TUNNELWORKS
KS4 SCIENCE LESSON 2 (ESSENTIALS)
TEACHERS' NOTES

About this lesson

This lesson explores energy, efficiency, power and circuits in a realistic situation. Students interpret simple Sankey diagrams to identify the most efficient industrial fan that can provide a minimum useful output. They then use their knowledge of circuits to connect six fans so each can be individually controlled and receive its correct operating voltage, and can calculate the current in each branch, and the whole circuit, to plan the protection for the circuit.

Learning outcomes

Students can:

- Interpret a Sankey diagram and calculate efficiency
- Explain differences between series and parallel circuits
- Draw a parallel circuit
- Calculate current at a point in a circuit

Curriculum links

KS4 Science (also suitable for GCSE Science, Additional Science and Physics courses)

- How science works 1.1c; 1.3a-c; 1.4a, b
- Breadth of study 2.3a, b; 2.4a

What you will need

- KS4 Science Lesson 2 presentation
- Lesson 2 worksheet

Students are likely to need calculators for the worksheet challenges.

Preparation

Review the KS4 Science Lesson 2 presentation, presenter's notes and worksheet. Decide on which content you will include in your teaching, and adjust the timings below to suit your own lesson length, or to spread the content across two lessons.

Think of links you can use to current or previous work on energy and electrical circuits.

Time (60mins)	Teaching activity	Learning activity	Assessment for learning
5 mins	**Starter:** Ask students how they could measure the energy efficiency of a motor (this links to the experiment to raise a mass while measuring current and voltage).	Students brainstorm ideas in groups and share as a class.	Verbal answers, questioning, discussion.
15 mins	**Whole-class:** Optional: Show the intro video and screens 1.1 to 1.3 of Lesson 1 if you wish. Watch the video in screen 1 and find out what students must do. Work through screens 2.1 to 2.5 (not the last step) and answer each question.	Answer on-screen questions. Discuss the importance of energy efficiency when operating the ventilation system. Suggest series/parallel circuits, eg ring mains, Christmas lights etc.	Verbal answers. Discussion. Discussion.
10 mins	Read the engineer's note on the worksheet and review challenge 1.	Contribute to discussion. Calculate missing energy outputs and identify the correct or best fan.	Written work.
5 mins	**Pairs/individuals:** Students complete challenge 1 to provide the missing information and select the right fan (B).	Contribute to discussion.	Discussion.
10 mins	**Whole-class:** Review students' choices. Discuss challenge 2 and what their circuit should include.	Students plan and draw circuits, including main and individual switches.	Written work.
10 mins	**Individuals:** Ask students to draw their circuits to complete challenge 2.	Calculate currents and select circuit breakers.	Written work.
5 mins	**Plenary:** Review students' circuits. Use screen 3. Complete challenge 3: using one circuit as an example, calculate individual and overall current and choose breakers. Watch the video on screen 4	Discuss safety and operational implications of wrong circuit and protection.	Discussion.

Differentiation

Easier	Harder
Omit Challenge 1 or just ask students to calculate A and B and choose. Start students' parallel circuits off by drawing the first branch. Omit challenges 1 and 3 and build series and parallel circuits (as per screen 4) to test with meters.	What if the system is designed to run on four fans with two spares (redundancy)? What useful power does each fan need if the four must provide 4140W? What overall power will each one need if they are 70% efficient? 40% efficient? Re-calculate the current drawn in this version and the circuit breakers needed.

Presentation Notes

Lesson 1

<table>
<tr><th>Screen</th><th>Notes</th></tr>
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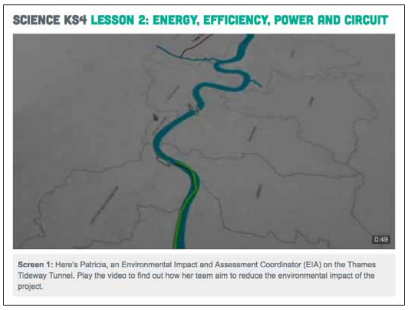
1



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Use this video clip to introduce the challenge in KS4 Science Lesson 2.

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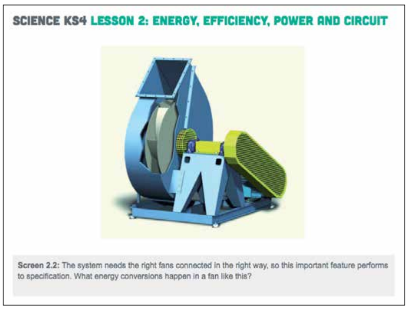
2.1

2.2



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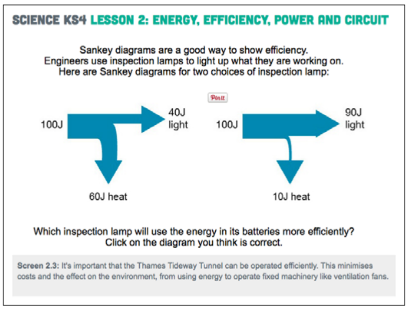

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Use this clickable image to set the scene in KS4 Science Lesson 2.

This shows Abbey Mills Pumping Station at the Eastern end of the Thames Tideway Tunnel. This is also one of the main ventilation sites that will ensure that the air in the Tunnel is replaced once each day.

To perform to specification, it's important that the engineers plan this system carefully, selecting and wiring together the right fans for the job. They need to be able to change the air in an 'empty' Tunnel once each day, and also be controllable for when the Tunnel is filling up and the air volume to exchange is lower.

Strict European emissions regulations govern the acceptable odour levels in any air emissions from the Tunnel. Carbon scrubbers at each ventilation point will remove most odours, but refreshing the air plays an important part, as well as keeping the air within safety standards should there be a need for a manual inspection of the Tunnel.

Discuss the energy conversions in a fan unit, where electrical energy is converted into the kinetic energy of the moving blades and then into the kinetic energy of moving air. Some energy is lost as heat and sound.

Use this simple example to introduce or remind students of Sankey diagrams. These look at energy and use Joules as their units, but Sankey diagrams can also use power input and output, and this is what students will interpret in challenge 1, where they must calculate the missing information to make their choice.

Lamp B represents a modern LED inspection lamp and coverts 90% of the energy it uses into light, so it's a far more energy-efficient choice and will allow its batteries to last much longer.

Discuss energy efficiency in a home context and how consumers can rate appliances, for example using the A – G system when browsing in a shop. How else could Tideway minimise its energy use for the lights in the pump house? One solution will be to design the lighting system so the lights are spaced such that a safe level of light is achieved with a minimum number of fixtures. Another might be to install motion detectors that turn them off when the pump house is empty, while another approach will be to train personnel so they always switch off when not in an area.

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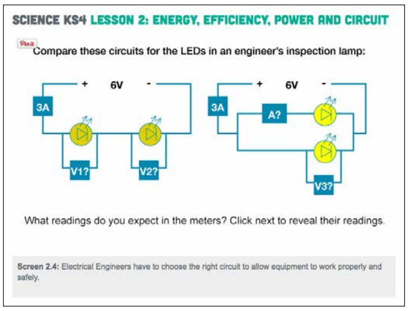
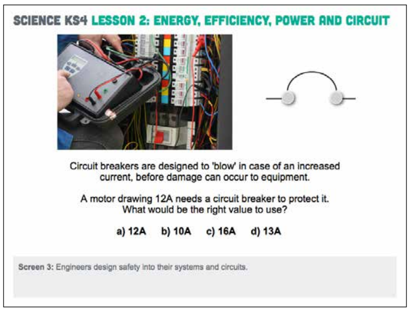
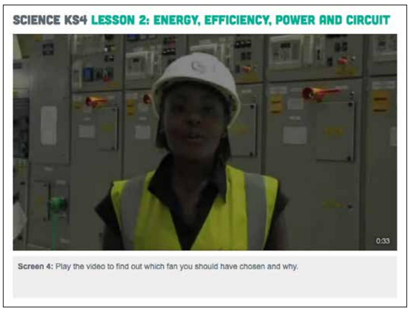
Screen	Notes
2.4 	Safety standards mean some areas must be lit at all times, however. These two circuits could be a simple representation of how two LEDs might be connected in an inspection lamp (in reality a lamp may contain many LEDs). Use this step to review series and parallel circuits. Ask students to name each circuit. Discuss how current and voltage are being shared in each circuit. Click the next arrow to reveal the answers for V1? V2? A? and V3? You can choose to identify that students should use a parallel circuit for their fans, discussing the need for each one to receive the full 240V and be controlled independently (i.e. by inserting a switch into each branch), or let them identify this for themselves. (In reality the currents would be slightly different due to how resistances are added in parallel. You can explore this with more able students using real test circuits, as in Dig Deeper.)
3 	Discuss how circuit breakers are used in a home setting. These are better than fuses because they generally act quicker and can be reset. The next value up from the designed current should be selected, so here, a 13A circuit breaker is best for protecting the 12A current. Discuss why the other values would not be good choices.
4 	Use this to provide feedback and answers for KS4 Science Lesson 2.

TUNNELWORKS
KS4 SCIENCE DIG DEEPER
EXTENSION IDEAS

Turning moments

Demonstration: See if you can demonstrate how higher frequencies are diffracted less than lower frequencies using a wave tank and gap for the waves to pass through.

Imagine that the ultrasound could pass through the concrete and be deflected by the bedrock surrounding the Tunnel. The lining segments have a thickness of 0.35m and the Tunnel has an internal diameter of 7.20m. What peaks (time delays) should be detected:

- When the tunnel is empty of water?
- When the tunnel has 1m depth of water
- When the tunnel has 7m depth of water

(Assume there are up to three returned signals: one from the water surface, one from the bottom of the Tunnel and one from the outer edge of the Tunnel lining.)

Consider how the sensor must be orientated normal to the water surface, what will happen to waves that reflect at an angle and how this can affect accuracy.

Movement and energy

Use these ideas to extend your students' knowledge and understanding of energy and movement: The Thames Tideway Tunnel is 26km long and has a gradient of 1 in 790. How much gravitational potential energy does 1m^3 of water lose if it enters the Tunnel at Acton (its far Western end) and travels all the way to Abbey Mills (its Eastern end, where the Tunnel joins the Lee Tunnel)?

From its deepest point, the water must be pumped 67m back to the surface for treatment at Beckton Sewage Treatment Works. What work must be done to pump 1m^3 of water this height?

Assuming there are six 1000W fans at the ventilation station, what is the energy used by the fans in an hour, day or year? How much useful output is used in these times to move air though the Tunnel?

Consider powering the ventilation fans using wind power. A simple formula for the kinetic energy in wind available to a wind turbine is: **kinetic energy = ½ x ρAvt x v2 = ½ ρAtv3**

Where **ρ** is the density of air, **A** the circular cross-section swept by the wind turbine blades, **t** the time in seconds and **v** the wind speed.

Using this, the available power (energy per second) = ½ ρAv3 and is proportional to the area swept by the wind turbine blades (and therefore the square of blade length) and the cube of the wind speed.

Explore the blade lengths and wind speeds that might provide power to the fans, assuming a turbine efficiency of 30%. Discuss the practical issues for wind power in London: effective turbines have large blades and are tall (to get away from turbulence). What's the likelihood of this in London? Could tidal power offer another alternative source of energy?

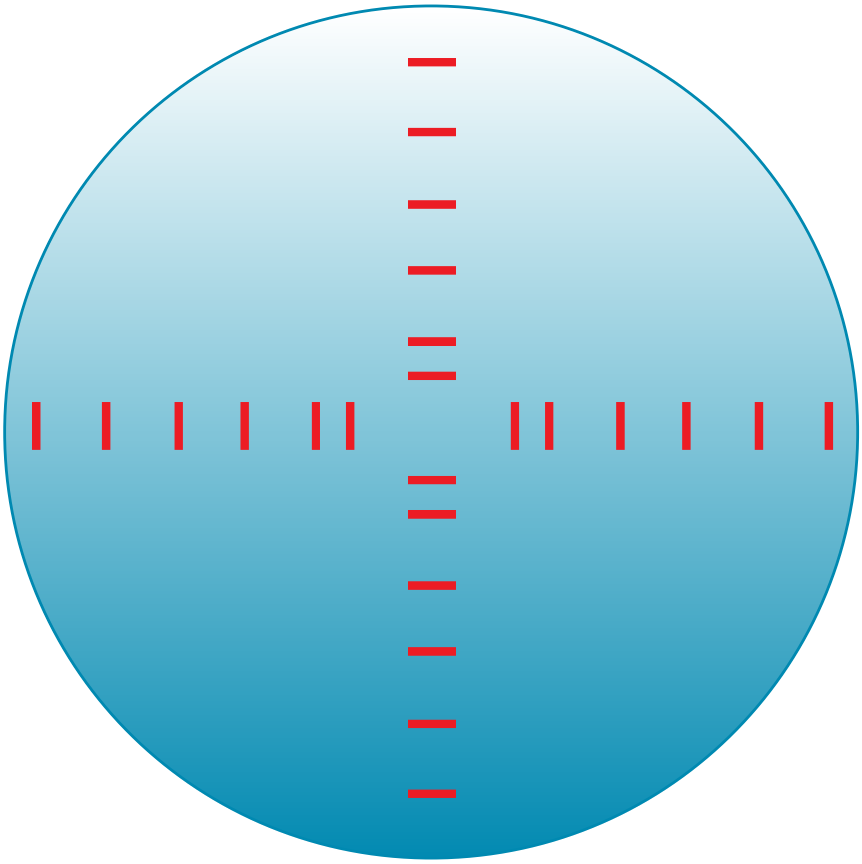
Circuits and energy

Use these ideas to extend your students' knowledge and understanding of energy and electricity:

Build demonstration circuits to test the differences between series and parallel circuits, for example connecting lamps. Measure the voltage and current at different points in each circuit. Using an example efficiency of 10% for filament lamps, explore how much electrical energy is being supplied to a lamp each second, and how much of this is being converted into light and heat.

The motors in the fans are in many ways the opposite of simple generators. Explore the key components in a motor or generator using a demo device. Ask students to explain the energy conversions taking place, including useful conversions and conversions into energy that is lost.

Challenge students to think about the energy needed to rotate the TBM cutter head below. This has four rows of six cutter disks:



In each row, the cutter disks are the following distances from the centre:
0.5m, 1.0m, 1.5m, 2.5m, 3.5m, 4m

To break through the chalk, each cutter disk must act with a force of at least 35,000 N. What work must the motor do to move each cutter disk? Assume the cutter head makes two rotations per minute. Consider W = F x d for each cutter disk in one row and then add up for all four rows. If the motor is 40% efficient, what total power will it consume?

(This ignores the energy needed to rotate the mass of the cutter head itself – can students spot this?)