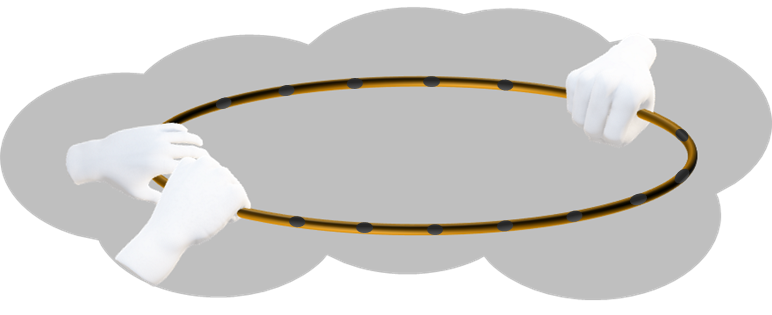
**Dotty rope**

A group of students mark a loop of rope with dots.

The dots represent equal amounts of electric charge.



‘bulb’

‘electric charge’

‘battery’

**To answer**

1. How could they use the model to demonstrate I = Q/t?

1. How could they use the model to demonstrate V = E/Q?

*Physics > Big idea PEM: Electricity and magnetism > Topic PEM8: Mains electricity > Key concept PEM8.2: Paying for electricity*

|  |
| --- |
| **Response activity** |
| **Dotty rope** |

**Overview**

|  |  |
| --- | --- |
| 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. |
| Observable learning outcome: | Explain the relationships I = Q/t and V = E/Q. |
| Activity type: | Clarifying - demonstration |
| Key words: | Power, energy, potential difference, current, charge, volt, amp, coulomb |

This activity can help develop students’ understanding by addressing the sticking-points revealed by the following diagnostic questions:

* Diagnostic question: Defining current
* Diagnostic question: Defining p.d.

**What does the research say?**

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.

**Ways to use this activity**

This demonstration gives you the opportunity to re-teach a challenging concept, and show your students how it builds up from simpler ideas, using a structured teacher-led discussion.

You should use carefully selected questions to check your students’ understanding of each step, before progressing onto the next one.

The steps you follow in this demonstration might be:

* Introduce the rope model to the class:

For the rope model, a group of four to six students stand in a circle and each holds out both hands, palms upwards. A continuous loop of rope (or string) passes from person to person, right around the circle. One student now acts as a ‘battery’, making the rope move slowly round, passing over everyone’s hands as it goes. Another student acts as a bulb and squeezes their hands more tightly to slow down, and not to stop, the rope. The moving rope represents electrons (charge) moving round the circuit and the dots on the rope represent equal amounts of charge (perhaps 1 coulomb).

* Challenge the students to use the model to explain the relationship between current, charge and time.
  + What happens to the amount of charge passing through the bulb if current is doubled or tripled in a fixed amount of time?
  + What is meant by the rate of charge (moving through the bulb)?
  + What is the relationship between the current and the rate of charge?
* Challenge the students to use the model to explain the relationship between potential difference, energy and charge.
  + How do you increase the p.d. without increasing the current? (Add an extra ‘battery’ *and* an extra ‘bulb’.)
  + What happens to the energy transferred *by the circuit* in a fixed amount of time if the p.d. is doubled or tripled?
  + How does the model demonstrate what happens? (‘Battery’ pushes harder with friction causing greater heating, in total, to the hands of the ‘bulbs’.)

The worksheet provides opportunity for students to record their own answers following a demonstration.

*Differentiation*

You could challenge different individuals by asking them follow-up questions to clarify or to extend their original answer. If a student is having difficulty with a particular question, it is often helpful to break it into smaller *chunks*, to lead them to a fuller answer. This technique models more thorough answers, and can be used to support an open classroom culture in which students are encouraged to ‘have a go’.

**Equipment**

For the demonstration: A rope (or string) loop, with clearly marked dots equally distanced along the length of the rope.

**Technician notes**

The ideal rope is non-synthetic so that it is not too slippery, with a diameter in the order of 1 cm. The ends are tied together to form a loop with a circumference of approximately 6 m.

A 6 m length of rope should be long enough to allow 4-6 students to hold the rope whilst standing in a ring, and short enough so that one of the students can, relatively easily, act as the battery and pull the rope round through the other students’ hands.

Clear dots need to be marked on the rope, for example by using a permanent marker pen.

The particular length at which this is possible is likely to depend on the specific rope used and should perhaps be trialled in advance.

**Health and safety**

Pulling ropes too quickly and with too much force through hands could potentially cause friction burns.

Carried out as a class practical in small groups would involve significant movement of students throughout.

Practical work should be carried out in accordance with local health and safety requirements, guidance from manufacturers and suppliers, and guidance available from CLEAPSS.

**Expected answers**

There are several ways to answer these questions. One example is provided below:

1. One person (the battery) makes the electric charge (represented by the rope) move through the bulb. Each dot on the rope represents a fixed amount of charge (1 coulomb). Doubling the current means that either twice the charge passes in a fixed amount of time, or the same charge passes in half the time. 2I = 2Q/t and 2I = Q/½t.
2. The rope is moved through one bulb and the person who is the bulb grips the rope which heats up their hand, which represents how electrical charge heats up a bulb’s filament and causes it to emit light. The ‘bulb’ could call out the word ‘warm’ more quickly or less quickly depending on how much friction they are feeling, to represent the energy transferred in a real circuit. The p.d. can be doubled by adding a second ‘battery’ with a second ‘bulb’ added to keep the current the same. When the same amount of charge passes through the bulbs as before, twice the energy is transferred – heard by the ‘bulbs’ calling out ‘warm’ at twice the rate (together). 2V = 2E/Q or alternatively 2V = E/½Q.

**Acknowledgments**

Developed by Peter Fairhurst (UYSEG).

Images: Peter Fairhurst (UYSEG), with hands from MS Word Online 3D Models

**References**

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