QUANTUM (Q)-KIT

Light and Photons:

Laboratory for Primary Level Students

Teacher Manual

WOMEN SUPPORTING
WOMEN IN THE SCIENCES

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. Using this Guide

This manual is to be used by the teacher or facilitator of the laboratory kit, and it is similar in content to the student manual but may contain additional material, namely: Fundamental Science Concepts Covered, Practical Skills, Summary of Experiments, Teacher Pre-Lab, and Troubleshooting. These additional sections are intended to provide the teacher with the background and foundation critical for successfully implementing this laboratory kit in the classroom. It is recommended that the teachers of this laboratory kit go through the guide from beginning to end to familiarize themselves with the content prior to teaching the laboratory kit to students. Questions about the content can be directed at any time to ws2global.org@gmail.com, using the subject line "Question about Lab Kit Content".

IMPORTANT NOTES:

- This laboratory kit is intended for use with primary-level students (ages ~5-11), but depending on the specific students' educational background, the content may need to be modified by the teacher to be made simpler or more complex. The teacher is encouraged to also cover the content at the pace that works best for the students; some younger students may need more time and attention from the teacher and/or facilitator to go through the questions and experiments, while older students may be more independent and require less attention from the teacher and/or facilitator. Thus, the content covered, depth of coverage, and pacing are left to the teacher's and/or facilitator's discretion.
- The content in this lab kit manual may not fit into the specific curriculum of the school in which it is being taught. It is up to the facilitator(s) and teacher(s) whether they would like to introduce new content or skip certain sections that are not applicable to their classrooms.
- In certain areas, modifications to the supply list may need to be made depending on the availability of the supplies in the specific area in which the lab is being taught. We have attempted to list some alternatives in the supply list, but we understand this list of alternatives is not exhaustive.
- In the experiments, the students are split into groups of three to four. If supplies allow, students may instead be split into groups of two.

1.3. 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

1.4. Key Questions

- What is light?

- *Answer: Light is a type of energy that helps us see.*

- Is light a wave or a particle?
  - *Answer: Light is both a wave and a particle.*

1.5. 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.

1.6. Fundamental Science Concepts Covered

This laboratory kit introduces the topic of light as a wave and a particle, relevant to numerous fields including Physics, Chemistry, and Biology, to elementary and primary-level students. Specifically, the lab kit encourages students to think about how light acts as a wave through refraction and as a particle through the photoelectric effect analogy. Students will come away with the following key takeaways: (1) light is refracted to produce a rainbow; (2) photons of different color are different energy, and when they hit a metal surface, they can cause electrons to be ejected if they are energetic enough.

1.7. Practical Skills

- Students will understand light properties and how this leads to different phenomena observed.
- Students will connect concepts to everyday experiences at school and home (e.g., rainbows, devices that produce and use light)

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.

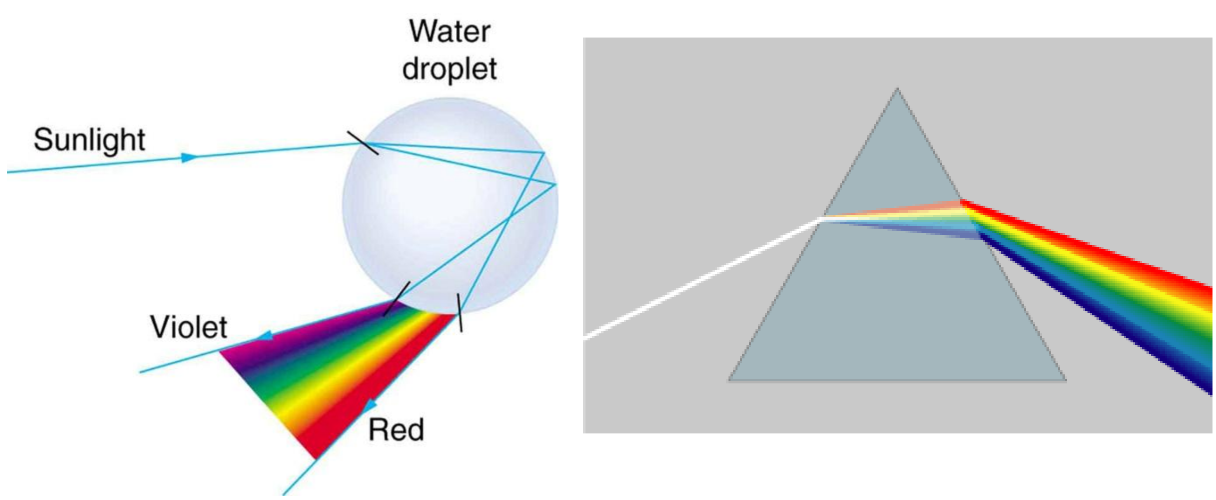


Figure 1. (Left) Refraction of light through water droplets to form a rainbow. This Photo by Unknown Author is licensed under CC BY. (Right) Refraction of light through a glass prism to form a rainbow of colors. This Photo by Unknown Author is licensed under CC BY-SA

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).

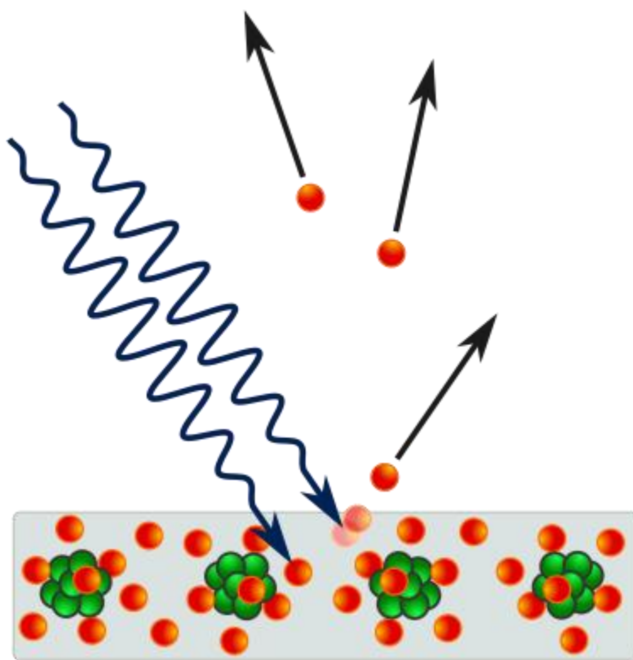


Figure 2. In the photoelectric effect, photons (packets of light shown in blue) hit a metal surface and cause emission of electrons (circles shown in red). This image by Unknown Author is licensed under CC BY-SA.

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.

3. Summary of Experiments

This lab kit consists of one demonstration, one experiment, and one design challenge to understand the concept of light and photons. This investigation will begin by providing background on light as a wave and particle, before demonstrating phenomena that emerge based on these descriptions. The goals of the experiments and design challenge are the following:

Part I: To demonstrate light refraction to make a rainbow using water and sunlight

Part II: To observe how different energy photons can eject electrons in the photoelectric effect via an analogy with marbles and a ramp

Design Challenge: To design a device that uses light to do something useful

3.1. 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

3.2. 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.

3.3. Teacher Pre-Lab

Teachers can organize the supplies for the experiments ahead of time. For each student or each group of 2-4 students, the materials needed are: 1 piece of cardstock (heavier) paper, 2 wooden dowels or straws, 2 marbles, and a pen or pencil. There should be spray bottles, colored markers, scissors, and tape that the classroom can share.

4. Experiments

Note for teachers:

Encourage open discussion and questions from the class when introducing the experiments.

4.1. Part I: Rainbow in a Bottle

4.1.1. *Pre-Demonstration Questions*

1. Does light have color?
    a. *Answer: Yes, light has color. All of the colors of the rainbow are contained in visible light.*

2. When have you seen the colors of light?
    a. *Answer: Answers will vary and teachers should encourage student creativity. Students may answer: rainbows, using a glass prism in the sunlight, laser pointers, light bulbs, etc.*

4.1.2. *Materials*

- Spray bottle
- Water

4.1.3. *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.

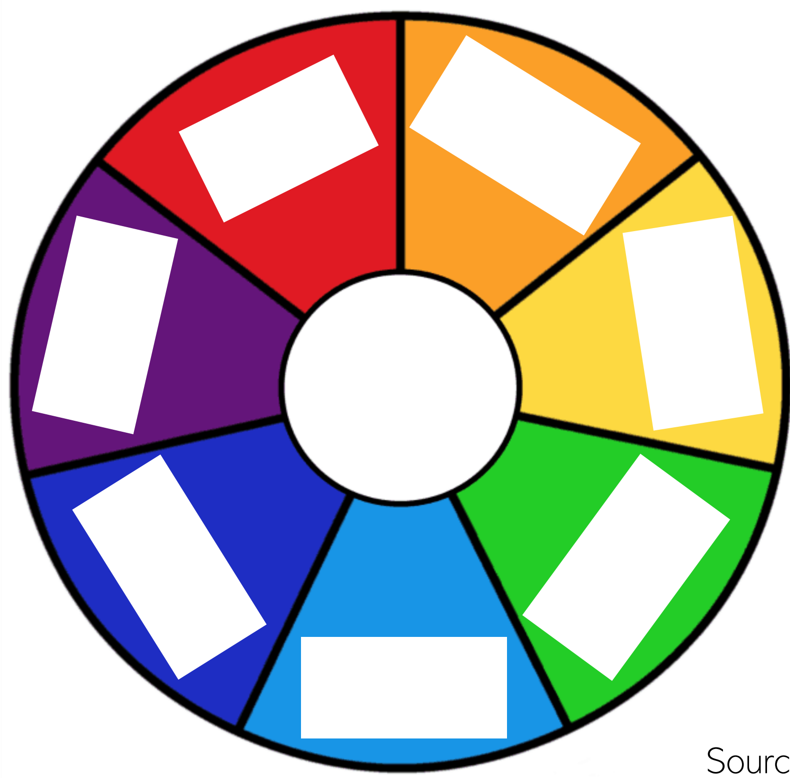
4.1.4. *Post-Demonstration Questions*

1. When water is sprayed under the Sun, what do you see? Describe this using the word refraction or refracts.
    a. *Answer: A rainbow appears when light shines through the water droplets. This happens because the light bends, or refracts, in the change from air to water and back to air. The bending, or refraction, is slightly different for each color in the light, so we see a band of colors.*

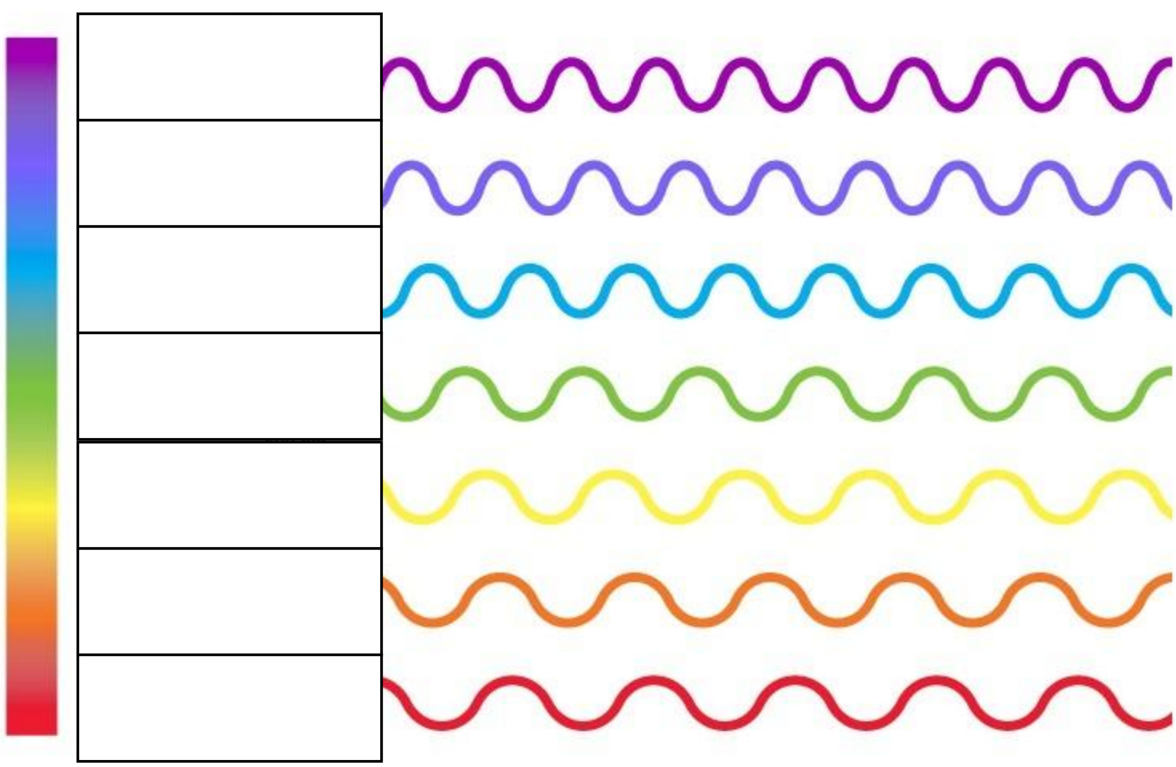
2. If you see colors, how many colors do you see?
    a. *Answer: We see many colors, including red, orange, yellow, green, blue, and violet.*

3. What are some other examples of when you see a rainbow of light?
    a. *Answer: We can see a rainbow when passing light through a glass prism or glass container. Sometimes we see a rainbow when looking at a thin oil layer on water in the sunlight.*

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!

4.2. Part II. Modelling the Photoelectric Effect

4.2.1. *Pre-Experiment Questions*

1. Recall the photoelectric effect from Section 2. How do you define the work function of a metal?
    a. *Answer: The work function is the amount of energy needed for an electron to break free from a metal surface.*

4.2.2. *Materials*

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

4.2.3. *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.

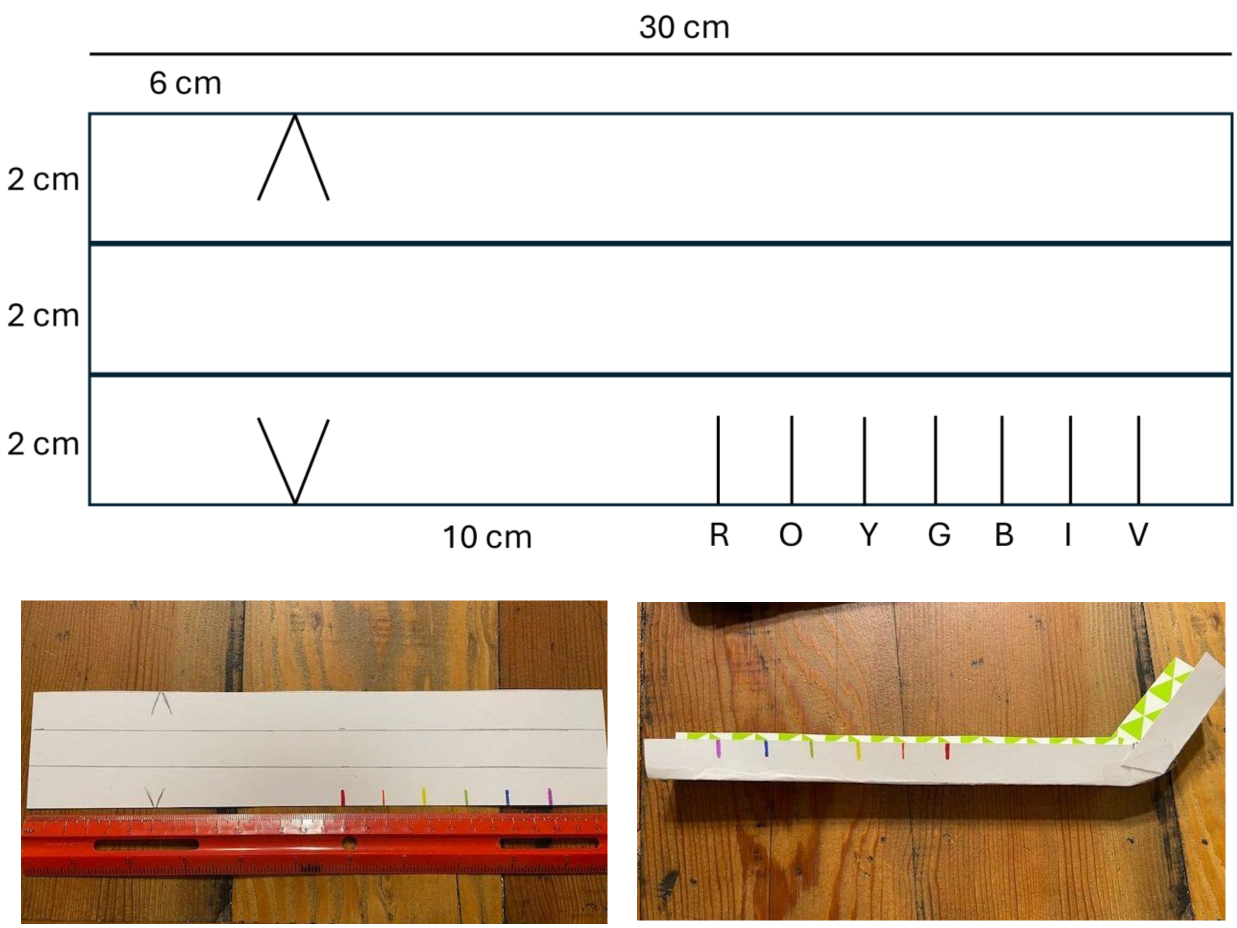


Figure 3. (Top) Dimensions of ramp to be constructed. Note that this is not drawn to scale and should not be directly printed and used. (Bottom left) Ramp construction prior to cutting and taping. (Bottom right) Complete ramp construction.

4.2.4. *Results*

Color	Observations	Did marble 1 launch off the ramp? (Y/N)
Red		

Orange		
Yellow		
Green		
Blue		
Indigo		
Violet		

4.2.5. *Post-Experiment Questions*

1. At what line does marble 1 launch off the ramp?
    a. *Answer: This will vary slightly depending on the construction of 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?
    a. *Answer: Marble 1 continues to be launched off the ramp but with more energy as the "color" of marble 1 changes higher up the ramp. Colors higher up the ramp are more energetic compared to colors lower on the ramp.*

3. Based on your knowledge of the photoelectric effect:
    a. What does marble 1 represent?
        i. *Answer: incoming photon (light)*

    b. What does marble 2 represent?
        i. *Answer: electron in metal*

c. What does moving marble 2 up the ramp represent?
    i. *Answer:* *shining light with higher energy*

5. 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.

5.1 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.

Possible answers to questions (encourage discussion of class):

There are many sources of light including the Sun, flashlights, lasers, light-emitting diodes. Light could be used to do many things in life, like heat a surface, liberate electrons (which could be used as electricity), and stretch or bend materials. The goal is to get the students thinking creatively and to encourage sharing of ideas.

5.2 Design Sketch

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

6. 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.