Simulating Rods and Cones with Electronic Circuits
Instructions for Students

Learning Outcomes

- Use solar cells and LEDs to show how rods and cones are arranged in the retina.
- Investigate the relative sensitivity of rods and cones to low light intensity.
- Explore how different types of cone are used to detect a range of colours.

Teaching Resources

- Rods, Cones and Colour Perception document.
- Equipment (see list below).
- Rods and Cones Quiz and Photoreceptor Summary Quiz (for follow-up activities).

Background Knowledge

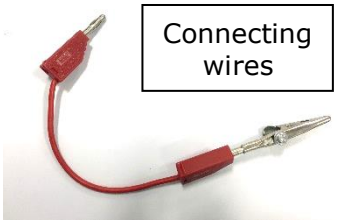
- Students must be familiar with the information given in the document "Rods, Cones and Colour Perception".

Equipment/materials – per student pair

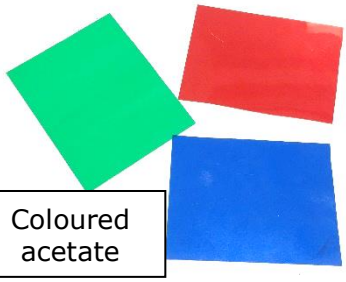
- Three solar cells.
- 10 mm LED indicators (white, red, green and blue – one of each colour).
- Six crocodile clips
- 4 short connecting wires
- Bench lamp
- 30 cm ruler
- One variable colour light bulb with remote.
- Green, red and blue coloured acetate cut to the size to cover solar cells.

Bulb with remote

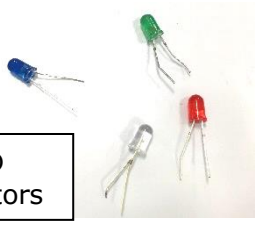
Solar cell



Connecting wires



Coloured acetate



LED indicators

Activity Instructions

Safety:

The bench lamp is an electrical hazard and burning hazard as it may get hot during prolonged use. Switch off the lamp when not in use and allow to cool before putting it away at the end of the activity**.**

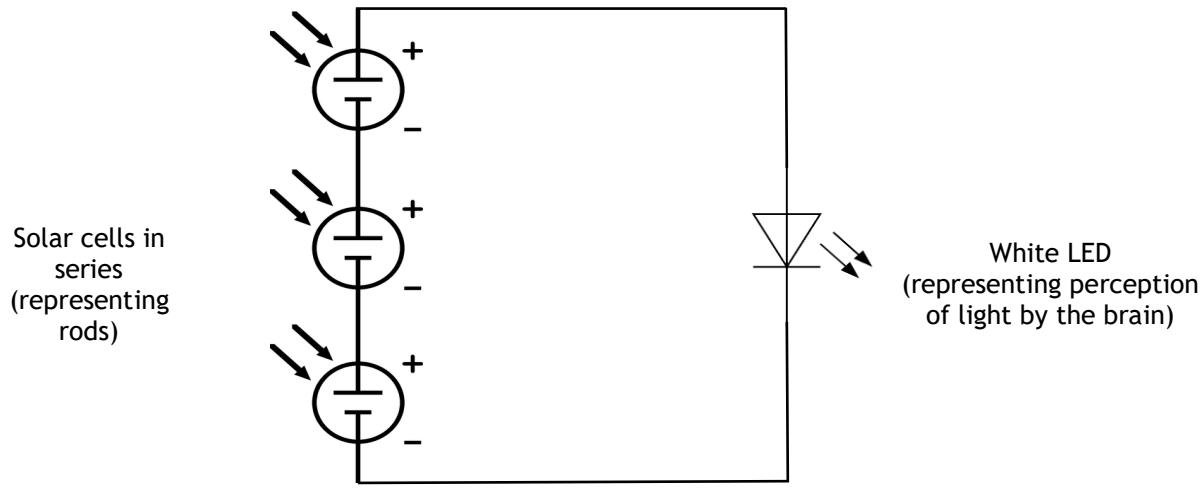
Practical considerations:

Store solar cells in an envelope and store with photosensitive side facing down. Switch off all lights and when ready, work in a dimly lit room. These precautions will prevent the solar cells absorbing extraneous light as, ideally the only light source should be the bench lab.

Simulating Rods

Set up an electronic circuit with three solar cells connected in series, as shown in figure 1. Attach the use the wires and crocodile clips to attach the positive terminal to the long wire of a white LED and the negative terminal to the short wire.

Figure 1 Electronic Circuit of Rods



When everything is connected and the lamp is switched off, the LED should not light up (showing extraneous light is not exciting the solar cells).

Place the lamp about 40 cm away from the solar cells. Turn the lamp on and move it slowly toward the solar cells.

Qu 1. At what distance does the LED light up?

Qu 2. What happens when the light is brought gradually close to the solar cells?

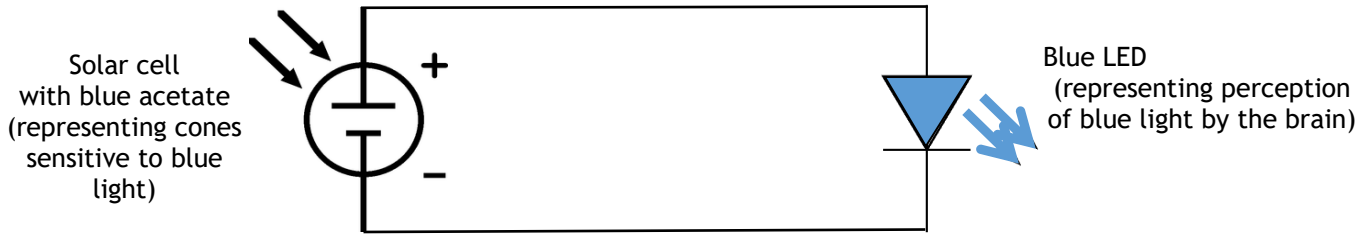
Qu 3. Explain how this set-up simulates how rods are able to detect low light intensity.

Simulating Cones

Set up three separate electronic circuits, each with a solar cell connected to either a red, green or blue as shown in figure 2.

Place a sheet of blue acetate over the 'blue' solar cell, red acetate over the 'red' solar cell and green acetate over the

Figure 2 Electronic Circuit for Blue Cones



Place the three circuits next to each other. When everything is connected and the lamp is switched off, the LED should not light up (showing extraneous light is not exciting the solar cells).

Place the lamp about 40 cm away from the solar cells. Turn the lamp on and move it slowly toward each solar cell.

Qu 4. At what distance does each LED light up?

Qu 5. What happens when the light is brought gradually close to the solar cells?

Qu 6. Explain how this set-up simulates why, unlike rods, cones are unable to detect low light intensity.

Once you have chosen a suitable lamp distance, use the remote to change the colour of the lamp. Investigate the effects of different lamp colours on each type of solar cell ('cone'). Try red, green, blue, purple and yellow lights.

Complete the Results Table for each colour of illuminating light using the headings provided below. The first entry has been done for you as an example.

RESULTS TABLE			
Colour of Illuminating Light	Which LEDs light up?	Solar cell explanation	Relation to colour vision
White	Red, Green, Blue	White light is made up from the whole visible spectrum, including red, green and blue light. All three solar cells absorb enough light to create a current.	When all three types of cone are stimulated, the brain interprets light as being white.

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Notes for Teachers

Alternative Approaches

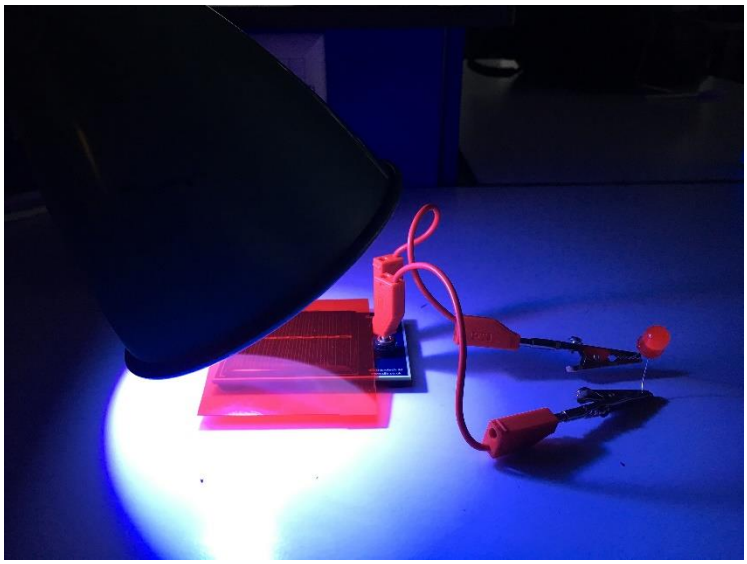
- This simulation could be carried out as a class demonstration using one set of apparatus (a cheaper option) but students could be asked to predict which bulbs will light up and why using the different set-ups described in the Instructions for Students.
- Students could be challenged to come up with the correct circuits and methods themselves instead of following the instructions on page 2.

Possible Equipment Suppliers

These are UK suppliers. The details on each product are given so that teachers from different countries can source similar pieces of equipment.

- 4.4V, 90mA solar cells, product code B8R07117 available from www.philipharris.co.uk
- 10mm LED indicators (packs of 10) product code 311167 (white), 311166 (blue), 311165 (green) and 31162 (red) available from www.switchelectronics.co.uk (also available on ebay).
- Variable colour light bulb with remote LONOVE® RGB 3W B22 LED Global Bulb Lights, which are supplied with a remote control to set the light colour to either red, orange, yellow, green, blue, purple or white). https://www.ebay.co.uk/i/222586582516
- Green, red and blue coloured acetate, product code B8R07827 available from www.philipharris.co.uk

Experimental Set-up (red cone)



Sample Results

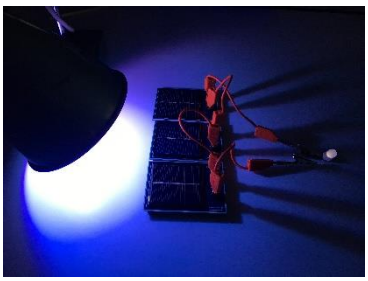
RODS

Questions 1-3

The white LED lights up when illuminated with white light, even when the lamp is 30 cm away from solar cells. This is because the combined electricity generated by three solar cells connected in series is sufficient to light up the LED. This represents summation of the generator potentials of three rods, leading to an action potential in the connecting bipolar neuron.

As the lamp is brought closer to the solar cells, the brighter the LED becomes. However, the rhodopsin in the retina is completely bleach at high light intensity, so the rods stop working (the white light would no longer light up the LED if this was represented by the simulation).

The white LED lights up when illuminated by white light from a distance (low intensity light).



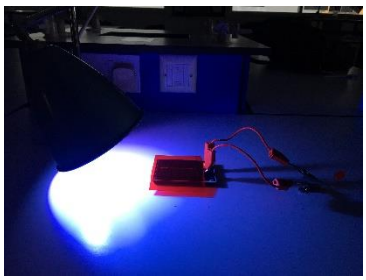
CONES

Questions 4-6

None of coloured LEDs light up when illuminated with white light, until the lamp is at least 5 cm away from each solar cell. This is because individual solar cells do not produce sufficient electricity to light up an LED at low light intensity. This represents the fact that cones have single connections to bipolar neurons and a high light intensity is required to reach threshold potential to set up an action potential in the connecting bipolar neuron.

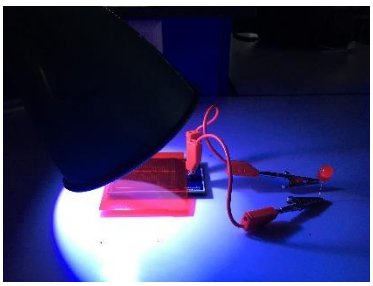
When the lamp is brought close to each 'cone' in turn, the combination of LEDs which light up depends on the colour of the light used.

The red, green and blue LEDs *do not* light up when illuminated by white light from a distance (low light intensity).



The red, green and blue LEDs *do* light up when illuminated by white light close up (high light intensity).

Each type of cone shows maximum absorption of red, green or blue light. White light contains all three



RESULTS TABLE			
Colour of Illuminating Light	Which LEDs light up?	Solar cell explanation	Colour vision explanation
White	Red, Green, Blue	White light is made up from the whole visible spectrum, including red, green and blue.	When all three types of cone are stimulated, the brain interprets light as being white.
Red	Red	Red filter on the solar cell lets red light through – enough to create a current. The green and blue filters do not let red light through and as the light source is red, the green and blue solar cells do not absorb enough light to set up a current.	Stimulation of red cones is perceived as red light.
Green	Green	Green filter on the solar cell lets green light through – enough to create a current. The red and blue filters do not let green light through and as the light source is green, the red and blue solar cells do not absorb enough light to set up a current	Stimulation of green cones is perceived as green light.
Blue	*Blue	Blue filter on the solar cell only lets blue light through – enough to create a current. The red and green filters do not let green light through and as the light source is blue, the red and green solar cells do not absorb enough light to set up a current	Stimulation of blue cones is perceived as blue light.
Purple	Red, Blue	Red and blue filters on the solar cell let purple light through – enough to create a current.	Stimulation of both red and blue cones is perceived as purple light.
Yellow	Red, Green	Red and green filters on the solar cell let yellow light through – enough to create a current.	Stimulation of both red and green cones is perceived as yellow light.

*Note, if the colour of the blue light used is blue-green, then both the green and blue LEDs may light up, though the blue LED shines brighter than the green LED. This is a reminder that although each type of cone contains a photosensitive pigment that shows maximum absorption at wavelengths equivalent to red, green and blue light, each pigment also absorbs other wavelengths to a lesser extent. Your brain makes up what colour the light was by taking into account the relative numbers of blue, green or red cones that are stimulated.