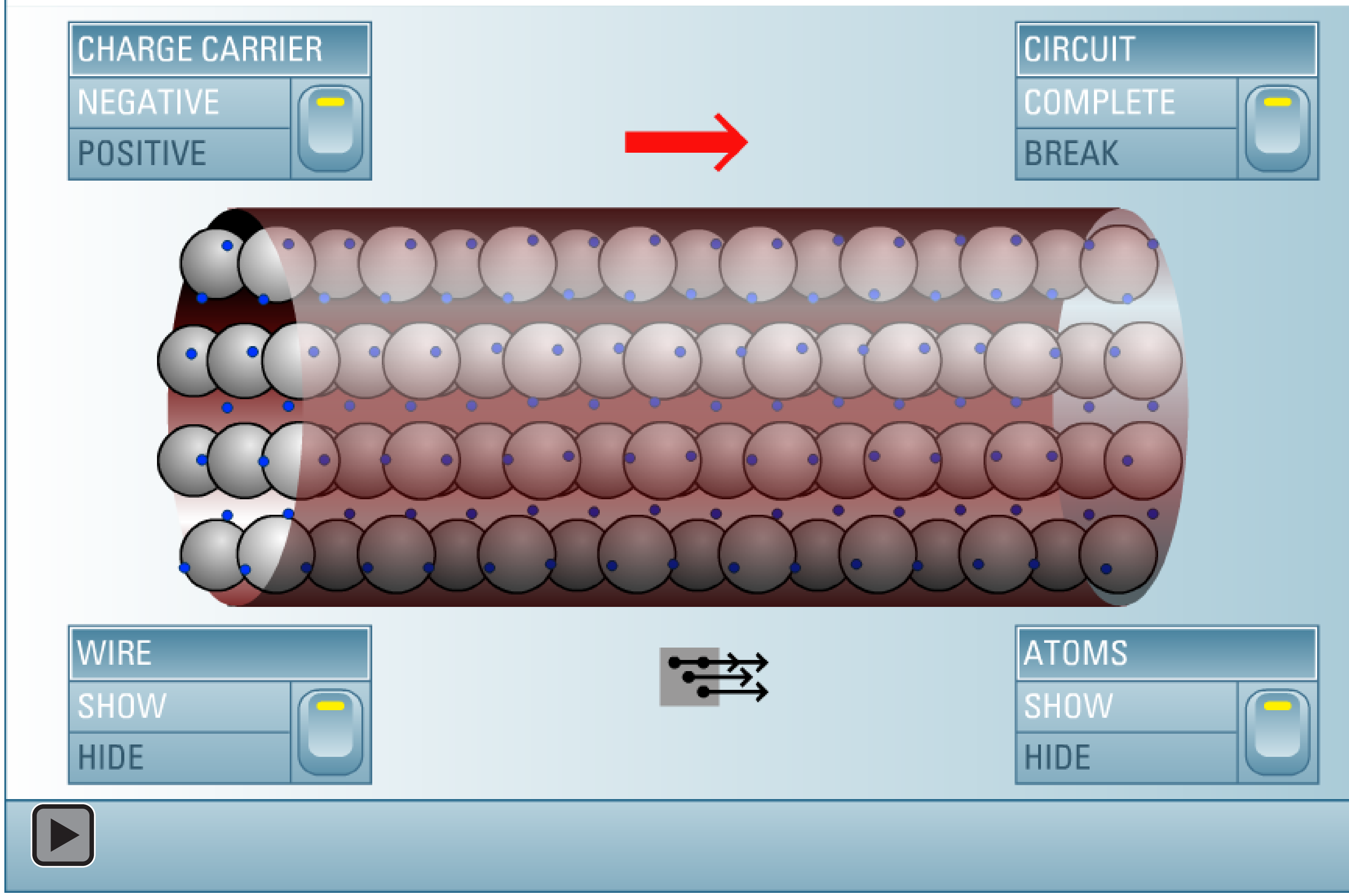
We refer to the electrons drifting for a very good reason. The additional motion towards the positive terminal causes them to move only about 1 cm per minute. This is very much slower than their random buzzing around, so we have simplified the diagrams, by not showing the buzzing around.

There are lots of electrons but they move around the circuit rather slowly.

Is it the case that electric currents always consist of a flow of electrons? The answer to this question is yes if we are thinking about currents through the metallic conductors typically used in electric circuits.

A wire in a circuit

Use the top pair of switches and the current and charge flow arrows to explore the flow of charge in the circuit. Use the bottom pair of switches to change what is visible.



Electric Current: A flow of charges

There are, however, other situations in which the current is not carried by electrons. For example, a salt solution will conduct an electric current, and here the moving charges which constitute the current are provided by the ions in the solution.

In the following sections we shall refer to electric currents in terms of a flow of charges. In your own teaching you may prefer to talk about a flow of electrons.

Two jobs for the battery

The battery has two linked jobs in the circuit.

The battery:

- provides a "push" to set the sets the charges in motion
- and thereby acts as a store of energy for the circuit

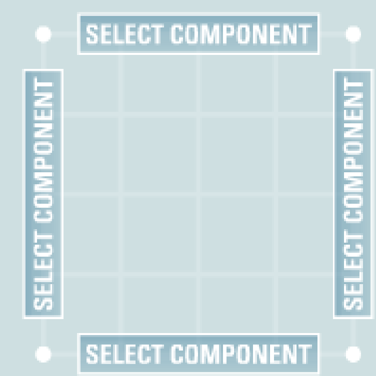
Strictly speaking, the term "battery" refers to a number of individual "cells" connected in series, and so we might talk about a 1.5 volt cell and a 9 volt battery (which consists of six 1.5 volt cells).

In practice this distinction between battery and cell adds nothing to an understanding of the workings of electric circuits. Since the word battery tends to be more commonly used, we shall refer to batteries throughout the following sections.

Cells do two jobs in a circuit

Build the simplest circuit where one lamp can be turned on and off

CHECK IT



Batteries, cells and energy stores

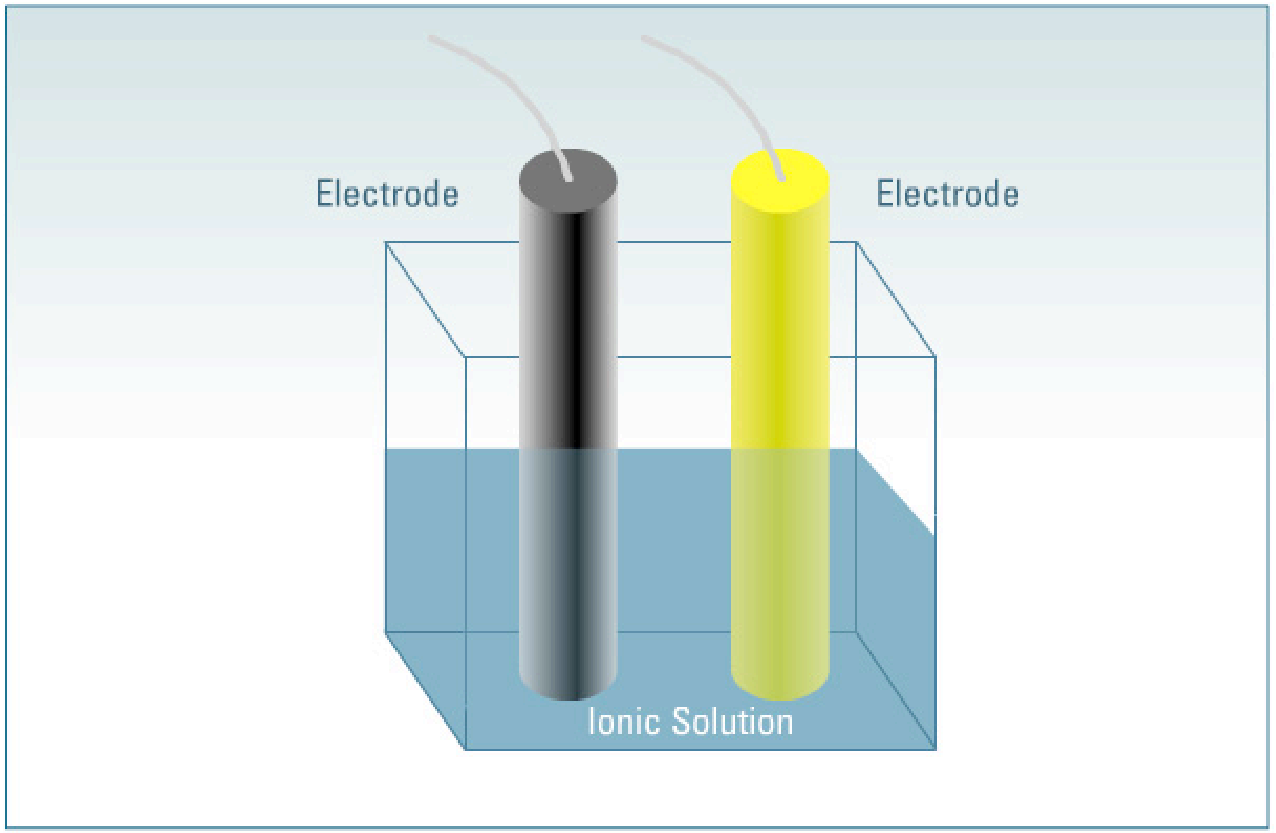
Here you can learn more about the history of cells and find out how to make simple cells.

In 1791, Luigi Galvani, an Italian physiologist, laid out a frog on a metal table prior to dissecting it. As he sliced through it with a metal knife, he observed the twitching of muscles, which he attributed to "animal electricity". Later, when preparing further specimens by hanging them out of doors to dry, he observed muscle contractions if the copper hooks upon which they hung came into contact with iron fence wire. Galvani concluded that electricity resided in the frog's nerve juices, and that the metals in contact allowed the "animal electricity" to flow.

A second Italian scientist, Alessandro Volta, disputed this, claiming that the electricity originated within the metal parts of the circuit. The controversy was resolved when, in 1800, Volta produced the first "Voltaic pile"; an electric cell. After touching connected pairs of different metals on his tongue to sense the small voltages, Volta constructed the first cell from alternate discs of zinc and silver, separated by absorbent disks soaked in water. He communicated his findings in a letter entitled 'On the electricity excited by the mere contact of conducting substances of different kinds'.

In their simplest form, modern cells consist of two electrodes of differing materials separated by an ionic solution. When the terminals are connected by a conductor, electrons flow from one side to the other enabling chemical reactions to take place. Energy is transferred by these reactions. Once all the available chemicals have reacted, the cell can no longer supply energy, it is "dead".

The amount of energy transferred per electron by the chemical reactions depends upon the materials used in the cells. The materials most commonly used typically produce a 1.5 volt cell (1.2 volt for certain rechargeable types). The term "battery" refers to a number of individual cells connected in series. This arrangement provides us with a greater output voltage. The packaging of a standard 9 volt battery hides six 1.5 volt cells connected in series (see Episode 4 for more information about voltage).



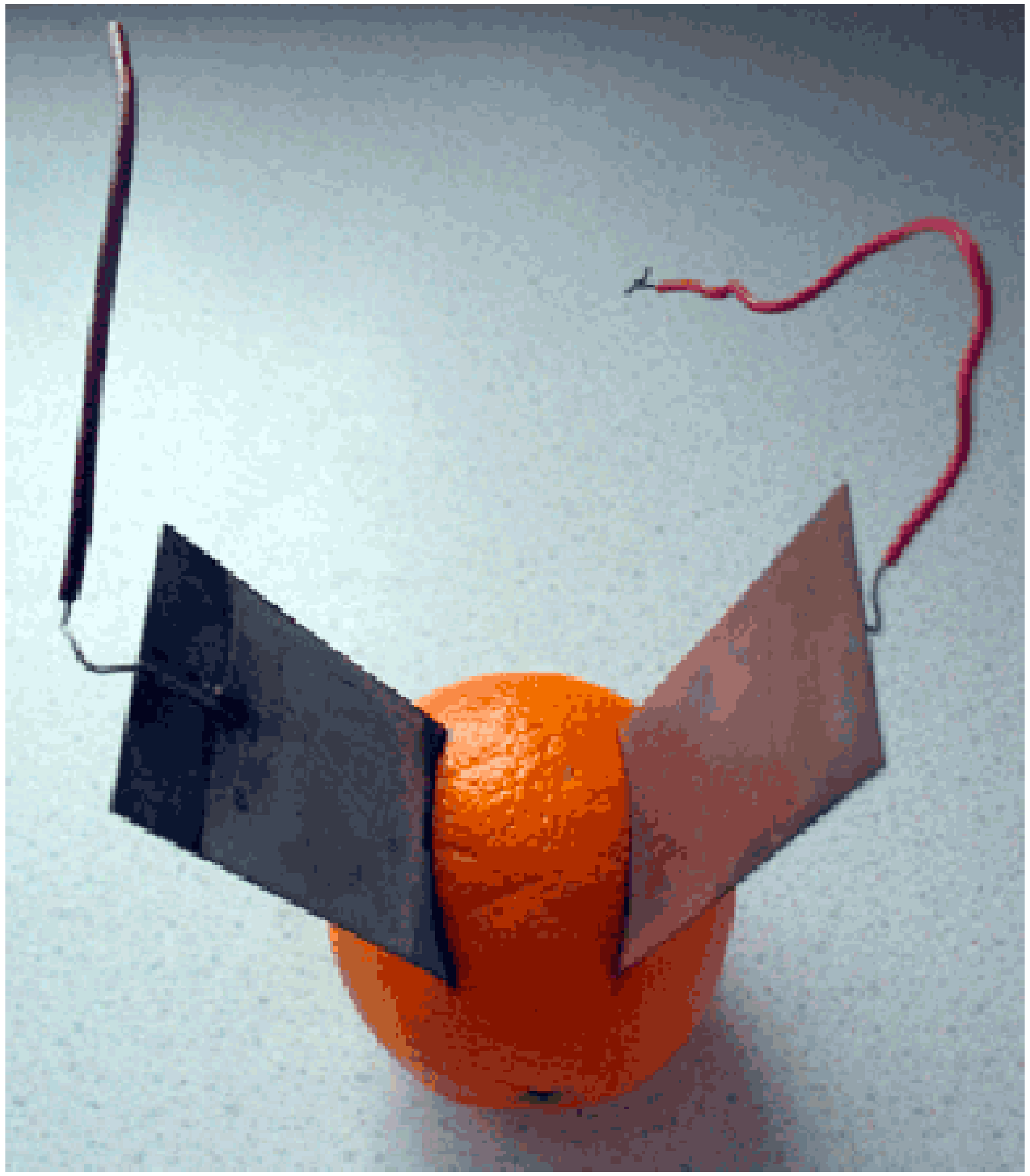
Batteries, cells and energy stores

Making a cell

A simple electrical cell can be made with fruit and two metals:

- Take 1 citrus fruit (lemons or limes work best). Gently squash the fruit to break the flesh structure without damaging the outer skin.
- Insert one clean piece of copper and one clean piece of zinc (each about 5 mm × 40 mm) into the fruit, close together but not touching.

You now have a cell. Unfortunately the energy available from this cell is rather limited.

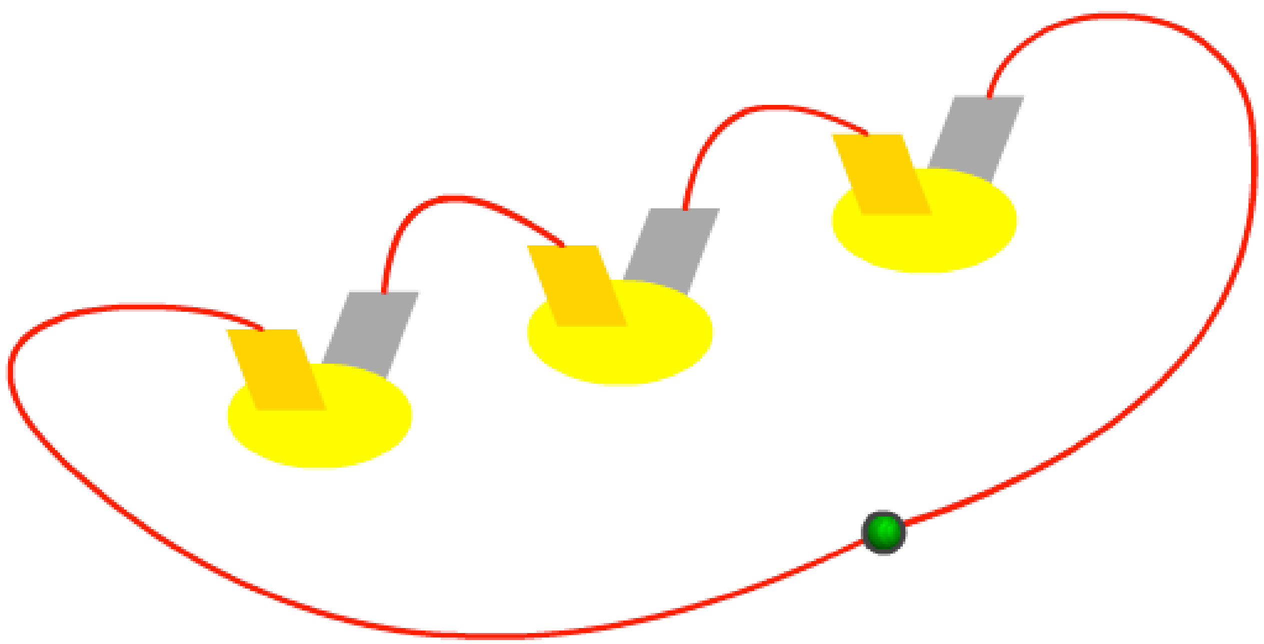


Batteries, cells and energy stores

Making a battery

- Connect several (five or six) separate fruit cells together, use normal lab wires with crocodile clips to connect the fruits, copper to zinc each time.

- Connect a light emitting diode (led) between the terminals of the first and last fruit. It should light. Note that the direction of electric current in an LED is important: you might have to reverse the connections to allow the charges to flow in the correct direction.



Resistance and energy transfer

How does energy get from the battery to the surroundings as the bulb lights? What happens is that when the circuit is completed, charges in all parts of the circuit are set in motion. As the charges pass through the bulb, energy is shifted to the surroundings. The bulb itself consists of a very thin wire, or filament, inside a glass globe. As the charges start to pass through the thin filament, it heats up and glows.

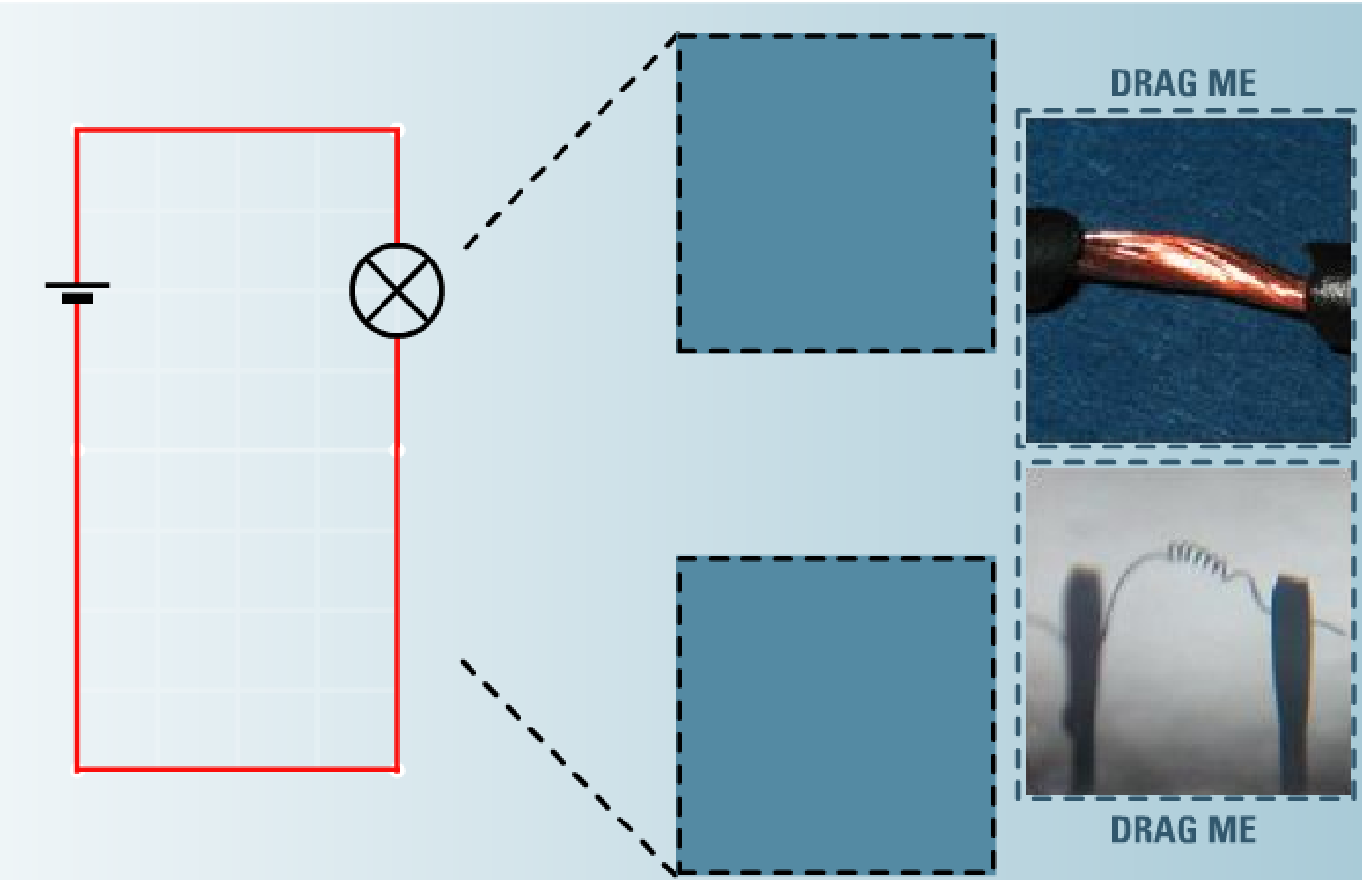
How does this happen? As the charges (or electrons) move around the circuit, they are constantly colliding with the fixed array of ions through which they pass. However, in the bulb the geometry (very small cross-sectional area) and internal structure (the layout of the atoms) of the filament wire combine to make it particularly difficult for the charges to pass through, and energy is therefore shifted by the filament wire during the collisions.

The filament wire is said to provide a high resistance to the passage of the charges. As the moving charges collide with the fixed ions, the ions are made to vibrate more and the filament heats up. After a while the energy radiated by the glowing filament matches the energy gained by the collisions, and the filament does not heat up any more.

Choosing where the energy gets shifted

Drag the wires to where you would expect to find them.

CHECK IT



Resistance and energy transfer

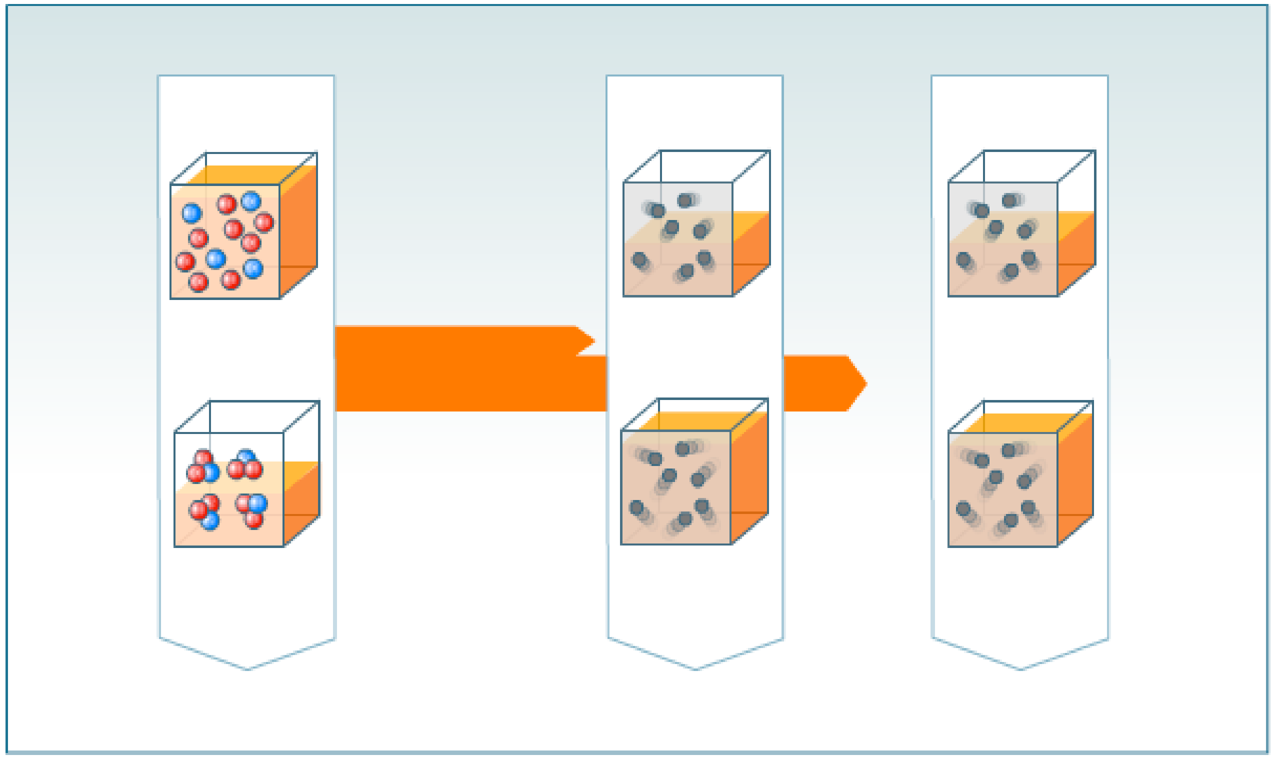
By way of contrast, the connecting wires for the circuit are usually made from relatively thick (i.e. large cross-sectional area) lengths of copper wire, which have a minimal resistance. The circuit components are designed so that most energy is shifted in the intended component (i.e. in the bulb). An important point to remember is that wherever an electric current encounters resistance, energy is shifted.

A summary, so far

So, to summarise the main points:

- Once the circuit is complete, charges (electrons) around the circuit are set in motion.
- Energy is shifted by the filament of the bulb as the charges pass through and light it up, dissipating energy to the surroundings.

In this way you might imagine a continuous shifting of energy by the circuit, with the battery's store of energy steadily going down at one end as energy is dissipated to the surroundings in many thermal stores at the other end.



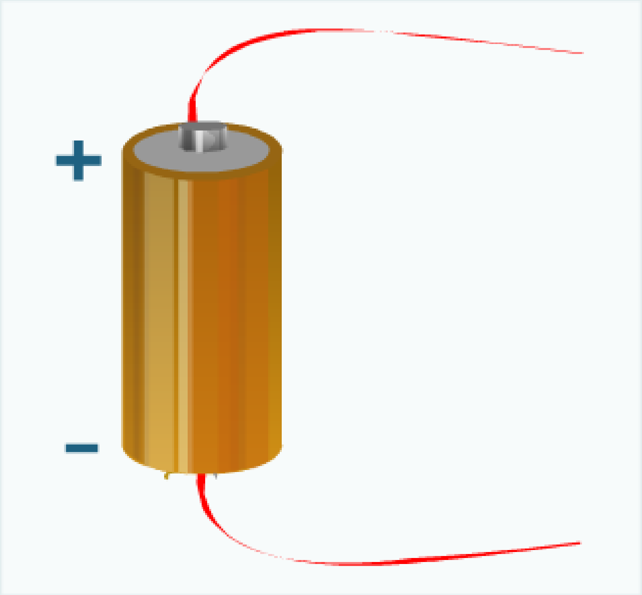
A summary, so far

We can also describe the event in terms of energy pathways (see Energy topic). When the bulb is connected to the battery, glowing steadily, it heats up the surroundings as energy is shifted (or transferred) through electrical working (as the current passes through the resistance of the filament).

So the bulb heats up and gives out light. This energy description of the event (see Energy topic, Episode 3), tells us nothing about the mechanism by which it happens. If you are interested in reading a more detailed account of how energy is shifted by the bulb, take a look at the following section.

What the battery does

Fade between a physical view and an energy description of the same process.



FADE
ENERGY DESCRIPTION
SEE THE BATTERY

STEP 1 of 3

Shifting energy from battery to surroundings via bulb

Read more about the mechanisms by which energy is shifted in a circuit.

When we say that it is the charges moving round the circuit, that enables the shifting of energy from battery to surroundings, what exactly do we mean? The answer to this question is not straightforward! It may be of interest to you, but is certainly not appropriate for pupils in the 11-16 age range.

The basic idea is that when the simple circuit is complete all of the charges in the circuit are set into motion as they are pushed away from the battery terminal of the same charge and attracted towards the battery terminal of the opposite charge (the negatively charged electrons throughout the circuit are pushed away from the negative terminal and attracted towards the positive).

An alternative way of thinking about this is to say that the battery creates an electric field around the circuit between its positive and negative terminals, and the charges start moving due to the effect of this field (just as a mass has a force exerted upon it in a gravitational field). All of the charges in the circuit experience the force or "push" of the battery, even if they are not in direct contact with either of its terminals (just as masses experience the "pull" of the Earth without being in direct contact with it). This is the phenomenon of action-at-a-distance, which is discussed in detail in the Forces topic. An important point here is that almost as soon as the electric circuit is completed, an electric field is created throughout the circuit.

These electrical forces are not equally large everywhere in the circuit. Where the forces are greater the charges shift most energy in moving a small distance. (See the energy topic for more detail).

Think about the comparative thickness of the wires. To keep the charges moving, you would have to push hardest where the wires are thinnest. That is where most energy gets shifted.

As a charge (along with the countless other charges) moves round the circuit under the influence of the electric field, it collides with the fixed ions, that make up the connecting wires and bulb filament. As a result of each collision, the mobile charges are slowed down and the ions vibrate more. The charge is then accelerated by the electric field and moves off once again before undergoing another collision with a different ion. In the thin, highly resistive wire of the bulb filament, there are many such collisions, so the ions here vibrate a lot. In the connecting wires, there are fewer collisions and so the ions vibrate rather less.

The difference in the rate of collisions leads to far less electrical working in the connecting wires and far more in the filament. Why then does one part come to glow when the circuit is first switched on? The thermal store of the filament is therefore filled and the filament warms up and glows. The connecting wire does not glow, as its thermal store is much emptier.

This difference in rate of collisions continues once the circuit has settled down. So most energy is shifted by the interactions of the ions and mobile charges in the filament wire, not the connecting wires.

Shifting energy from battery to surroundings via bulb

What happens in the battery?

When the charges reach the positive terminal of the battery, energy must be shifted as they move across onto the negative terminal. Again, a great force is needed for this section of the circuit, so lots of energy is shifted as each charge moves across this part of the circuit. All this happens within the battery, but only at the cost of emptying the chemical store of the battery. When this store cannot do its job any more, we say it has “gone flat”.

There is no mystery here - you simply engineer the parts of the circuit so that the forces on the charges vary as they drift around the circuit at more or less constant speed. A greater retarding force caused by the material that the charges are moving through is balanced by a greater driving force from the electric field set up by the battery.

It is with this kind of picture in mind that we say that the battery provides energy for the circuit and that the movement of the charges around the circuit enables energy to be shifted from battery to surroundings by the bulb.

It is not the case that charges must actually pass through the battery to shift energy. All of the charges in the circuit can shift energy due to the electric field created by the battery.

The charges are always there…but something must get used up!

When a battery is connected to a bulb, the bulb heats up and gives out light. It is clear that something must be getting used up somewhere. According to the electric circuit model introduced, it should also be clear that it is the energy provided by the battery, which is gradually dissipated, as lighting and heating occurs.

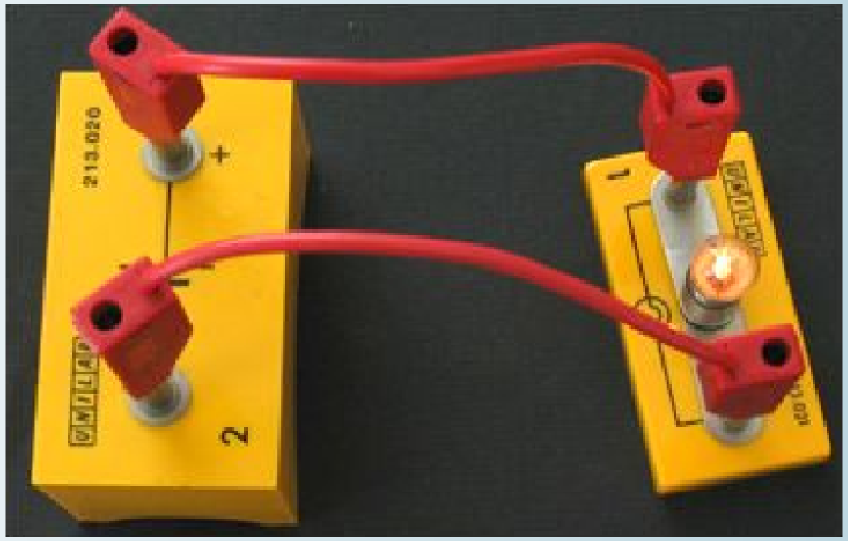
When all of the chemicals in the battery have reacted and there is no more energy to be supplied by the battery, we say that the battery has "gone flat". The charges stop moving and the bulb goes out. On first coming across these ideas, it is quite common for people to think that it is the electric current which gets used up. However, the current simply performs the job of shifting energy. What happens is that the store of energy in the battery runs down as energy is dissipated through heating and lighting in the bulb.

Two kinds of flow

Add to the image to show how much energy is shifted

CHECK IT

CHOOSE ENERGY



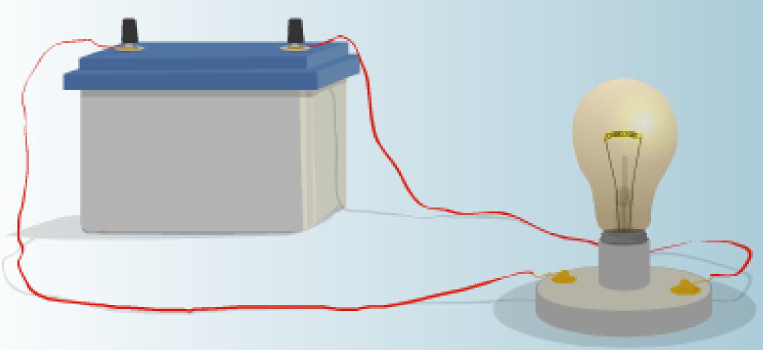
CHOOSE ENERGY

Check your progress

You can use the following questions to check your own understanding of this episode and your pupils' understanding.

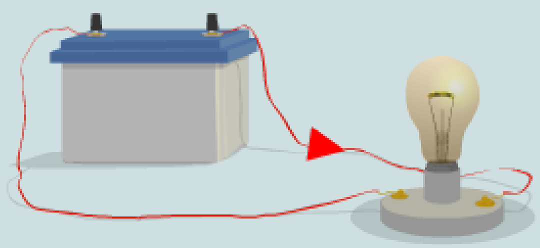
Electric Current — Question 1 of 4

1. A bulb is connected to a battery. The bulb is lit.

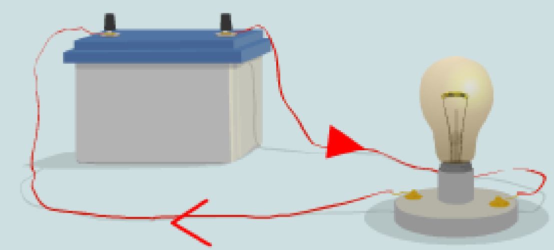


Which of the following best describes the electric current in this circuit?

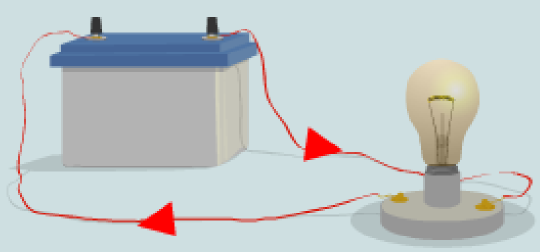
Tick one of the following, and press "check it" when you are happy with your answer.



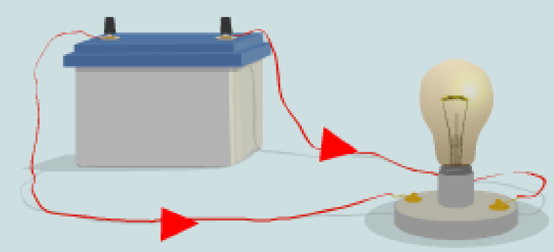
a) There is an electric current through one wire to the bulb. It is **all** used up in the bulb so there is **no current** in the other wire.



b) There is an electric current through one wire to the bulb. **Some** of it is used up in the bulb. So there is a **smaller current** in the other wire.



c) There is an electric current through one wire to the bulb. It passes through the bulb and back to the battery. The current in the other wire is **the same size**.



d) There are **two** electric currents from the battery to the bulb. They **meet** at the bulb and this is what makes it light.

Once you are happy with your answer click "check it" to continue

CHECK IT