DEPARTMENT OF PHYSICS AND ASTRONOMY
Faculty of Science and Engineering

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Red, Green or Blue, which scatters more for you?

Figure 1: Pleiades Star Cluster (Credit: NASA, ESA and AURA/Caltech)

Introduction

In astronomy, information is collected from a variety of wavelengths of electromagnetic radiation (i.e. cosmic rays, x-rays, ultraviolet, visible, infrared, and radio). However, only certain wavelengths can pass through the Earth's atmosphere with little extinction. The term "extinction" refers to the absorption and scattering of light by dust and gas between the source of the light and an observer. For example, air molecules in the atmosphere cause visible light from the Sun to scatter randomly in all directions. During the day, the shorter wavelength blue component of sunlight is scattered more frequently in our atmosphere creating the blue colour of the sky. However, at dusk or dawn, the sunlight must traverse more atmosphere so that nearly all of the blue light is scattered in a random direction, leaving us with a red-orange sunset and sunrise. This process is known as Rayleigh scattering, and it's something that also occurs in space. As shown in figure 1, the Pleiades stars are illuminating foreground dust. The blue appearance results from blue light being scattering more effectively by small dust particles.

The Beer-Lambert law relates the extinction of light to the properties of the material through which the light travels. Since a constant fraction of the photons in light is removed per unit thickness of material, the intensity (I) of light falls exponentially:

$$\boxed{I = I_0 e^{-kx}}$$

In this case, I_0 is the initial intensity, x is the thickness of the material, and k is the extinction coefficient. The extinction coefficient can be divided into an absorption and scattering component (i.e. $k = \alpha + \beta$). However, is this experiment, we will not attempt to separate these components, rather we will ascertain the overall extinction coefficient.

In this experiment, the extinction of red, green, and blue light by milky water will be measured. The light will come by way of lasers with wavelengths of 635 nm (red), 532 nm (green), and 473 nm (blue). Milky water represents an artificial atmosphere, where milk proteins act as an analogue to air molecules.

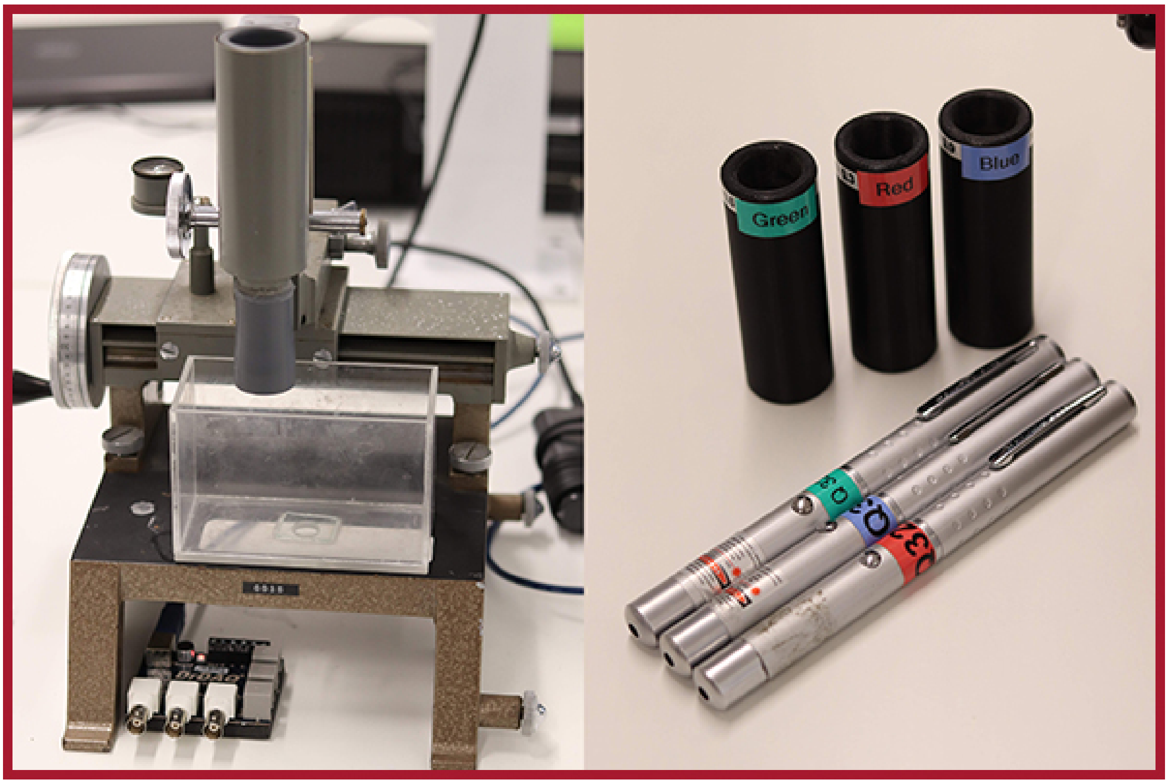

Figure 2: Activity Equipment: Travelling microscope, Perspex tank, DrDAQ, lasers, and sleeves.

Instructions

1. Start by filling the glass beaker with water and add a single drop of milk using the eye dropper.
2. Place the glass beaker on the travelling microscope, as illustrated in figure 2.
3. Turn on and place the red laser into the barrel of the travelling microscope and secure it firmly, but not too tight.
4. Place the light detector under the travelling microscope and in-line with the laser pointer.
5. Carefully adjust the travelling microscope so that the laser descends and lightly touches the bottom of the glass beaker - remove any bubbles around this area using the supplied wire.
6. Turn on the light detector and take a reading – note at this level, $I_0 = I$, and $\frac{I}{I_0} = 1$.
7. Raise the travelling microscope in 5 mm increments and take a lux reading – perform this between 0 and 5 cm.
8. Repeat the above steps for the green and blue lasers.

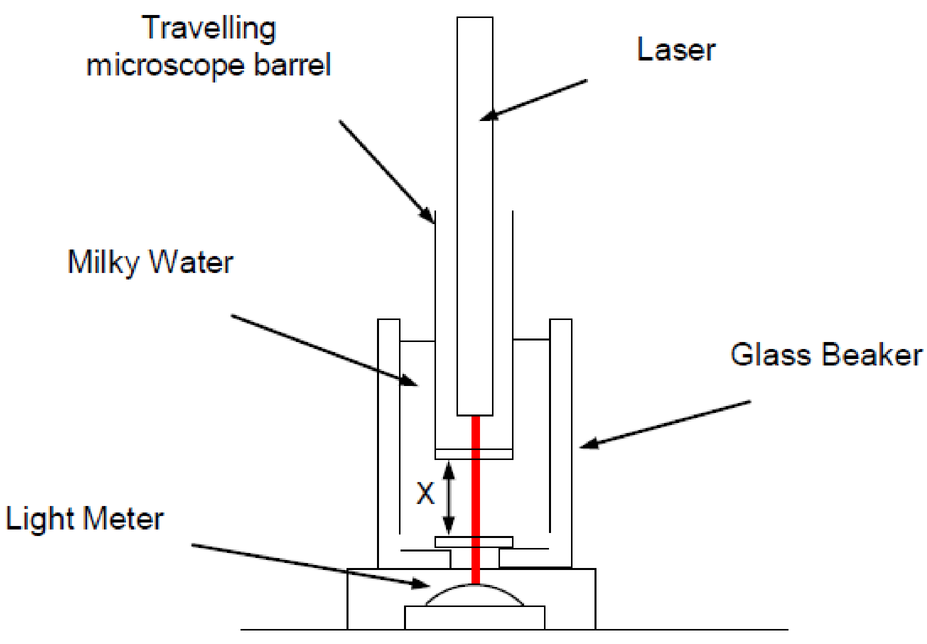

Figure 3: Schematic of the experiment. As the barrel of the travelling microscope is raised and lowered, the depth of water (x) varies.

Analysis

1. For each colour light, start at the bottom of the beaker, raise the travelling microscope in 5 mm increments and take a lux reading.

Red Light Source		
Depth (mm)	Light Reading (Lux)	I/I_0

Green Light Source		
Depth (mm)	Light Reading (Lux)	I/I_0

Blue Light Source		
Depth (mm)	Light Reading (Lux)	I/I_0

2. Plot $\left(\frac{I}{I_0}\right)$ versus x, the depth of water the beam travels through, for the red, green, and blue lasers. Recall that your first lux reading corresponds to $I_0 = I$.

3. Plot $\ln\left(\frac{I}{I_0}\right)$ versus x for each and then calculate the gradient of the line.

   (note that the gradient is the extinction coefficient, $-k$).

How does the extinction coefficient (-k) vary with wavelength?

Use your results to explain why the sky is blue and why sunset and sunrise is red-orange.

Laser Safety Information

Despite being commercially available laser pointers, there are some safety issues you need to adhere to.

1. Never shine a laser beam directly into your or anyone else's eye (i.e. don't wave the laser around the room).
2. Only switch on the laser when it's being inserted into the barrel of the travelling microscope.

Before beginning experiments with lasers, new students should:

1. Work through the relevant University and Faculty Induction modules and read the General Laboratory Safety Guidelines
2. Read the Laser Safety Procedures
3. Either watch the Faculty Laser Induction Module (PowerPoint Presentation) or read the free Faculty Laser Induction Module (PowerPoint Presentation), plus the Eye Effects Video (5 minutes) and the Laser Safety Video (30 minutes).

Hosts of visiting scholars and students should ensure that the visitor's home institution has an adequate laser safety induction. A hazard assessment should be performed to ensure the visitor is aware of local safety features and procedures. Regular visitors do not need to redo the hazard assessment.

Acknowledgements

The experiment is based on the work by Hughes, Cowley et al. 2015.