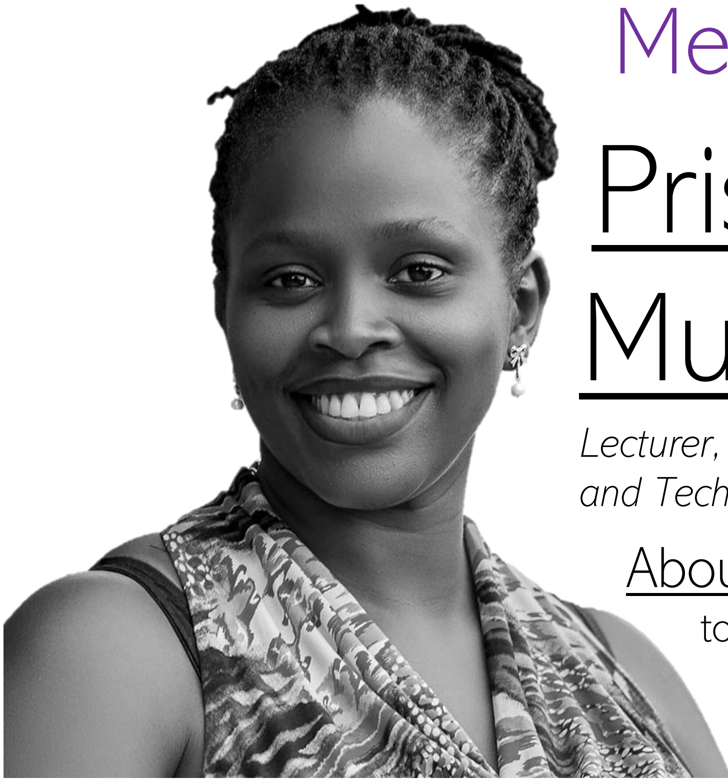
QUANTUM (Q)-KIT

Light and Photons:

Laboratory for Primary Level Students

Student Manual

WOMEN SUPPORTING
WOMEN IN THE SCIENCES



Meet a Scientist

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About me: I was born in a small town in Uganda where it was believed that the sciences were meant for boys and arts for girls like in most African communities. When I joined secondary school, I was so attracted to science especially Physics and Mathematics. This led me to study fundamental Physics courses like quantum mechanics and astrophysics at University, and I eventually earned my PhD in Physics specializing in Astronomy. I am interested in studying energetic phenomena, like flares, that take place on the surface of stars. Sometimes astronomers apply the principles of quantum mechanics to understand what is happening in stars. For example, atoms in stars' atmospheres where flares occur can exist in multiple energy states simultaneously, so-called superposition. This means that an atom might be in a state where it's both excited and unexcited until it interacts with another particle and its state is "collapsed".

My experience managing career and life: Don't think that if you pursue your dreams and career, you will lose out on your personal and family life. I am married with children, and I still manage to pursue my career. It is all about how you balance your boat. You can do anything you set your mind to, just believe, believe and believe.

Mission Statement

The mission of this laboratory is to teach primary level students (ages ~6-11) about light through experiments related to diffraction and the photoelectric effect, showcasing its wave-like and particle-like behaviors.

Contents

1. Introduction to WS2 Laboratory Kits

1.1. Information about WS2

Women Supporting Women in the Sciences (WS2), an international organization unifying and supporting graduate and professional-level women and allies in science, technology, engineering, and mathematics (STEM), was awarded an American Physical Society (APS) Innovation Fund in 2020 to form international teams to design and distribute low-cost physics and materials science lab kits to primary and secondary school students, predominantly in eastern Africa. The lab kits utilized local resources and included topics that are especially relevant to young girls in order to spur their interest in STEM subjects. From 2020-2023, over 5100 students from eastern Africa at over 40 school sites engaged with our lab kits, with 62% being girls.

WS2 was awarded their second APS Innovation Fund in 2025 to support another Lab Kit Initiative, though this time with a focus on quantum topics. For more information about WS2, please visit our website at ws2global.org.

WS2 is sponsored by the APS Innovation Fund, APS Forum on Education, Northwestern University Materials Research Science and Engineering Center, and Northwestern University Multicultural Student Affairs. WS2 is extremely grateful to the lab kit design volunteers for their hard work and external consultants (SciBridge and Projekt Inspire) for their advising. WS2 also thanks and acknowledges PhysicsQuest (https://www.aps.org/initiatives/physics-education/physicsquest) and Quantum Explorations Student Toolbox (QuEST) for example experiments that were used as foundation for the lab kit content.

1.2. Key Vocabulary

- Light: a type of energy that helps us see (the Sun is an important source of light!)
- Photon: a tiny particle of light
- Wave: form of moving light energy made of tiny particles (photons)
- Refraction: the bending of light waves as they pass from one material into another (like air into water)
- Photoelectric effect: when light energy knocks charged particles loose from a metal surface

1.3. Key Questions

- What is light?

- Is light a wave or a particle?

1.4. Purpose

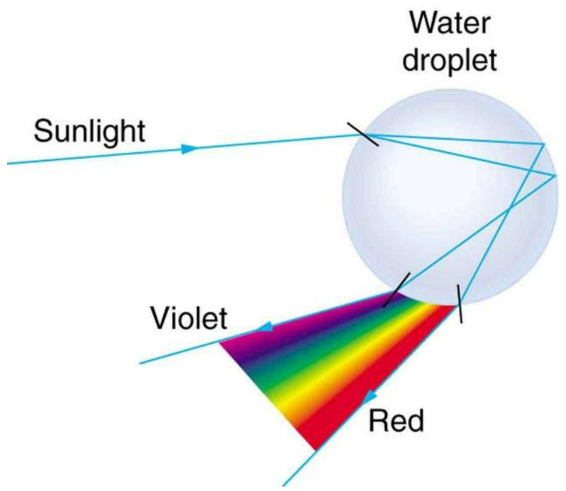
The purpose of this lab kit manual is to introduce light through demonstration and experiments. Students will think about light behaving as a wave through refraction and dispersion. The manual will also prompt students to think about light as a particle using the photoelectric effect.

2. Background on Main Topics

2.1. Light as a wave and a particle

Light is all around us. It comes from the Sun and appears in a dark room when you turn on a lamp. The basic question of "what is light?" is one that scientists have been asking for centuries, and the answer is not so basic. Light is a type of energy that helps us see, and it is made up of different lengths of light waves. These light waves travel through space to get to us. The light waves that humans can see are called visible light waves. Colors, like red, orange, and green, that we see come from visible light.

How can we see the different colors that are in visible light from the Sun? Have you ever seen a rainbow? A rainbow appears when light shines through water droplets in the sky. The change from the air to the water and back to the air causes the light to bend, which is called refraction, and this bending is slightly different for each color in sunlight. This results in the appearance of a band of colors, or a rainbow (see Figure 1). You can also see this band of colors if you pass light through a glass prism. The visible white light refracts as it passes from air to glass and back to air, and the different colors of the rainbow are visible (see Figure 1). Refraction shows the wave-like properties of light.



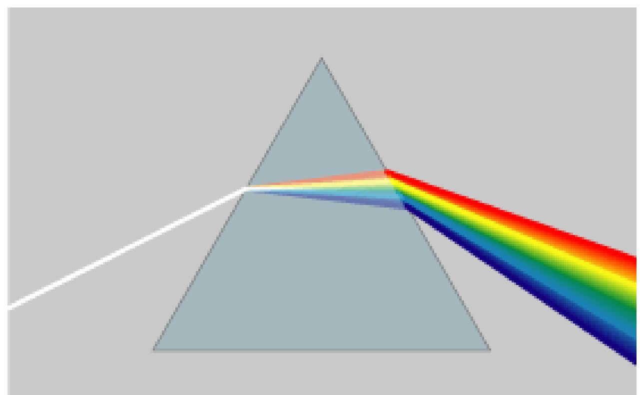


Figure 1. (Left) Refraction of light through water droplets to form a rainbow. This Photo by Unknown Author is licensed under CC BY. (Right) Refraction of light through a glass prism to form a rainbow of colors. This Photo by Unknown Author is licensed under CC BY-SA

Light can also be described as a stream of tiny particles, called photons. This was proposed by Albert Einstein in 1905. You can see how light behaves as a particle in the photoelectric effect, which is when light shone on a metal surface knocks charged particles loose from a metal surface (see Figure 2). These charged particles are called electrons. Interestingly, this only happens if the light is high enough energy. The color of light is related to its energy. Red light is the lowest energy visible light, and violet is the highest energy visible light. The amount of energy that is needed for an electron to break free from the metal surface in the photoelectric effect is called its work function. Light in the photoelectric effect is best described as photons because electrons are ejected immediately from the metal surface and only if the light has high enough energy (regardless of brightness).

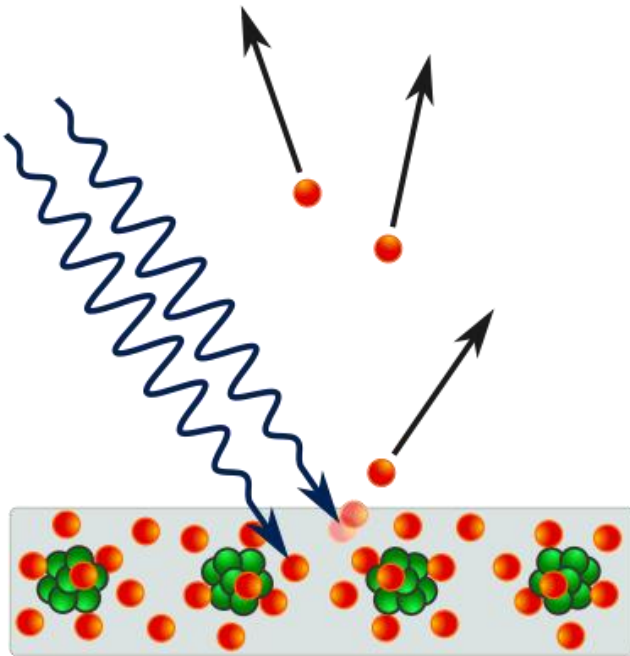


Figure 2. In the photoelectric effect, photons (packets of light shown in blue) hit a metal surface and cause emission of electrons (circles shown in red). This image by Unknown Author is licensed under CC BY-SA.

You can see now that light can be described as both a wave and a particle, depending on how it is observed and measured. This is known as wave-particle duality, which means that light can act both as a wave and as a particle. Furthermore, light waves can really be thought of as moving light energy made up of many tiny photons.

2.2. Supplies List

- Spray bottle
- Water
- Ruler or measuring tape
- Cardstock (heavy paper)
- Straws (or wooden dowels or sticks)
- Colored markers (or colored pencils or crayons)
- Marbles
- Tape
- Scissors

2.3. Safety Information

Before the students begin the laboratory, please take into consideration the following safety concerns:

- Students should never look directly at the Sun. This can permanently damage their eyes. If you are using the Sun as a light source, have the students look at a sunny spot on the ground or on the horizon away from the direction of the Sun.

3. Experiments

3.1. Part I: Rainbow in a Bottle

3.1.1. *Pre-Demonstration Questions*

1. Does light have color?

2. When have you seen the colors of light?

3.1.2. *Materials*

- Spray bottle
- Water

3.1.3. *Procedure (work in groups or demonstrated by teacher)*

1. Fill a spray bottle with water.
2. Find a space outside where you are in direct sunlight.
3. Spray water a few times in the sunlight and watch the sprayed water.

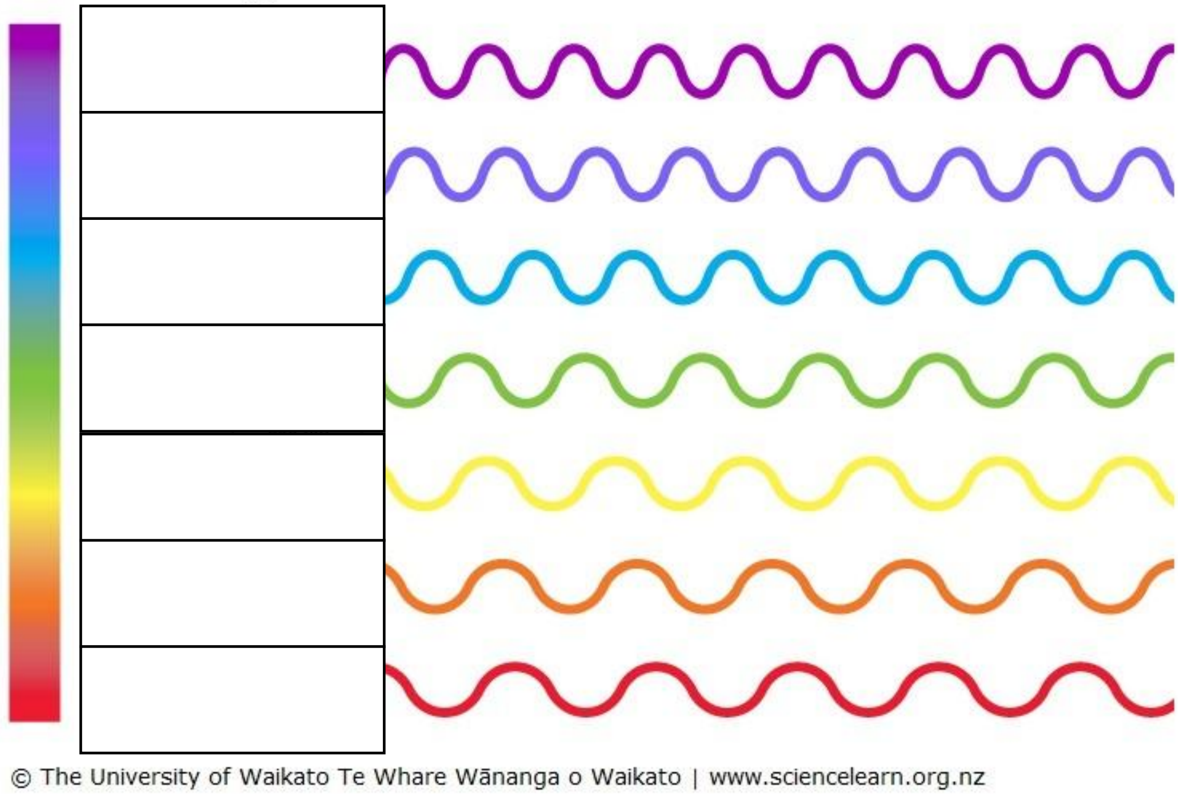
3.1.4. *Post-Demonstration Questions*

1. When water is sprayed under the Sun, what do you see? Describe this using the word refraction or refracts.

2. If you see colors, how many colors do you see?

3. What are some other examples of when you see a rainbow of light?

4. Extension: The colors of light that you identified in your rainbow are all in visible light from the Sun. These seven colors are sometimes remembered with the letters ROY G BIV, and these colors are often placed on lines or in a circle, sometimes called a color wheel. Now that you know the seven colors in the rainbow, try labelling them on the color wheel and color line below (in the white rectangles).



Source: Pinterest

Remember that light travels in waves? The length of the wave of visible light is specific to the color. See how the red wave looks more stretched out than the purple wave? The color red is a type of light that has a longer wave than purple. If you combine all of the colors on this color line, you end up with white light. Sunlight contains all of the colors of the rainbow!

3.2. Part II. Modelling the Photoelectric Effect

3.2.1. *Pre-Experiment Questions*

1. Recall the photoelectric effect from Section 2. How do you define the work function of a metal?

3.2.2. *Materials*

- Cardstock paper
- Straws (or wooden dowels or sticks)
- Colored markers (or colored pencils or crayons)
- Marbles
- Scissors
- Tape

3.2.3. *Procedure (work in groups of 2-4)*

1. Create ramp that will be used to model the photoelectric effect (see Figure 3). (This may have been done ahead of time by your teacher.)

a. Draw the two middle lines with a pencil and cut the two “V” shapes 6 cm from the end.
b. Draw lines starting 10 cm from the “V” cuts starting with red (R) and continuing every 3 cm until you have R, O, Y, G, B, I, V.
c. Fold the paper on the middle lines and bend the end up at the “V” cuts, taping the sides near the “V”s. This should produce a ramp.
d. Use the straws or dowels and tape to create legs to hold up the ramp.

2. Place marble 1 at the bottom of the ramp.
3. Hold marble 2 at the red (R) line on the ramp and release it so that it collides with the marble 1.
4. Record your observations.
5. Repeat steps 3 and 4 with the other colored lines.

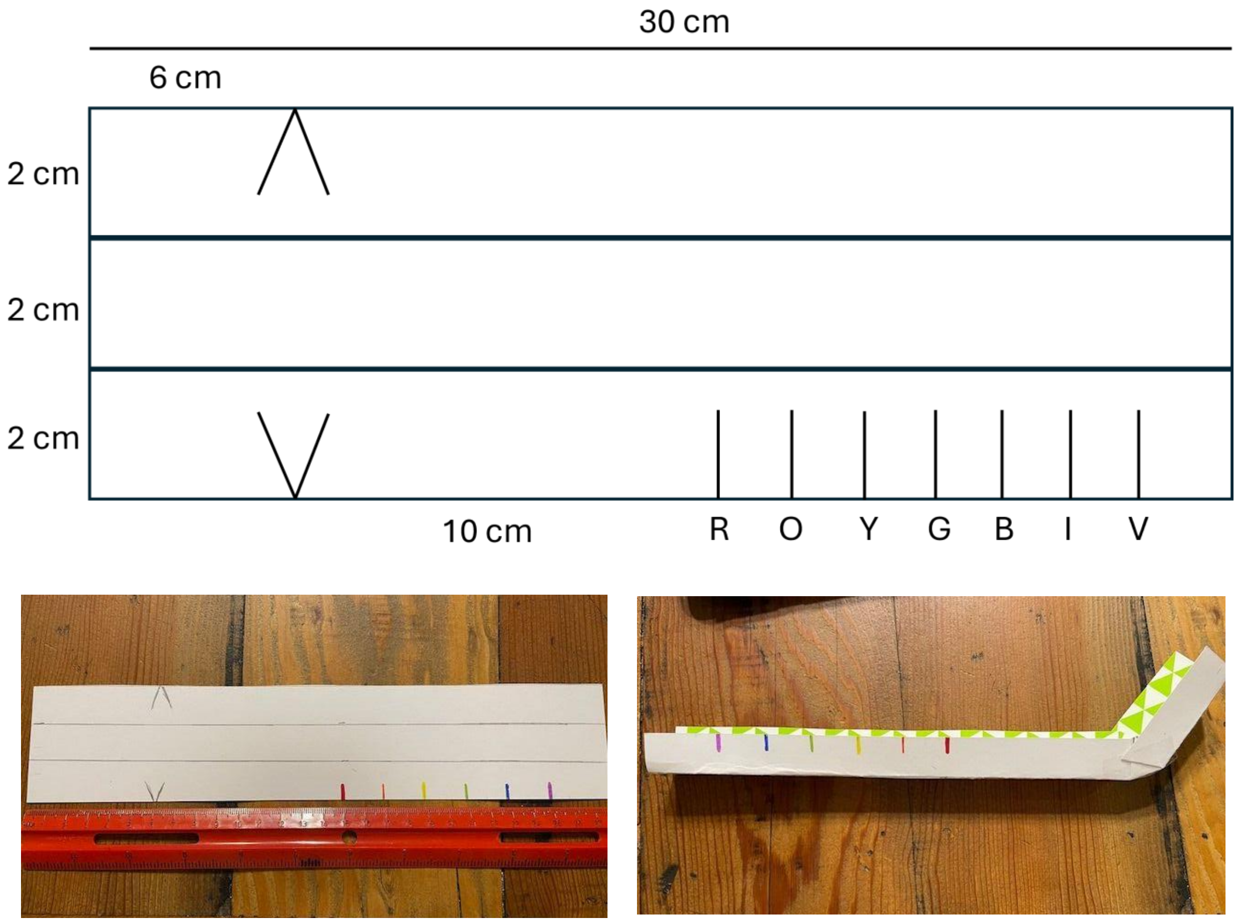


Figure 3. (Top) Dimensions of ramp to be constructed. Note that this is not drawn to scale and should not be directly printed and used. (Bottom left) Ramp construction prior to cutting and taping. (Bottom right) Complete ramp construction.

3.2.4. *Results*

Color	Observations	Did marble 1 launch off the ramp? (Y/N)
Red		
Orange		
Yellow		
Green		
Blue		
Indigo		
Violet		

3.2.5. *Post-Experiment Questions*

1. At what line does marble 1 launch off the ramp?

2. What happens to marble 1 when you release marble 2 at “colors” higher up the ramp? How does the height on the ramp relate to the color’s energy?

3. Based on your knowledge of the photoelectric effect:
    a. What does marble 1 represent?
    b. What does marble 2 represent?
    c. What does moving marble 2 up the ramp represent?

4. Design Challenge

The Challenge: Design a tool or machine that uses light!

We have seen in previous experiments that light can be described as a wave and as a particle, and we know from our lives that there are various sources of light (the Sun, light bulbs, lasers, etc.). Now it is time to think about a way light could be used in a tool or machine to do something useful or interesting.

4.1 Design Questions

1. What are different sources of light that you could use in your tool?

2. How could what you have learned about light in this kit be useful in your tool? Consider refraction and the photoelectric effect.

4.2 Design Sketch

Sketch the design of your tool below, describing the ways in which light will be used.

5. Sources

http://phy.sites.mtu.edu/RETlessonplans/the-photoelectric-effect/

https://phet.colorado.edu/sims/cheerpj/photoelectric/latest/photoelectric.html?simulation=photoelectric

Zitzewitz, P. W.; Davids, M. (1999). *Glencoe physics: principles and problems.* Glencoe/McGraw Hill.