COSMOS LESSONS

Physics

Electrical Circuits: Dressing smart

Electrical circuits are everywhere in the modern world – hidden in the walls of our houses and packed inside our phones, computers and cars. Engineers are now working at knitting circuits into our clothes so we might one day wear devices that continuously monitor our health.

In this lesson you will investigate the following:

- What is electrical current and how is it created?
- What are the necessary components of a circuit?
- What are voltage and resistance, and how are they related?
- What is Ohm's law?

Charge up for a lesson on what's current in electrical circuits!

This is a print version of an interactive online lesson. To sign up for the real thing or for curriculum details about the lesson go to **www.cosmosforschools.com**

Introduction: Electrical Circuits

Electronics are everywhere. And as older people like to say, young people today are "digital natives" – you're confident and competent with computers, smartphones, and any other electronics devices thrown at you. It's likely you've had to give a grandparent or neighbour advice on how to use a computer or the car navigation yourself!

But when it comes to the clothes on your back there's not much that your grandparents wouldn't recognize – apart from the fashion, maybe. There are cotton, silk and woollen garments just as there have been for hundreds of years, and synthetic fibres have been around for over a century now.

But the electronics geeks have their eyes on your threads now, too, with scientists working on ways to integrate electronics into fabrics.

For a start, they envisage building in sensors. These would monitor the forces your muscles are exerting, impacts on your body, and your temperature, heart rate and respiration. This information could be recorded for later use or be set up to trigger a warning, if needed. Some fabrics might even be clever enough to react, for example stiffening up to give you extra support when your muscles are straining.

The problem, though, is that the best materials to make electrical circuits out of are metals. Unless you're happy in a mediaeval knight's armour, they're not the best clothing option. But a team in Hong Kong has created yarn from very thin copper wire coated with lycra, and then knitted it! Copper doesn't stretch, but when it's knitted there's enough slack that the resulting fabric can. So you can be comfortable and switched on.

That just leaves the scientists to design the circuits they want to build into your jumper.

Read the full *Cosmos Magazine* article here.

Question 1

Imagine: You wake up one morning to find that electricity has disappeared from the world. How will your life be different from now on? Either give a simple description or let your imagination loose and write a short story.

Gather: Electrical Circuits

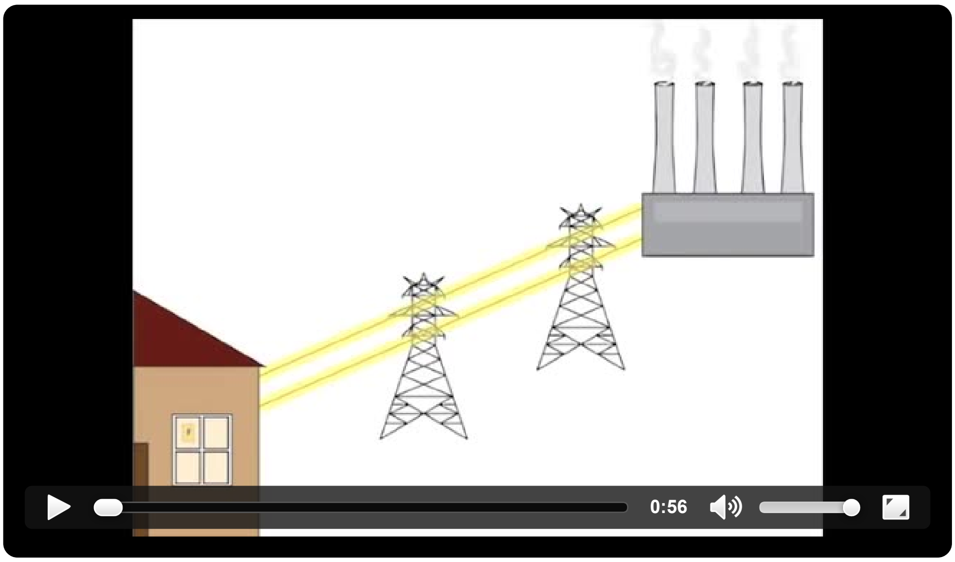
What is electrical current?

You've probably already relied on electricity countless times today: the alarm clock that woke you up, the lights that dazzled your sleep-filled eyes, the fridge that kept your eggs, milk or juice cold for breakfast and maybe the electronic gadgets that entertained you on your way to school.

In this lesson we'll investigate the basics of electricity, or electrical current, and what we need to put it to use:

- it must have a closed pathway, or **circuit**, to flow around,
- it must have an energy source such as a power station, generator or battery which causes the current to flow, and
- it must flow through certain parts, or **components**, of the circuit that can use the energy to do something useful – for example, a light globe, motor or computer.

A river or ocean current is a flow of water, but what exactly flows in an *electrical* current?



Question 1

Recall: Electrical current in a metal wire involves the flow of:

- [ ] electrons
- [ ] metals
- [ ] atoms
- [ ] water

Question 2

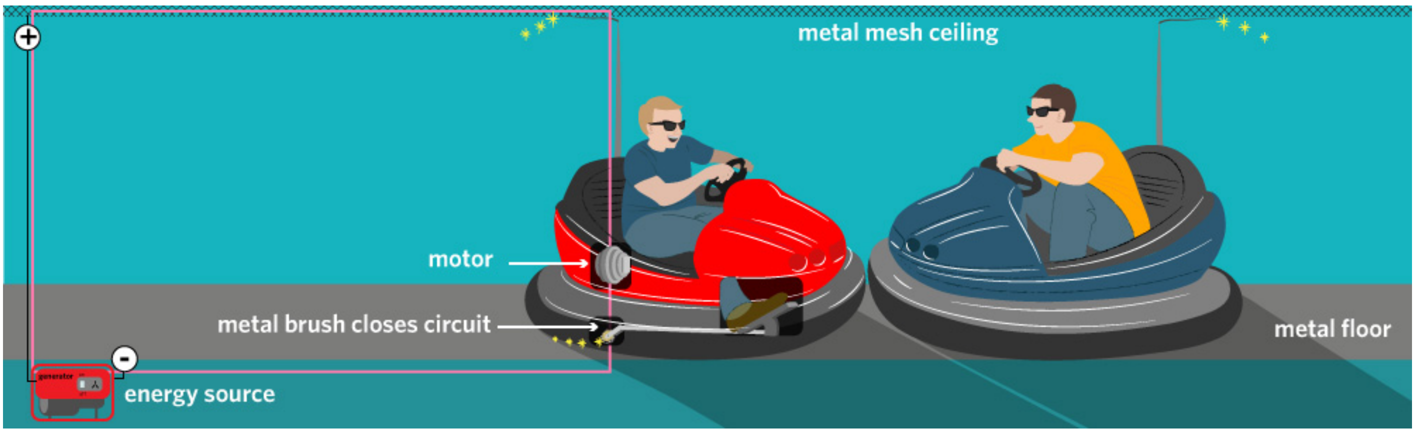
Remember: Which of the following are needed to light up a light globe as part of an electrical circuit?

- [ ] The circuit must be closed.
- [ ] The circuit must be open.
- [ ] The electrons in the connecting wires must be moving in random directions.
- [ ] There must be a difference of charge at either end of an energy source, such as a power station.

Have you ever taken the wheel of a dodgem car, or bumper car, and tried to ram other cars out of your way? Dodgem cars get the power to move by forming part of an electrical circuit connected to an energy source, as shown in the diagram below. When you press down on the accelerator a wheel with a metal brush is lowered to the metal floor. This acts as a switch that closes the circuit – shown by the pink line – allowing electrons to flow through the motor.

Just like a flow of water, a flow of electrons is known as a **current**. The standard unit of electrical current is the **ampere** (A) – or "amp" for short. A current of 1 amp means that about 6,241,000,000,000,000,000 electrons are flowing through a point on the circuit every second!

Dodgem cars might get up to 100 A – the higher the current, the faster they move.



Question 3

Decide: Which of the following components form part of the electrical circuit that powers the dodgem car shown above?

- [ ] A light globe
- [ ] A motor
- [ ] A switch
- [ ] An energy source

Question 4

Infer: As the current flowing around the dodgem car circuit increases from 10 A to 50 A, which of the following are true?

- [ ] The dodgem car speeds up.
- [ ] The number of electrons flowing through the motor each second increases.
- [ ] The dodgem car slows down.
- [ ] The switch formed by the metal brush opens, breaking the circuit.

Voltage

Electrons need to be given energy to "push" them around a circuit. A battery stores chemical energy that is transferred to electrons when the battery's two metal contacts, or **terminals**, are connected by a circuit. Electrons use the energy to flow from the negative to the positive terminal. Along the way they transfer their energy to components such as light globes, motors and heating elements.

Voltage, measured in **volts** (V), is a measure of how much energy is given to the moving electrons in a circuit. Another way of thinking of voltage is by analogy with the pressure that pushes water through the pipes in a house. This likens voltage to a force: the higher the voltage supplied to a circuit, the bigger the "push" the electrons receive.

Question 5

Compare: Which of the following provides the most energy to moving electrons?

- ☐ A 1.5 V torch battery
- ☐ A house power supply of 240 V.
- ☐ A 12 V car battery
- ☐ A laptop power supply of 19 V.

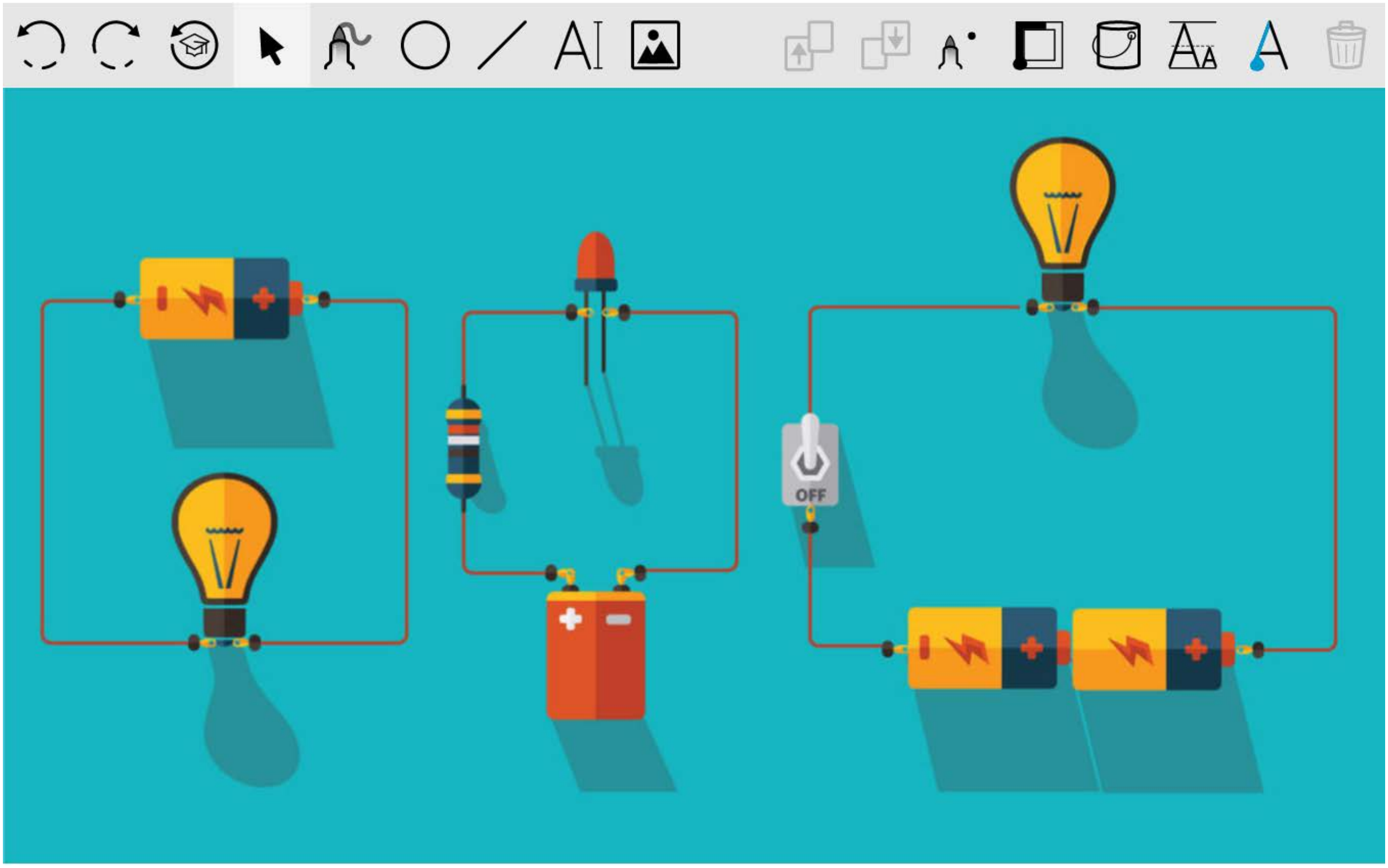
Question 6

Calculate: When batteries are stacked end to end their voltages add together. What is the total voltage provided by six 1.5 V batteries used in a torch?

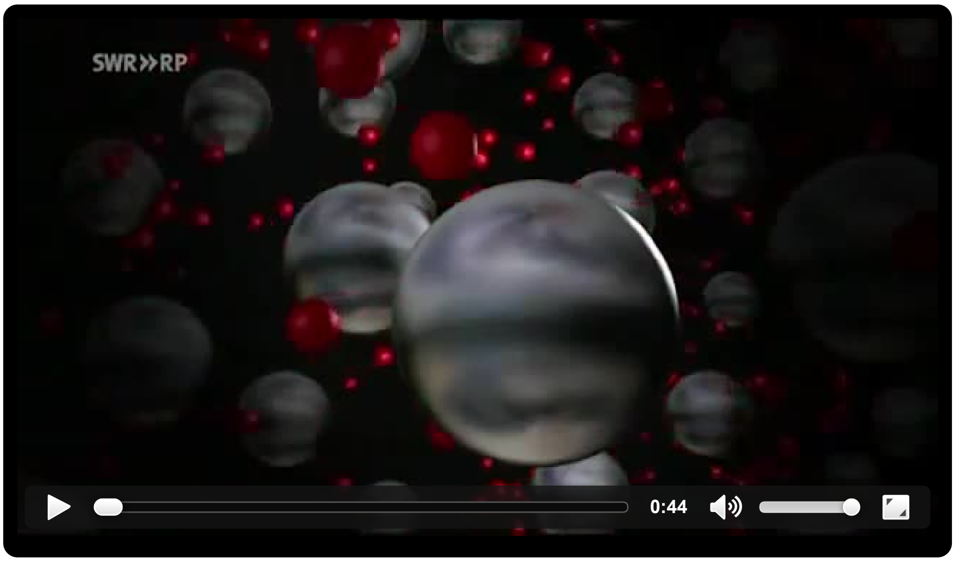
- ☐ 3 V
- ☐ 6 V
- ☐ 9 V
- ☐ 12 V

Question 7

Draw: Draw two arrows (one up and one down) within each of the following circuits to show the direction of electron flow.



Resistance



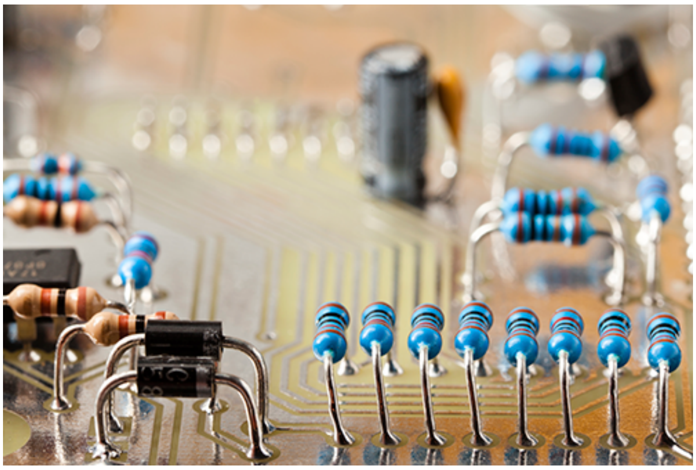
Question 8

Paraphrase: Using the information provided in the video, explain in your own words what **resistance** is.

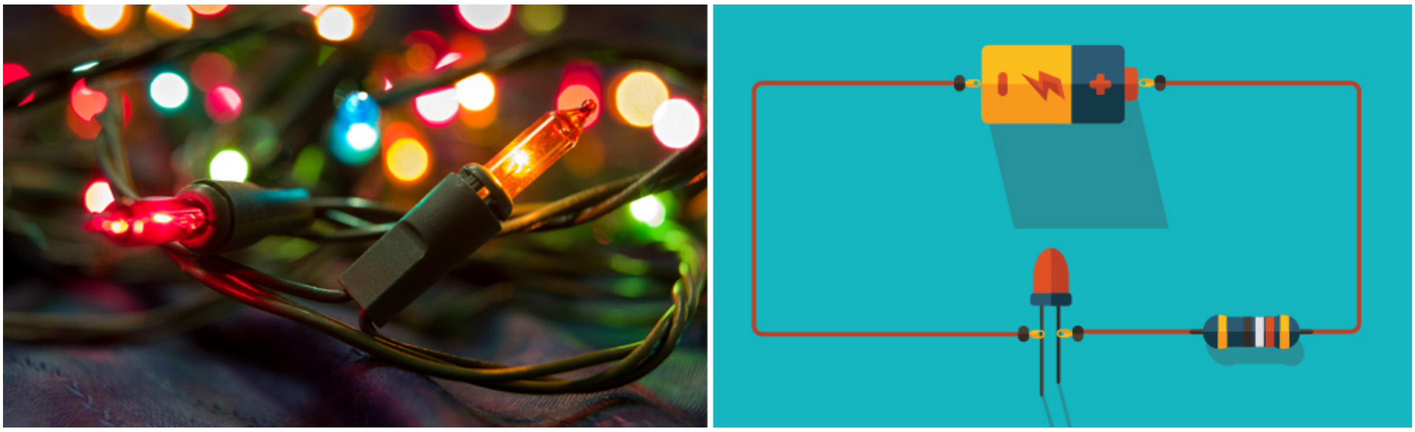
Resistance is measured in the special unit of **ohms**, symbolized by the Greek letter omega (Ω). The higher the resistance of a component, the harder it is for electrons to flow through it and the more energy they lose. The resistance of the connecting wires in typical electrical circuits is so low that we can assume it's zero.

Resistors are special components with high resistance designed to lower the current passing through a circuit. One example of their use is to protect **light emitting diodes (LED's)**, which need low currents between 1 to 20 mA or they will burn out.

Note: There are 1000 milliamps (mA) in 1 amp.



Resistors have coloured bands to indicate the exact amount of resistance they provide.



Left: Christmas or fairy lights use LED's. Right: An LED coupled with a resistor in a simple circuit.

Question 9

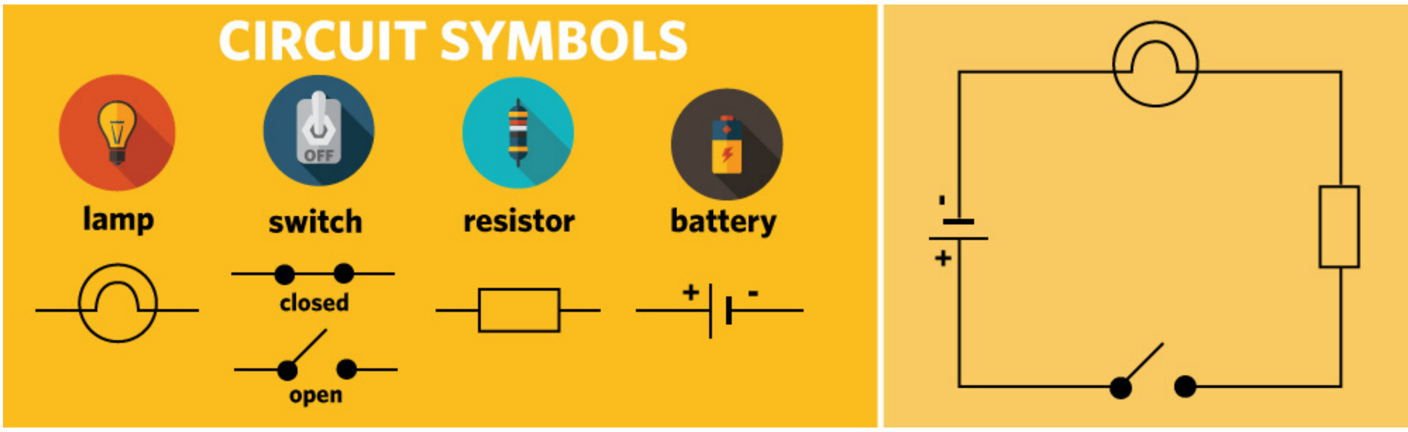
Complete: Identify what is being described in each row of the following table and type your answers into the right hand column.

A flow of electrons around a circuit.	
The standard unit of resistance.	
A number of components connected together to form a closed loop.	
The type of subatomic particle that flows through an electrical circuit.	
The standard unit of current.	
A measure of the amount of "push" supplied to electrons in a circuit.	

Circuit diagrams

Just as it's useful to have house plans so that the builders know how to put your house together, it's also useful to have diagrams to clearly show how circuits are put together.

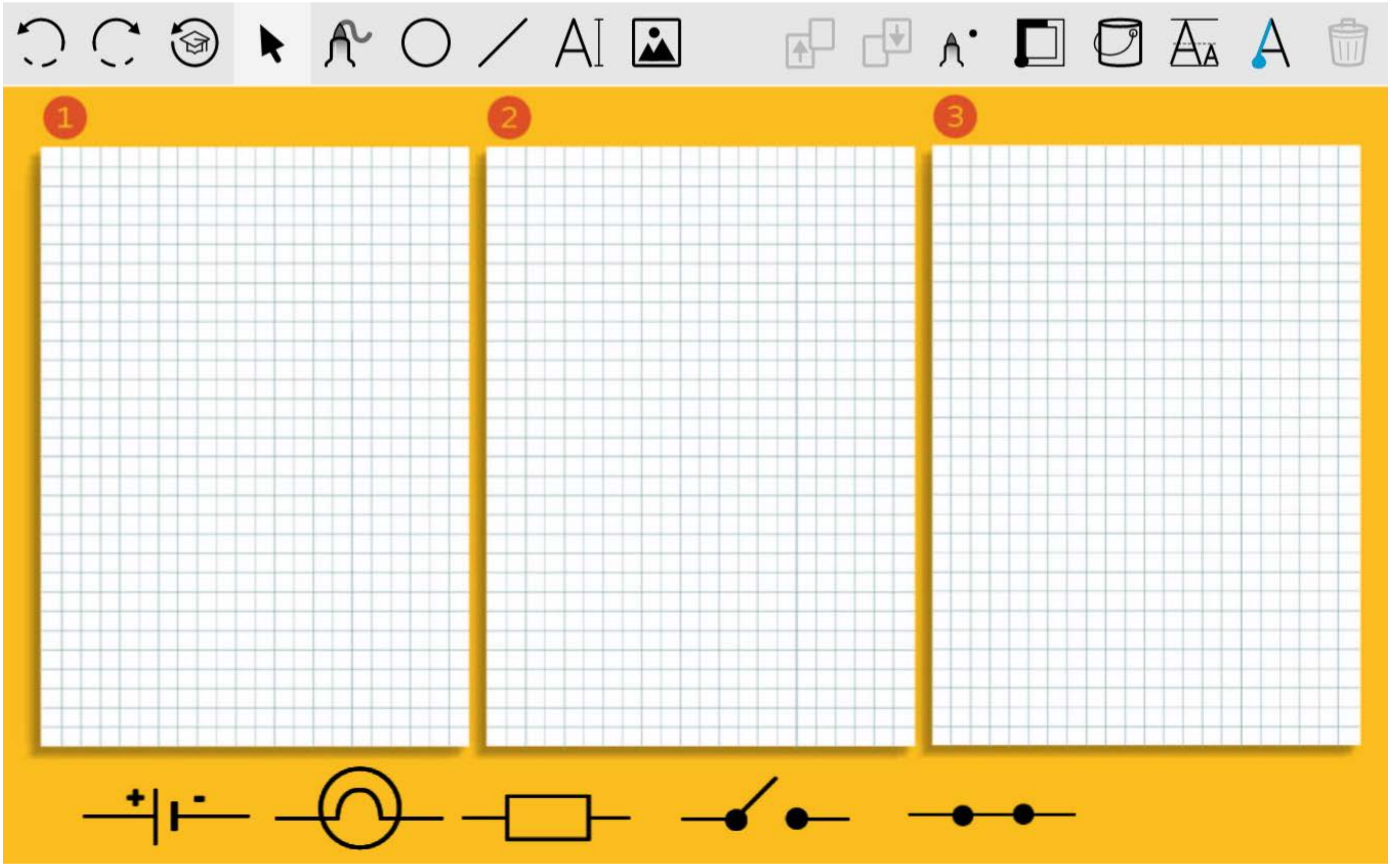
Some of the most common symbols are shown in the diagram below, along with an example of a circuit diagram.



Question 10

Design: Using the symbols provided in the sketchpad as well as the line tool, construct diagrams for:

1. A circuit that contains two light globes, both of which are lit up.
2. A circuit that contains two light globes, neither of which are lit up.
3. A circuit in which the electrons first flow through a resistor and then through a light globe.



Process: Electrical Circuits

COSMOS LESSONS

Ohm's law

The standard unit of resistance was named after Georg Ohm, the rather cranky-looking German gentleman shown above. Ohm investigated the basic principles of electrical circuits and discovered a simple mathematical relationship between current, voltage and resistance.

Question 1

Predict: Recall that voltage is a measure of the "push" that moves electrons around a circuit. If you have a resistor in a circuit powered by a single 3 V battery and then simply add another 3 V battery, what do you expect will happen to the amount of current produced? Explain your answer.

Question 2

Infer: If you then remove both batteries from the circuit and connect the wires together, how much current will flow? Why?

We should expect that increasing the voltage in a circuit will increase the current because the added voltage will "push" more electrons through each point per second. You can test this hypothesis experimentally by systematically varying the voltage of the batteries in a circuit and measuring the current produced. When you graph the results you get a simple linear relationship, or straight line.

Ohm discovered that current is **directly proportional** to voltage: double the voltage of a circuit and you double the current. Written as an equation:

$$I = mV$$

where *I* is the current in amps (A), *V* is the voltage in volts (V) and *m* is the gradient or slope of the straight line.

The following section explains this mathematical relationship in more detail and Question 3 relates to this explanation. If you have trouble with this section you can skip ahead to Question 4.

Optional section:

The general equation for a straight line is:

$$y = mx + c$$

where:

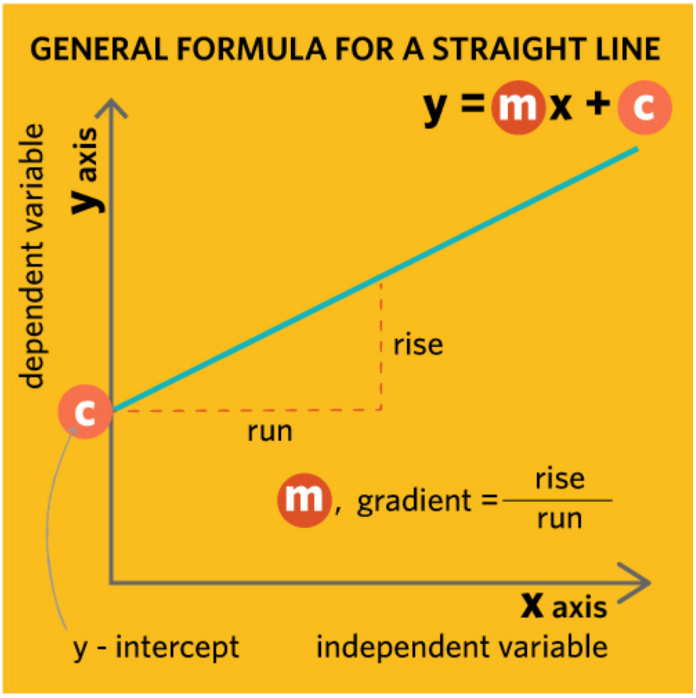
- *y* is the dependent variable on the vertical axis,
- *x* is the independent variable on the horizontal axis,
- *m* is the gradient or slope, and
- *c* is the *y*-intercept – the point where the line hits the *y*-axis.

Current depends on voltage, so current is the dependent variable and voltage is the independent variable. So:

$$I = mV + c$$

But if the voltage is zero then electrons have no energy to flow at all and the current is also zero. This means that the *y*-intercept, *c*, must be zero and it disappears from our equation.

This is what makes current directly proportional to voltage. If the y-intercept wasn't zero then doubling the voltage wouldn't lead to a simple doubling of the current.

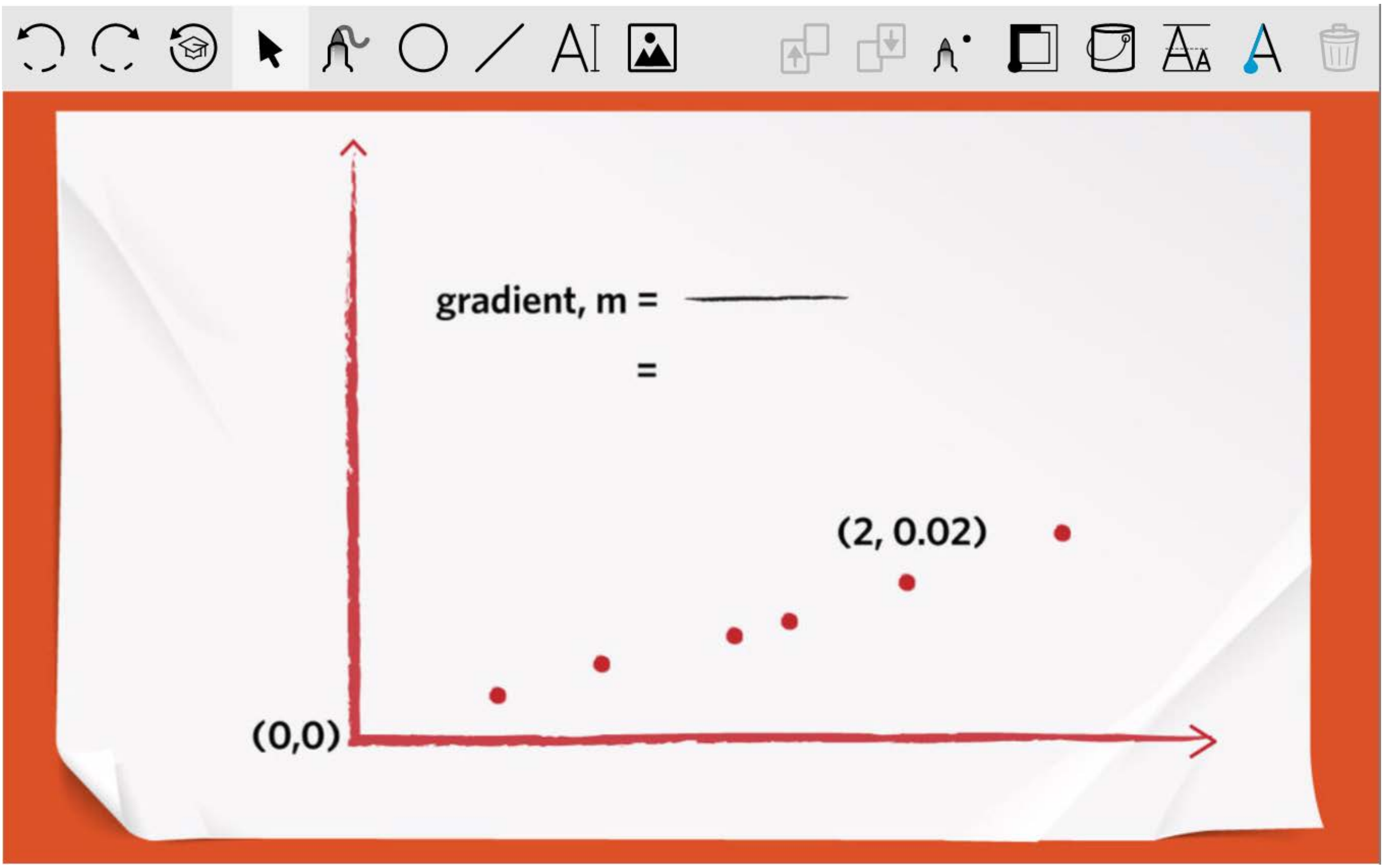


Question 3

Optional question:

Label: Ohm has carried out some experiments on the way current depends on voltage and plotted some points on a graph but he's forgotten to finish the job.

1. Label the *x* and *y* axes using the format: *variable, symbol (unit symbol)*. e.g. mass, m (kg)
2. Draw a straight line through the points and show where it intersects the *y* axis.
3. Calculate the gradient using m = rise/run and the labelled points and type your answer in the space provided.
4. Use the gradient value to write the equation of the line.
5. Add a title to the graph.



Question 4

Select: Doubling the voltage supplied to a circuit will:

- ☐ double the amount of resistance.
- ☐ double the amount of current.
- ☐ halve the amount of current.
- ☐ halve the amount of resistance.

Question 5

Infer: A certain circuit with a 9 V battery has a current of 3 A. How much current would flow if the same circuit was powered by a 3 V battery?

- ☐ 0.3 A
- ☐ 1 A
- ☐ 3 A
- ☐ 9 A

Question 6

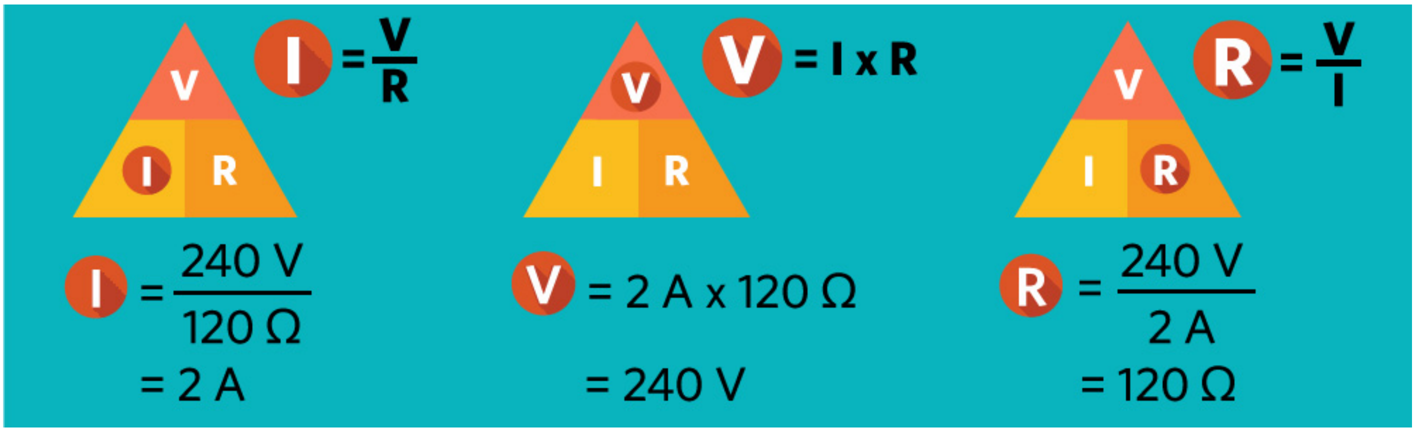
Predict: Now suppose we keep the voltage constant and see how the current changes when we alter the amount of *resistance* in the circuit. Would you expect the amount of current to increase, decrease or stay the same as the resistance increases? Explain your answer.

Experiments show that if you keep the voltage constant and double the resistance in a circuit you will halve the amount of current. We say that current is **inversely proportional** to resistance. This means that resistance, R – measured in ohms (Ω) – will need to appear on the bottom of a fraction in our equation for current. It turns out that $1/R$ is the gradient, m, in our earlier equation $I = mV$.

Putting all of this together, we get what is known as **Ohm's law**:

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

We can use Ohm's law to calculate one of the three quantities so long as we know the other two. If we need to calculate V or R, it helps if we transpose the equation so that the unknown quantity is on the left hand side.



This triangle is a handy way of remembering the three forms of Ohm's law, which can be found by transposing the equation. Worked examples show how you can find an unknown quantity so long as you know the other two.

Question 7

Calculate: The circuit in a particular walkie-talkie has a total resistance of 450 Ω and the battery is supplying 9 V. How much current, in amps (A), is flowing?

Question 8

Calculate: You have a red LED that you want to connect to a 12 V battery. The maximum current that it's safe to put through this LED is 10 mA. How much resistance does the circuit need?

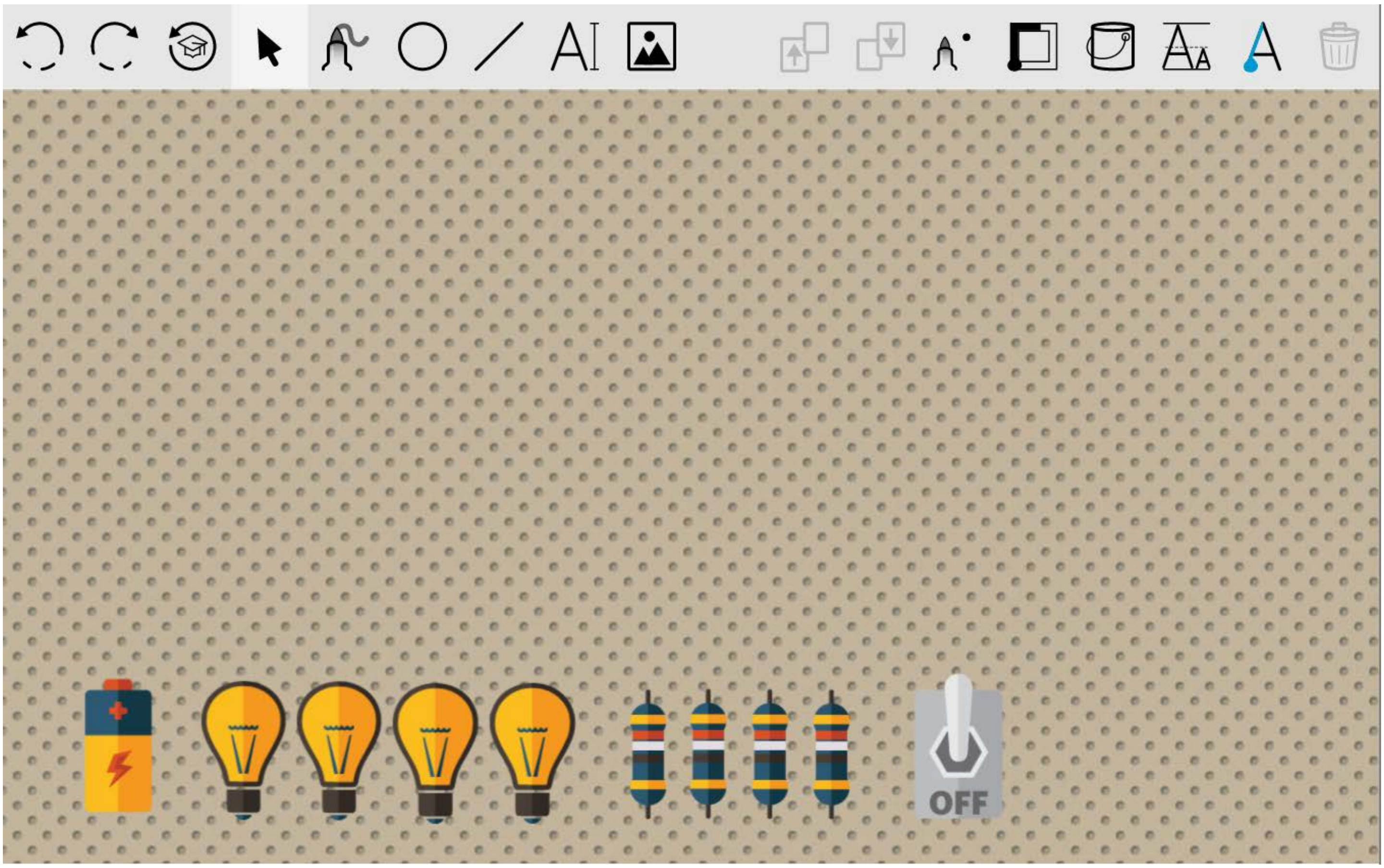
Hint: Remember that there are 1000 mA in 1 A.

Question 9

Construct: Suppose you want to build a circuit with a 12 V battery and a current of 1 A flowing through it.

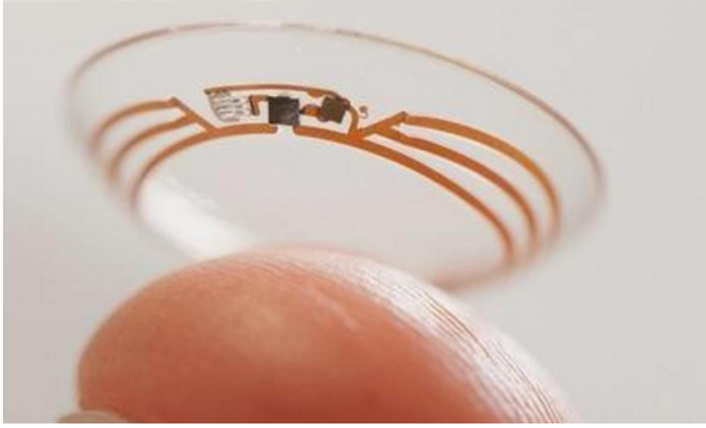
1. Use Ohm's law to calculate the total resistance required.
2. Construct the circuit by rearranging some of the components below. Each resistor has a resistance of 5 Ω and each light globe has a resistance of 2 Ω. Draw straight lines or a rectangle to represent the connecting wires and assume that they have a resistance of zero.

Hint: The order of the components doesn't matter.



Question 10

Calculate: You've been given a new robot for Christmas! The total resistance of its internal circuitry is 900 Ω and the current it requires is 5 mA. How many 1.5 V batteries will it need to operate?



Left: A smart contact lens which is being developed to help diabetics keep track of their sugar levels. A sensor monitors the sugar in their tears and a microchip can send an alert to their mobile phone. Right: The "spider dress" designed by Anouk Wipprecht uses sensors to detect emotional stress and responds by raising its spider-like arms.

Question 11

Design: The *Cosmos Magazine* article describes how scientists are developing ways of building electrical circuits into clothes. Imagine wearing a jacket that keeps tabs on your health, gloves that act as a lie detector, or a T-shirt that doubles as a flexible TV screen!

Now that you understand the basics of electrical circuits, it's time to get your creative juices flowing and think of a useful or fun application of this sort of technology. You can use any of the tools in the project space to present your idea but be sure to include the following:

- the type of clothing that your design requires, e.g. jacket, dress, hat, glasses, socks, shoes.
- the locations of the key components of the electrical circuit, e.g. batteries or other power source, light globes or LED's, heating elements, resistors, motors, sensors (for detecting light, temperature, movement, smells, and so on).
- how the components are connected by wires.
- the purpose of the technology and why you think people would want to buy it – maybe even write, draw or record an advertisement!

Apply: Electrical Circuits

COSMOS LESSONS

Experiment: Variations in current and voltage

Aim

To investigate whether current and voltage vary around a simple electrical circuit.

Hypothesis

Question 1

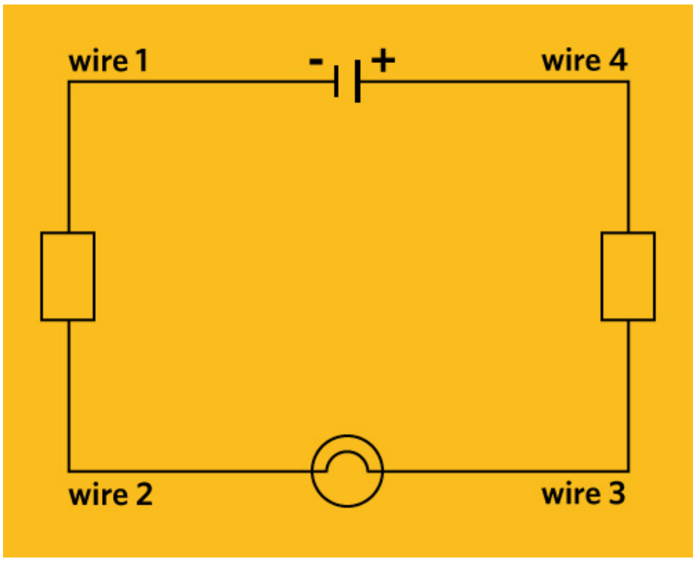
Predict: Current is the number of electrons flowing through *a single point* in a circuit. Make a prediction about whether the amount of current will increase, decrease or stay the same as it flows around a simple circuit. Why do you think this?

Question 2

Predict: Voltage is the force that drives electrons *between two points* in a circuit – for example, between the two terminals of a battery. Would you expect the same voltage across different sections or components of a circuit? Explain your reasoning.

Materials

- A battery
- A light globe or lamp
- 2 resistors
- 4 connecting wires
- An ammeter and a voltmeter (or a multimeter)

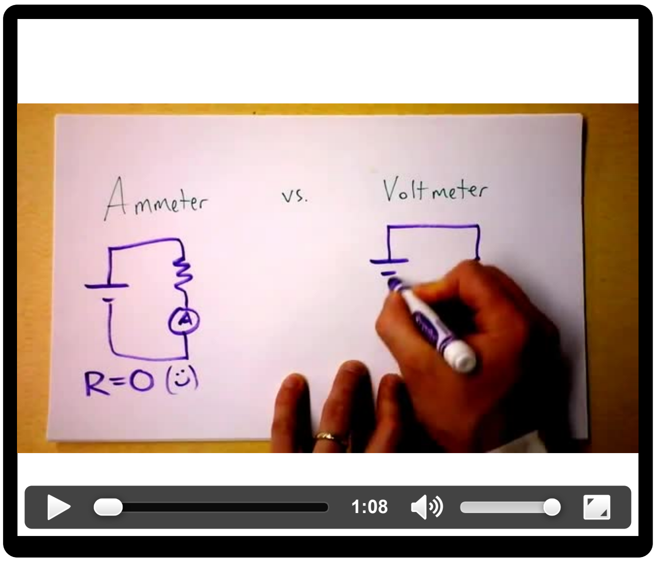


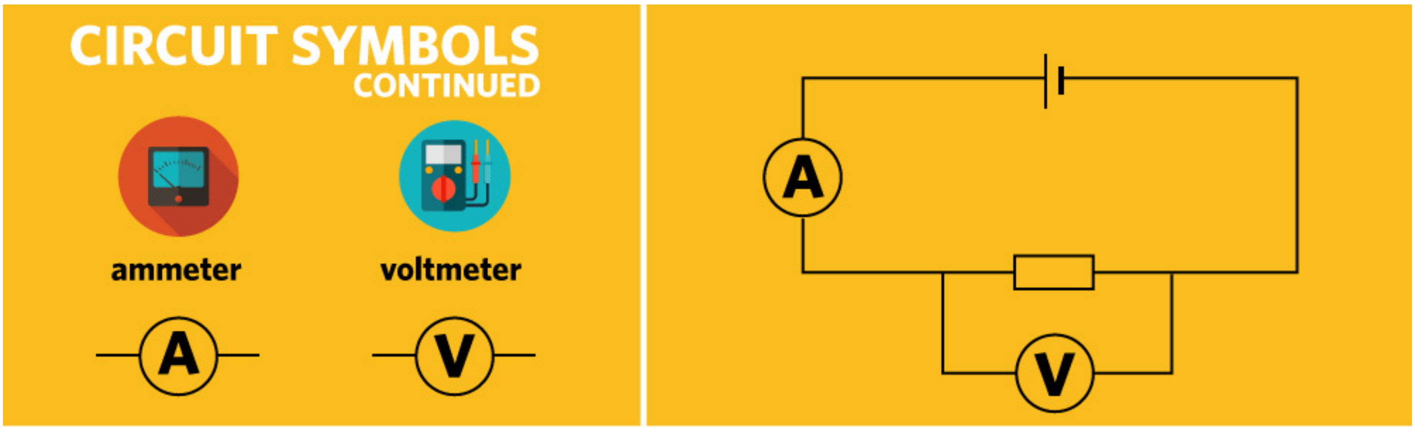
Procedure

1. Construct the simple circuit shown in the diagram on the right.

Measuring instruments:

An **ammeter** is a device used to measure current and a **voltmeter** is used to measure voltage. Alternatively, a **multimeter** can be used to measure either variable depending on which mode is selected on the control dial.





The symbols for an ammeter and a voltmeter (left), and a simple circuit diagram showing the different ways in which they need to be connected in order to make measurements (right).

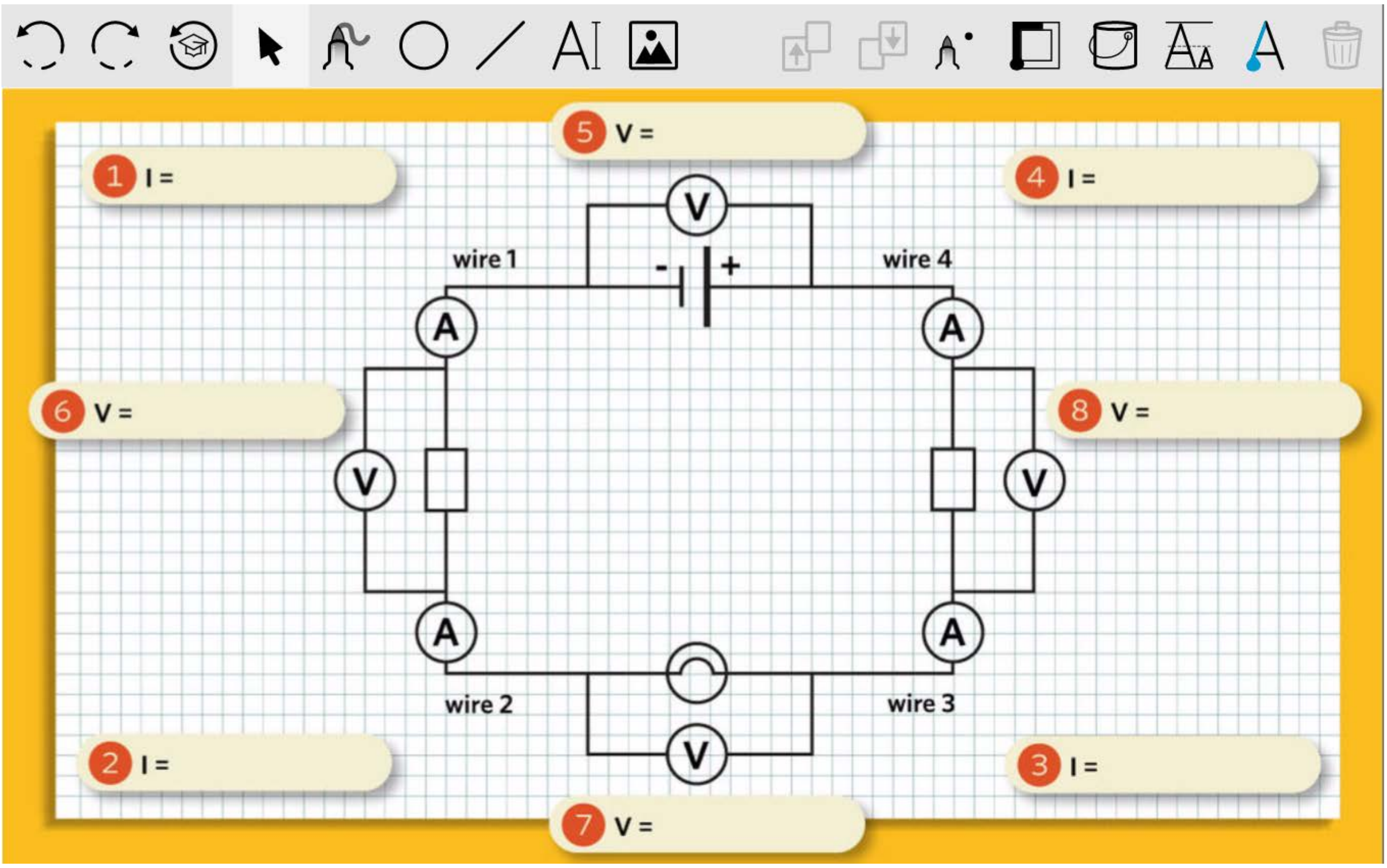
Procedure (continued)

1. Returning to the circuit you've constructed, replace wire 1 with the ammeter by disconnecting both ends of the wire and then connecting the ammeter's black lead to the negative terminal of the battery and the red lead to the first resistor.
2. Adjust the setting of the ammeter (or multimeter) until you can read the current in milliamps (mA). Record this value in the sketchpad below.
3. Disconnect the ammeter and replace the original wire.
4. Repeat steps 2-4 for each of the remaining three wires in turn. Record your results in the sketchpad as you go.
5. Measure the voltage provided by the battery by connecting the black lead of the voltmeter to the black or negative terminal of the battery and the red lead to the red or positive terminal. You don't need to disconnect anything in the original circuit. Record this measurement in the sketchpad.
6. Measure the voltage across the first resistor by connecting the two leads of the voltmeter to either side. To get positive readings, connect the black lead closer to the negative terminal of the battery – but if you do get negative readings then just ignore the negative sign. Record this measurement in the appropriate place in the sketchpad.
7. Repeat step 6 for the light globe and the second resistor.

Results

Question 3

Record: Enter your results into the following sketchpad. The position of the ammeter or voltmeter is shown at the appropriate place for each measurement but the measurements should be made one after the other, in the order shown by the numbered red circles.



Discussion

Question 4

Describe: Did you discover any variation in the current in different sections of the circuit? If so, were they large enough to be significant (given that all measuring instruments have some degree of error)?

Question 5

Explain: Is this result consistent with your initial hypothesis? If not, explain the result in terms of the flow of electrons through the different parts of a circuit.

Question 6

Analyze: Did you discover any variation in the voltage across the different components of the circuit? Is this consistent with your initial hypothesis? Compare the voltage across the battery to the voltage across the other components and describe the relationship between them.

Question 7

Calculate: Use Ohm's law to calculate the resistance of each of the resistors and of the light globe.

Question 8

Explain: In terms of the effect of resistance on electrons, explain why the voltage "drops" over components in the circuit.

Conclusion

Question 9

Compare: Write a concluding statement addressing the aim of the experiment.

Career: Electrical Circuits

Brought to you by Edith Cowan University

Question 1

Investigate: As the video shows, electrical engineers get to work on a wide range of interesting projects in diverse fields. Use an internet search to find out more about one of these projects and write a short summary of how electrical engineers contribute to it.

Cosmos Lessons team

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