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

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| **Key concept (age 14-16)** |
| **PEM8.2: Paying for electricity** |

**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 reviewing ideas about the power of an electric circuit and the energy it transfers, and developing understanding of the connections between power, current and potential difference. ****The conceptual progression starts by checking understanding of the relationship between power and energy. It then supports development of the understanding of how the power of a circuit depends on current and potential difference by making connections between observations and a microscope model of current.

**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: Paying for electricity**

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| **Learning focus** | The amount of energy that an electrical appliance transfers is proportional to time; and its power is proportional to the potential difference across it *and* the current through it. | | | | |
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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 difference between energy transferred and power.  **P** | Describe how the power of an electric circuit depends on current through it.    **P** | Explain why the power of a component depends on the potential difference across it. | Explain the relationships I = Q/t and V = E/Q. | Explain why power of a component can be calculated using  P = I x V. |
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| **Diagnostic questions** | Calculating energy | Power and current | Power and p.d. | Defining current | Mystery circuit |
| Defining p.d. |
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| **Response**  **activities** |  | Rope power | | Dotty rope | Mains power |

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| |  |  |  |  | | --- | --- | --- | --- | | Key: | | | | | **P** | Prior understanding from earlier stages of learning | **B** | Bridge to later stages of learning | | | | |
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| **Calculating energy** | **Power and current** | **Power and p.d.** | **Defining current** | **Defining p.d.** |
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| Simple multiple choice | Two-tier multiple choice | Confidence grid | Confidence grid | Confidence grid |
| **Mystery circuit** | **Rope power** | **Dotty rope** | **Mains power** |  |
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| Confidence grid | Clarifying - demonstration/modelling | Clarifying - demonstration/modelling | Talking heads |  |

**What’s the science story?**

The energy transferred when electric charge flows through a component (or device), depends on the amount of charge that passes and the potential difference across the component. The power rating (in watts, W) of an electrical device is a measure of the rate at which work is done by an electrical power supply that transfers energy to the device and/or its surroundings. The rate of energy transfer depends on both the potential difference and the current. The greater the potential difference, the faster the charges move through the circuit, and the more energy each charge transfers.

**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 concept PEM 5.1 Analysing series circuits**  **Learning focus:** Rules for current and potential difference around a circuit and the equation I = V/R can be used to calculate values of current, potential difference and resistance in series circuits.  This key concept:   * Reviews the rules for current and potential difference in a series circuit * Develops understanding of the equation I = V/R * Applies understanding of the relationship between current, potential difference and resistance to the systematic analysis of series circuits. |
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| **Key concept PEM 5.2 Analysing parallel circuits**  **Learning focus:** Rules for current and potential difference around a circuit and the equation I = V/R can be used to calculate values of current, potential difference and resistance in parallel circuits.  This key concept:   * Reviews the rules for current and potential difference in a parallel circuit * Develops strategies for using the equation I = V/R for the systematic analysis of parallel circuits. * Applies understanding of the relationship between current, potential difference and resistance to explain changes in complex parallel circuits. |

**What does the research say?**

The key purpose of an electrical circuit is to do work of some kind. In a simple electric circuit, over time, energy is transferred from a battery to the surroundings. Historically, science teachers have often used the power ratings of light bulbs in the home to illustrate ideas about energy and power in electric circuits, with bulbs that have higher power ratings clearly shifting energy more quickly because they are emitting more intense light. Nowadays a mix of LED and filament lights in many homes perhaps confuses this example. A good alternative is to compare the heating effects of different power settings on a microwave oven (IoP). It is likely that most students will be aware that at a higher power a microwave oven cooks food faster because it is shifting more joules of energy each second – the higher the power setting, the less time it takes to provide a fixed amount of energy to cook a sample of food.

The amount of energy transferred can be calculated using the equation for power in an electrical circuit: power = current x potential difference (P = I x V), and by multiplying the answer by time (E = P x t). The standard units for power and time are Watt (W) and second (s) respectively. However, alternative units are used for mains electricity to provide smaller and more convenient numbers, measuring power in kilowatts (kW) and time in hours (h). Multiplying these together gives the number of units (kilowatt-hour) of energy that people are charged for, for the energy they have ‘consumed’. Calculating the amount of energy transferred by an electric circuit is relatively straightforward in most cases, but understanding the science that determines the calculation is more challenging.

Novice learners typically lack a scientific understanding of how a circuit works and rely on memorising equations and procedures. They may be able to solve routine circuit calculations correctly, but often cannot predict or explain the behaviour of a circuit. To develop a more expert understanding of electric circuits and to be able to solve a wide range of problems, in both familiar and novel contexts, learners need to be supported in making connections between microscopic and macroscopic phenomena. This is because, for electric circuits, it is the microscopic models that provide the mechanisms which explain the relationships between macroscopic properties (Liu et al., 2022).

As always, when developing new understanding about electric circuits, it is helpful for a teacher to begin by checking for any persisting misunderstandings students may have. It has been found that older secondary school students typically resort to alternative conceptions less often than younger ones, but they tend to apply misunderstandings they do have more consistently (Licht and Thijs, 1990) making blocks on further learning potentially more challenging to resolve.

Some common misunderstandings that students may continue to hold, which are relevant to this key concept, are:

* that most students do not discriminate sufficiently between current, voltage, energy and power (e.g. Gott, 1984; Shipstone, 1985; Driver et al., 1994; Engelhardt and Beichner, 2004)
* the amount of current provided by a battery is always the same no matter what circuit it is connected to (Driver et al., 1994; Engelhardt and Beichner, 2004)
* a bulb or appliance gets the energy ‘it demands’ regardless of the potential difference of the source (van den Berg and Grosheide, 1997)
* a circuit can be analysed sequentially moving around a circuit in one direction, so changes to components ‘further around a circuit’ do not affect earlier parts of the circuit (Driver et al., 1994; Stocklmayer and Treagust, 1996; Duit and von Rhoneck, 1997)
* the higher the resistance of a component, the more energy is transferred as current passes through it and therefore (this is the misunderstanding) components with a greater power rating always have a higher resistance (Licht, 1991).

A useful bridge between addressing common misunderstandings and developing understanding of energy and power in an electric circuit, in relation to current and potential difference, is the rope-loop analogy used in earlier BEST key concepts: *PEM1.2 Electric current* and *PEM1.3 Voltage*. This model can be used to: review ideas of current, charge and potential difference in simple circuits; to introduce ideas of energy shifting from a ‘battery’ to a ‘bulb’; and to reason about the effects on energy transfer caused by changing currents, resistances or potential differences (DCFS, 2008).

When developing understanding about connections between the ideas of energy and power and what happens in an electric circuit, some useful starting questions are: ‘*how is it possible that electric devices use different amounts of energy?’* (Licht, 1991); or *‘what determines the brightness of a bulb in a particular circuit?’* (Wong, Lee and Foong, 2017). It is likely that students’ answers to these questions will involve ideas about both potential difference across devices and current through them.

The understanding of why power can be calculated using P = I x V begins with the understanding of electric current as a flow of charge. This leads on to the introduction of relationship I = Q/t as a shorthand way of writing this down and of quantifying currents for comparison (Hartley, Fairhurst and Norris, 2021). The next step is to understand that potential difference is linked to energy because it (causes an electromagnetic field that) provides an electrical ‘push’.

With a bigger potential difference across a component, electric charges are ‘pushed’ harder which means they can do work at a higher rate (Hartley et al., 2021). The equation V = E/Q represents this relationship and shows that when the potential difference pushing a certain amount of charge through a component is doubled (or tripled etc.), then two times the amount of energy is shifted – because with two times the ‘push’ on the same charge, the charge can do work at twice the rate.

Both I = Q/t and V = E/Q are derived from a microscope model of current that comprises charged particles caused to move by forces due to an electric field and impeded by collisions with microscopic structures and particles in a conductor (Liu et al., 2022). The two equations can be combined (I x V = Q/t x E/Q = E/t = P) to show that P = I x V; and the microscopic model of current used to explain the relationship.

In solving novel problems using P = I x V, students will need to consider the nature of the interdependence of current, potential difference and resistance, which can vary in different situations.

Without a good scientific understanding, it is likely that some students will interpret the equation V = I x R in a purely mathematical sense, (Liegeois and Mullet, 2002; Chasseigne et al., 2011; Liu et al., 2022) and, for example, think that a change to either current or resistance always results in a change in potential difference. The scientific understanding of a specific situation may indicate that one or other of the ‘variables’ is determined and ‘fixed’ by the situation, in which case the equation needs to be applied differently. This is another reason why a good understanding of the microscopic model of current is important, and why experts reflect on it when solving problems and when predicting or explaining electric circuits.

**Guidance notes**

The learning progression for this key concept does not specifically include calculations of payment charges for electricity use. Instead the learning progression begins by developing understanding of the calculation of the amount of energy transferred and then develops understanding of how to calculate the power of electrical devices. It has been left to teachers to add in extra steps of calculating energy transferred in kilowatt-hours and multiplying by the cost of each ‘unit’. Learning about these calculations after studying this key concept will mean students are likely to understand clearly why the calculations are made, and therefore be more adept at calculating ‘units’ in novel contexts.

Care needs to be taken when using examples of mains appliances for exploring the connection between power, current and potential difference. This is because all mains appliances operate with the same potential difference across them. This means that mains appliances with higher power ratings have more current flowing through them, and therefore have a lower resistance than those with lower power ratings.

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