*Physics > Big idea PEM: Electricity and magnetism > Topic PEM8: Mains electricity*

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| **Key concept (age 14-16)** |
| **PEM8.1: Electrical safety** |

**What’s the big idea?**

A big idea in physics is electricity and magnetism. The familiar everyday world we live in is largely a consequence of the properties and behaviour of electric charge. Matter is held together by electrostatic forces, and these influence chemical changes. Electricity and magnetism initially seem distinct phenomena but are later found to be closely interrelated. Understanding electricity and magnetism helps us to develop our technology and find applications that can transform our everyday lives.

**How does this key concept develop understanding of the big idea?**

This key concept helps to develop the big idea by developing an understanding of how fuses, circuit breakers and earth connections help to make mains electricity safer to use. ****The conceptual progression starts by checking understanding of the potential severity of electric shock caused by different currents. It then supports the development of understanding of how electric circuits are wired in homes and protected with circuit breakers in a consumer unit. These ideas are extended to include the action of fuses in the case of a short circuit and the role of an earth connection in preventing potential electric shocks from faulty metal appliances.

**Using the progression toolkit to support student learning**

Use diagnostic questions to identify quickly where your students are in their conceptual progression. Then decide how to best focus and sequence your teaching. Use further diagnostic questions and response activities to move student understanding forwards.

**Progression toolkit: Electrical safety**

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| **Learning focus** | Fuses, circuit breakers and earth connections, used correctly, can prevent excess mains current and electric shocks. | | | | |
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| **As students’ conceptual understanding progresses they can:** | **C o n c e p t u a l p r o g r e s s I o n** | | | | |
| Describe the effects of an electric shock on a person. | Explain why there are no standard mains sockets in a bathroom. | Explain how electric circuits are wired in a home, with circuit breakers for safety. | Explain the effects of a short circuit in an appliance or in a mains circuit. | Explain how earth wires can protect people from electric shock. |
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| **Diagnostic questions** | Shocking! | Resisting a shock | Consumer unit | Short circuit | Metal case |
| Mains circuits |
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| **Response**  **activities** |  | Shocking calculations | A working fuse | | Earthing |

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| |  |  |  |  | | --- | --- | --- | --- | | Key: | | | | | **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning | | | | |
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| **Shocking!** | **Resisting a shock** | **Consumer unit** | **Mains circuit** | **Short circuit** |
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| Linking ideas | Simple multiple choice | Confidence grid | Simple multiple choice | Simple multiple choice |
| **Metal case** | **Shocking calculations** | **A working fuse** | **Earthing** |  |
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| Confidence grid | Application and practice - problem | Clarifying – demonstration | Predict, explain; observe, explain (PEOE) |  |

**What’s the science story?**

Mains electricity in the home works when there is a complete circuit through an appliance between the live wire and the neutral wire. Fuses or circuit breakers are added to the live wire, before an appliance, to break the circuit if too much current is flowing. This helps prevent electric shocks and fire. Earth wires are connected to appliances with metal cases and will complete a circuit with the live wire if there is a fault and the metal case becomes live. Current flowing in this circuit causes the fuse or circuit breaker to break the circuit and helps to prevent electric shocks. Appliances with non-conducting cases are double insulated and do not need an earth wire.

**Earlier development of understanding (BEST 11-14)**

When applying their understanding to novel situations, students of all ages often revert to earlier misunderstandings. Before moving forward, it is worthwhile using diagnostic questions from earlier topics to check that students do not have any persistent misunderstandings that can form barriers to learning. Time spent consolidating the scientific understanding of earlier key concepts before moving forward can accelerate progression later.

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| **Key conceptPEM2.1 Resistance**  **Learning focus:** The size of current in a circuit depends on the voltage of the battery and the resistance of the component(s) in the circuit.  This key concept:   * Reviews the effect on a simple circuit of changing the voltage of the battery * Develops understanding of why conductors have a greater resistance if they are longer and/or thinner * Explains how the size of current is affected when both voltage and resistance are changed at the same time. |
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| **Key concept PEM 2.2 Parallel circuits**  **Learning focus:** The voltage across each branch of a parallel circuit is the same as the voltage of the battery; and the current through each branch of a parallel circuit adds up to the current through the battery.  This key concept:   * Reviews methods for measuring voltage and current * Develops understanding of parallel circuits as like a set of nested simple circuits * Explains how the size of electric current in each branch depends on the voltage across the branch and the resistance of components in the branch. |

**What does the research say?**

There is very little science education research about students’ understanding, or misunderstanding, of mains electrical safety. Much of what can be found in the literature either provides a descriptive overview of the topic (Brown, 1986; Goodenough, 2007) or focuses on describing ways in which aspects of the topic can be demonstrated (Harrison, 2017). This is perhaps because mains electrical safety builds upon the understanding and application of several key concepts that have individually attracted much more attention from researchers. These include electric current, conduction and insulation, voltage, resistance, Ohm’s law and parallel circuits.

In thinking about mains electricity, a few students may revert to earlier misunderstandings, which are not apparent when they are dealing with series and parallel circuits, because mains electricity can appear to be very different to simple electric circuits. A common misunderstanding that children have when they first learn about mains electricity, age 7-11, is that mains appliances draw electricity from one connecting wire, without the need for a complete circuit (Pilatou and Stavridou, 2004).

In order to develop a good understanding of mains electrical safety, students need first to understand that the severity of an electric shock is largely due to the size of current passing through a person’s body and the route it takes. The size of current passing through a person is determined by the potential difference (p.d.) across the person, perhaps between an exposed live wire and the ground, and the resistance\* of their skin (Goodenough, 2007), which can decrease by a factor of several hundred when the skin is wet (Brown, 1986). A high p.d. can cause a dangerously large current to flow through a person, but in a steamy bathroom the same p.d. can cause a current to flow that is several hundred times bigger.

Goodenough (2007) describes in detail the effects of current on the human body. A current of 0.5 mA through a person’s body can be felt and a current of 0.5 – 10 mA would be painful. At some point, between 10 mA and 50 mA, a person’s nervous response would be affected so they are unable to release a grip and if the current is maintained it can cause involuntary muscle contractions, difficulty breathing and disturb heart function. Higher currents than 50 mA can stop the heart, stop breathing and cause burns and other tissue damage. The main cause of death from an electric shock is ventricular fibrillation, which is when the heart stops beating rhythmically and becomes unable to pump blood. Alternating current is more likely to affect the rhythm of the heart than direct current.

It is a common misunderstanding that if the plug connecting an appliance to the mains contains a fuse, then the appliance cannot give a person an electric shock (Goodenough, 2007). This is not true because a current of 0.15 A through a person can kill them in about 0.1 s and the smallest fuse in a mains plug (in the UK) stops current flowing only when it exceeds 3 A.

A residual current circuit breaker (RCCB) would stop current flowing through the person being shocked in about 0.04 seconds. Without a RCCB fitted, a person touching an exposed live connection from the mains could receive a fatal electric shock, which is why electric lawnmowers and hedge-trimmers should always be used with a RCCB, because accidentally cutting trailing wires is relatively common.

However, a fuse can turn off the current *before* a person touches the live metal casing of a faulty appliance, if the appliance is wired correctly. Common causes of a metal casing becoming live is a movement and pulling on connecting cables that cause the live wire to become loose, or physical damage to the appliance. The casing of a metal appliance should be connected to an earth wire. If the live wire touches the casing there will then be a short circuit, a large current will flow, and the fuse will melt, turning off the current. This happens the first time the appliance is turned on after the fault is caused. Some demonstrations, of how a fuse works, risk giving the false impression that excess current only flows and the fuse makes the appliance safe when it is touched by a person (Harrison, 2017).

In a study of 41 pre-service teachers, Önder, Senyigit and Silay (2017) found that 69% could not explain a short circuit using scientific understanding. 20% described a short circuit as a circuit that did not work, a further 15% that it didn’t work because components had been damaged by excess current, and 12% described a short circuit as an incomplete circuit. Rather, a short circuit is formed by an extra connection between parts of a circuit that provides a very low resistance path for current to flow, leading to increased current in that part of the circuit.

*\*Strictly speaking, the resistance to alternating currents is called impedance and includes the resistive effects of capacitance and inductance. This understanding is usually covered in undergraduate courses at university.*

**Guidance notes**

*Why is the live wire more dangerous than the neutral wire when they are opposite ends of the mains circuit?*

There is a common misunderstanding that a battery contains ‘electricity’ and that when current flows around a circuit the electricity flows from the battery.

In science teaching for ages 14-16, it is rarely explained clearly why a fuse needs to be placed on the live wire and not on the neutral wire; and it is a small leap for students into misunderstanding that all of the electricity flows from the National Grid and into the house through live wires and out again through the neutral – when most of it has been used up (sic).

To support the correct explanation, the live wire can be thought of as one end of a ‘mains battery’ whose voltage (more accurately potential) varies between +230 V and -230 V. The neutral wire can be thought of as the other end of the ‘mains battery’ which has a voltage (potential) close to 0 V, which is pretty much the same as the ground (earth). A current will flow round a complete circuit made between a live wire and a neutral wire or between a live wire and the ground because there is a potential difference across it. If a complete circuit is connected between the neutral wire and the ground, there is only a very small potential difference between the connections and any current will be very small.

In other words, completing a circuit between the neutral wire and the ground can be thought of as connecting both ends of the circuit to the same end of a high voltage battery. This means that it is quite safe for a person to be connected between a neutral wire and the ground, but not between a live wire and the ground – although it should be noted that neither should be attempted (it is not completely unknown for live and neutral wires to have been connected the wrong way round).

*Mains voltage in the UK*

Mains voltage is a compromise. Higher voltages enable electricity to transmitted more efficiently, but also cause a higher chance of serious injury in the case of an electric shock.

In 1994, mains voltage in the UK was changed (from 240 V) to 230 V. A potential difference of 230 V across dry skin is likely to hurt, but not cause significant harm in the vast majority of cases.

*Electrocution vs electric shock*

Electrocution refers to the specific situation in which an electric shock leads to death or to a very serious injury. Most electric shocks by contrast, are felt as a tingle or as a short sharp pain; although a small proportion are more severe.

*Shaver sockets in the bathroom*

There are regulations that govern the safe use of shaver sockets in the bathroom. A shaver socket is different to a standard socket in that it contains a device that can prevent electric shocks.

**References**

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