Red Moon

What's the mystery?	When the Moon travels through the Earth's shadow, sunlight is blocked. However, instead of turning completely dark, the Moon gets a reddish colour. How is this possible?
Domain(s)	Physics, astronomy.
Subdomain keywords	Optics, propagation of light.
Age group	16 to 18 years old.
Expected time for the mystery	Two 45-min lessons.
Safety/Supervision	No need for safety measures. Disclaimer: the authors of this teaching material will not be held responsible for any injury or damage to persons or properties that might occur in its use.
Preparation and list of materials	General: • Internet (for YouTube) Experiment 1. Dispersion and refraction: • (White) flashlight (not LED) • Prism • (Glass of water, straw) Experiment 2. Scattering of light: • (White) flashlight (not LED) • Large transparent container of water (~10 litres) • ¼ cup of whole milk (not skimmed)
Learning objectives	• Learn about the light scattering properties of the atmosphere. • Learn about the refracting properties of the atmosphere and other mediums.

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	• Learn why the sky is blue. • Learn why the sky turns red during a sunset. Learn why the Moon turns red during a lunar eclipse.

Guidance notes for teachers

This classroom-tested teaching plan uses the four innovations of the TEMI project, as detailed in the *Teaching the TEMI Way* book (TTTW). You should read this companion book to get the most from your teaching.
The TEMI techniques used in this teaching plan are: 1) productive science mysteries (TTTW section 1), 2) the 5E model for engaged learning (TTTW section 2), 3) the use of presentation skills (showmanship) to engage your students (TTTW section 3), and 4) the apprenticeship model for learning through gradual release of responsibility (GRR) (TTTW section 4). You might also wish to use the hypothesiser lifeline sheet (available on the TEMI website) to help your students document their ideas and discoveries as they work.

Engage: capture students' attention.

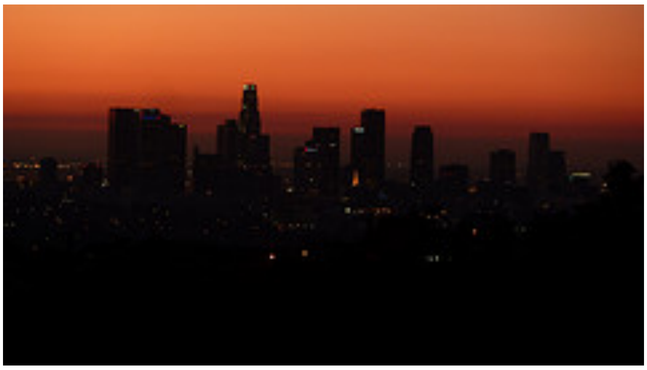
During a *solar eclipse*, the Moon passes between the Sun and the Earth: the Moon blocks the sunlight from illuminating a small part of the Earth, turning it dark. During a *lunar eclipse*, the Moon passes directly behind the Earth into its shadow (which is known as the 'umbra'). This can only occur when the Sun, Earth, and Moon are aligned exactly with the Earth in the middle. Even though the Earth blocks all the sunlight from illuminating the Moon, the Moon doesn't turn completely dark. Instead of becoming totally black, the Moon turns red!

Of which natural phenomenon does this reddish colour remind you?
Hint for the teacher: guide the students towards thinking about a red sunset.

Show the students pictures of a lunar eclipse:

The 4 April 2015 lunar eclipse over Melbourne. Credit: Scott Cresswell.

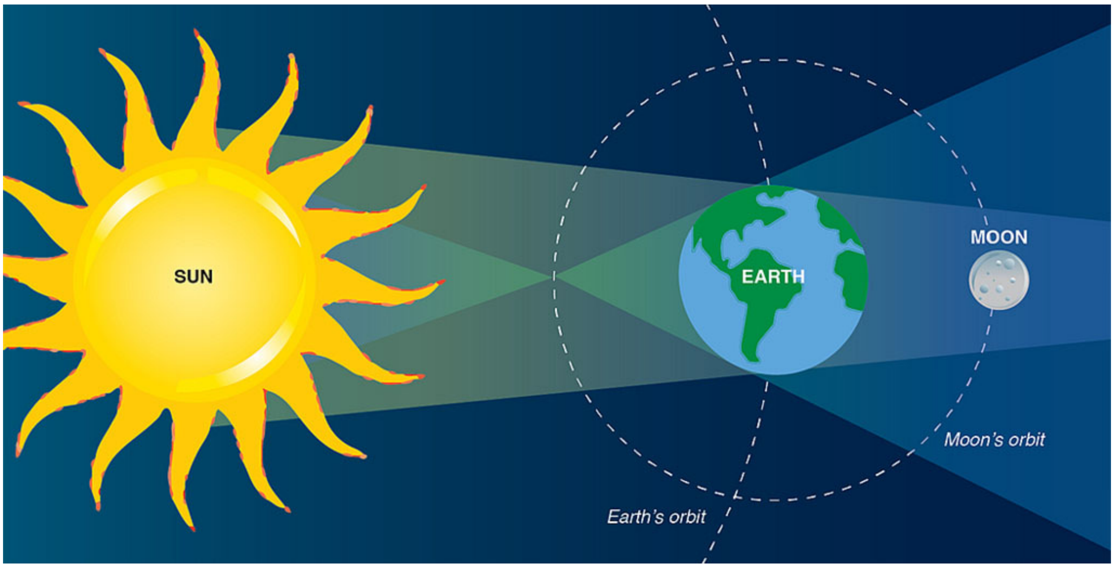
Also show them a picture of a sunset.



Sunrise over Los Angeles on 11 December 2011. Credit: Michael R. Perry.

Explore: collect data from experiments

Start out by asking the students to make a sketch of what happens during a lunar eclipse: this sketch should contain the Sun, Earth, and Moon, the sunrays, and the shadow of the Earth (obviously the scales don't need to be correct). The Moon should be inside the Earth's shadow (see image 3).



What happens during a lunar eclipse? Credit: NASA.

How is it possible for the Moon turns red during a lunar eclipse rather than black?

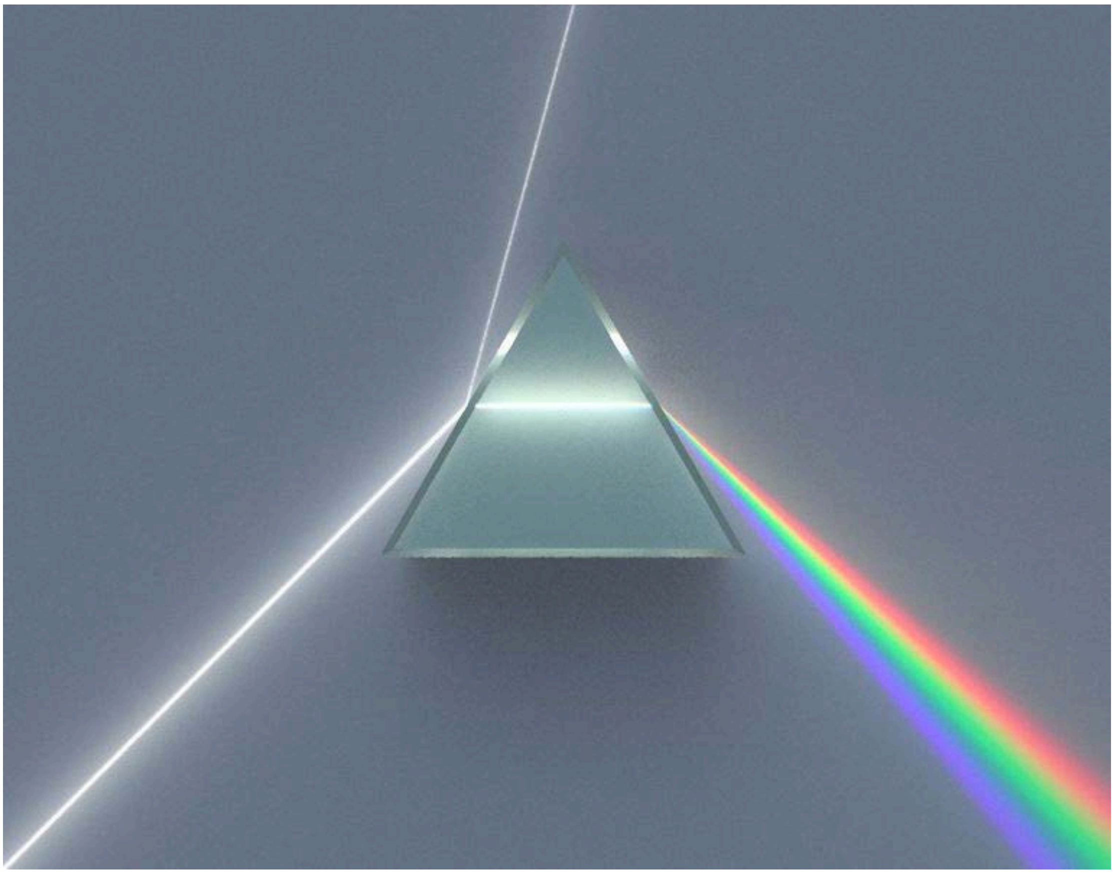
At this stage, the students should explore the *refractive* and *scattering* properties of 'white' (sun)light through different mediums. The following experiments can be performed by the teacher/students to gain more insight into these properties. In these experiments, the role of the teacher is very important for guiding the students in the right direction. Depending on the level of the students, the teacher can decide to only give a short introduction to each of the experiments and let the students find out the rest (with guidance if needed) or to walk the students through all the steps of the experiments.

Experiment 1. Dispersion and refraction of (white) light.
By using a white light source and a prism, the students can see that white (sun)light is in fact a combination of lights of different wavelengths on the visible electromagnetic spectrum

(image 4). Furthermore, this experiment shows students that as a ray of light passes from one medium into another (image 4 and image 5), the direction in which the ray propagates will change: the ray of light will 'bend', a natural phenomenon known as **refraction**. What should really stand out for the students is that the amount of refraction is not only dependent on the type of medium, but also on the *colour* (i.e. the *wavelength*) of the light. This difference in the angle of refraction for different colours of light is known as **dispersion**. The most commonly known example of dispersion is the appearance of a rainbow.

There are a lot of ways to demonstrate refraction, even with very basic material. A few examples can be found in the following videos (TEMI Youtube channel – playlist):

- Using refraction to 'bend' a straw: Refraction in water
- Using refraction to reverse text: Amazing water trick



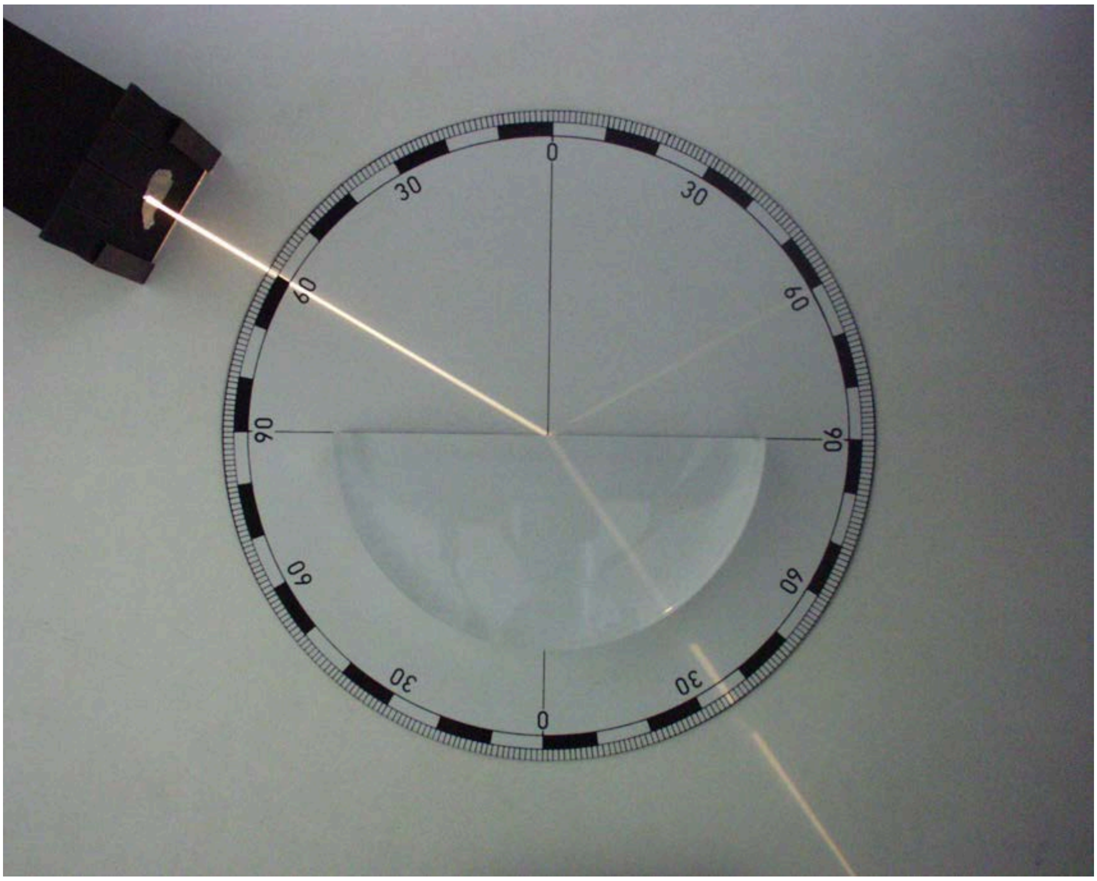
A prism refracting an incoming beam of white light and dispersing it into the visible colour spectrum.
Credit: Spigget.

The following questions may help the students at this point reach a better understanding:

1. Sunlight consists of all the colours of the rainbow. In what order do you see the colours in a rainbow?
2. When looking at the point where the beam of light enters the prism, what happens to the direction of the beam of light?
   Answer for the teacher: the beam of light bends due to refraction!
3. Can you name some everyday examples where you have witnessed the refraction of light?

Answer for the teacher: for example, when you are standing in a swimming pool and look at your feet or when looking at a straw in a glass of water.

4. What is the difference between the refraction of red light and the refraction of blue light?
Answer for the teacher: red light has a longer wavelength than blue light. By using the prism with white light, the students will see that blue light gets refracted more strongly than red light. The students can conclude from this that the power of refraction will decrease with increases in wavelength.
5. Can you think of another factor besides the type of media which influences the amount of refraction?
Answer for the teacher: the colour (i.e. the wavelength!) of the ray of light.



Refraction (and reflection) of a ray of light passing from air to Plexiglas. Credit: Zátonyi Sándor.

Scattering of (white) light

When light passes through transparent material, it can get scattered by particles (atoms or molecules) in the material that are much smaller than the wavelength of the ray of light. This phenomenon is called *Rayleigh scattering.* This type of scattering has a very strong wavelength dependence ($\sim\lambda^{-4}$), which results in blue light (shorter wavelength) being scattered far more strongly than red light (longer wavelength). This is also the reason for our blue sky: the blue light in sunlight gets scattered much more by the molecules in the atmosphere than the red light. In whatever direction you look in the sky, you will see the blue light.

Rayleigh scattering can be demonstrated using a flashlight, a large transparent container of water (~10 litres), and a ¼ cup of whole milk. By adding a bit of the milk to the water, you create a situation similar to that of the molecules in the atmosphere.
The students can hold the flashlight to the side of the container so its beam shines through the water. Let the students explore what happens to the colour of the light beam. Let them experiment by adding more milk or by positioning the beam of light in such a way that it has a longer/shorter trajectory through the water. What happens to the colour of the beam? Can the students create a setup that results in a bluish colour or a yellow/red colour?

The video "Create a sunset" (TEMI Youtube channel – playlist) shows an overview of the possible results that the students might get.

After this experiment, the teacher can ask the following questions to the students:

1. Can you now explain why the sky is blue?
2. Can you now explain why the sky turns red during a sunset/sunrise? *Answer for the teacher: at sunset, the sunlight we observe has to travel a much longer distance through the atmosphere than at noon. Therefore, there is much more scattering; by the time the light reaches your eyes, most of the blue light (as well as green and violet light) has been scattered and diffused away, leaving the yellow, orange, and red light, which is much less affected by the scattering.*

Explain: what's the science behind the mystery?

In order to explain the mystery, we must now apply what we have learnt about refraction, dispersion, and the scattering of light to a lunar eclipse.

The teacher can guide the students through the following questions:
During a lunar eclipse, the Earth will block all sunlight from directly reaching the Moon; however, what effect will the Earth's atmosphere have on the sunlight?
Which colour can best travel through the atmosphere?
Draw a diagram of what happens during a lunar eclipse: can you, with all the knowledge you now have of refraction, dispersion, and scattering, explain why the Moon is red during a lunar eclipse instead of completely dark?
At the end of this phase, the teacher can summarise the mystery for the students and provide them with an overview.
This mystery has everything to do with scattering and refraction. Sunlight is composed of all the colours of the rainbow, as you can see with the help of a prism. Each colour has a different wavelength, much in the the same way that the frequency of a musical note distinguishes it from the other. Each of these colours in the sunlight gets scattered and refracted differently according to their wavelength.
The sky is blue because of the scattering effect of the atmosphere on sunlight. The shorter the wavelength of a colour, the more it gets scattered. Blue has the shortest wavelength of all visible colours, so it gets scattered the most. Therefore, blue seems to come from all directions of the sky, whereas red and yellow light (longer wavelengths) only seem to come from the direction of the Sun.
A sunset is red because scattering is most extreme when the Sun is near the horizon. This is because the sunrays need to cover a much longer distance through the atmosphere to reach our eyes. Now the blue, violet, and green light in the sunlight gets scattered away and seems to come from other directions. The colour red has the longest wavelength and therefore

experiences the least scattering; it is the only colour that is left coming from the Sun's direction. All the other colours look as if they are coming from all directions. In this way, the horizon surrounding the Sun looks red. These phenomena play a big role during a lunar eclipse.

During a lunar eclipse, the Earth moves between the Sun and the Moon, blocking the light from Sun from directly reaching the Moon. However, some sunlight gets refracted twice by the Earth's atmosphere (refraction during the transition from space to Earth's atmosphere and again from the Earth's atmosphere back into space) as it travels around the curve of the Earth towards the Moon. During this journey through the atmosphere, all the colours that make up sunrays except red get scattered, thus never making it to the Moon. They get trapped inside the atmosphere. Red experiences the least scattering and thus is the only colour that makes it through the atmosphere to reach the Moon: hence the red Moon! From the point of view of the Moon, the Earth looks like a dark disk surrounded by a red glowing ring.

Extend: what other related areas can be explored?

Scattering and the diffraction of light through different lenses or colour filters.

Evaluate: check the level of student scientific understanding.

To evaluate the students' understanding of the mystery, the teacher can hand out the questionnaire on the student worksheet under 'evaluate'.

Showmanship: tips on how to teach and present this mystery.

The main difficulty with this mystery is that, in order to solve it, the students first need to understand several key aspects of refraction, dispersion, and the scattering of light in different scenarios. This can make it hard for the students to find out the reason for the red moon by themselves. In this mystery, the role of the teacher is therefore very important.
In order to understand this mystery, it can be very helpful for the students to visualise what is happening. This can be done by showing pictures and movies or by letting the students draw what happens during a lunar eclipse (position of the Sun vs. the Earth vs. the Moon) and how the light can and will travel in this scenario.

GRR: teaching skills using Gradual Release of Responsibility

The explain and explore parts can be done simultaneously. The teacher asks a question and will explore the answer together with the students. It would help to show the YouTube video beforehand. Thus, the students will get to know a bit more before exploring the issue themselves.

Resources

The teacher can watch the video YouTube video Why The Moon Is Red During A Total Lunar Eclipse"(TEMI Youtube channel – playlist) for more information on why the Moon turns red during a lunar eclipse:

a short video in which NASA planetary scientist Dr Shawn Domagal-Goldman explains why the Moon turns red during a lunar eclipse.

THE STUDENT WORKSHEET CAN BE COPIED AND USED IN THE CLASSROOM. Note that, in some cases, answers to earlier questions may be found later in the student worksheet.

Red moon

During a *solar eclipse*, the Moon passes between the Sun and the Earth: the Moon blocks the sunlight from illuminating a small part of the Earth, making it dark. During a *lunar eclipse*, the Moon passes directly behind the Earth into its shadow (which is known as the 'umbra'). Even though the Earth blocks all of the sunlight from the Moon, the Moon doesn't turn completely dark. Instead of becoming totally black, the Moon turns red. Which natural phenomenon does this reddish colour remind you of?

Engage: what's interesting?

Tasks
Circle the lunar phase(s) when a lunar eclipse can occur:

New Moon | *First Quarter* | *Full Moon* | *Last Quarter*

Explain why a lunar eclipse can only occur during this/these lunar phase(s) with a sketch (hint: make sketches with a top-down view of the Sun/Earth/Moon during each of the lunar phases).

Explore: what's happening?

Tasks

First, start by making a *sketch of what is happening during a lunar eclipse*: what is the position of the Moon compared to the Earth and the Sun? What happens to the light from the Sun as it tries to reach the Moon?

Now, let's explore some properties of (white) light by doing some experiments:

Experiment 1. Colours and bending of (white) light.
You probably know that 'white' sunlight is actually made up of all the colours of a rainbow. By using of a white flashlight (preferably with a very tight and dense beam) and a prism, you can 'disperse' white light; that is, break up the white light into its *spectral components* (i.e. the colours of the rainbow). Now look at these different colours more closely:

1. In what order do you see the colours in the rainbow?

1. ………………………
2. ………………………
3. ………………………
4. ………………………
5. ………………………
6. ………………………
7. ………………………

As you know, light moves on a straight line when it travels through the air. Now look very closely at the point where the beam of your flashlight enters the prism.

2. What happens to the direction of the beam of light?

As the ray of light passes from one medium (in this case: air) into the other (the glass of the prism), the ray of light will bend! Once the light has crossed the boundary between the two media, it continues to travel in a straight line again. This bending of the light ray as it passes from one medium to another is known as the 'refraction' of light. The amount of bending depends on several factors, one of which is the type of media.

3. Can you name some everyday examples where you have witnessed the refraction of light?

   Look closely again at the prism and the spectral components into which the white light breaks: do you notice something about how each of the colours bends? What is the difference between the refraction of red light when compared to the refraction of blue light?

4. Can you think of another factor besides the type of medium which influences the amount of refraction?

Experiment 2. Scattering of light.
When light passes through transparent material, it can get scattered by particles (atoms or molecules) in the material that are much smaller than the wavelength of the ray of light: this phenomenon is called *Rayleigh scattering*. It plays a big role in why the sky is blue during and red during a sunset.

The effects of Rayleigh scattering in the Earth's atmosphere can be demonstrated using a flashlight, a large transparent container of water (~10 litre), and a ¼ cup of whole milk. By adding a bit of the milk to the water, you can create an environment similar to that in the atmosphere (the milk represents the molecules while the water represents the atmosphere).

After adding some of the milk to the water and stirring, hold the flashlight to the side of the container so that its beam shines through the water. What happens to the colour of the beam? Now explore the effects on the colour of the beam when you change different factors in the experiment (more/less milk in the water, a longer trajectory of your beam through the mixture, etc.).

Compare your experiment to when the sunlight travels through the atmosphere:

1. Can you create an experiment that results in the light beam being bluish (i.e. a blue sky)? Write down the conditions of the experiment.

2. Can you create an experiment that results the light beam being red or yellow (i.e. a sunset)? Write down the conditions of the experiment.

3. Can you now explain why the sky is blue?

4. Can you now explain why the sky turns red during a sunset/sunrise?

Explain: what's causing it?

Tasks

Go back to your sketch of what happens during a lunar eclipse and combine it with the knowledge you acquired while doing the experiments to answer the next questions:

1. During a lunar eclipse, the Earth will block all sunlight from directly reaching the Moon: what effect will the Earth's atmosphere have on the sunlight?

2. Which colour has the best ability to travel through the atmosphere?

3. Look at the sketch you made of the lunar eclipse: can you, with all the knowledge you now have of refraction, dispersion, and scattering, explain why the Moon is red during a lunar eclipse instead of being completely dark?

Extend: what's similar?

Tasks

How can you compare a red sunset to a red moon during a lunar eclipse?

Evaluate: what's my understanding?

Tasks

Answer the following multiple-choice questions to show your understanding of the physical phenomena behind the red Moon:

1. What happens to sunlight within the Earth's atmosphere?
a) It gets scattered.
b) It gets reflected.
c) It gets refracted.
d) It turns blue.

2. Why is the sky blue?
a) Blue light is scattered the most because it has the shortest wavelength.
b) Light turns blue in the atmosphere.
c) The colour of air is blue.
d) The colour of the ocean is reflected on the sky.

3. Why is the horizon red during sunset?
a) After all the other colours experience extreme scattering, red is all that's left.
b) The Sun is a 'Red Giant' star.
c) The Sun cools off and becomes red.
d) Red gets scattered the most because it has the longest wavelength.

4. Why does the Moon still receive some light when the Earth gets in front of the Sun?
a) Atmospheric diffraction causes sunrays to bend around the Earth towards the Moon.
b) With a lack of sunlight, stars illuminate the Moon.
c) Earth's gravity causes sunrays to bend around the Earth towards the Moon.
d) Atmospheric refraction causes sunrays to bend around the Earth towards the Moon.

5. Why does an eclipsed moon have the same colour as the horizon at sunset?
a) Only red light can travel through the Earth's atmosphere without being scattered in all directions.
b) The Moon cools off and becomes the same colour as the Sun.
c) The Moon is illuminated by starlight, like when it gets dark on Earth.
d) In the absence of sunlight, Mars is the primary light source.

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