

Toy box optics: bringing optical technologies home and to schools

Mable Fok* and Steven Binder

Photonics and Soft Robotics Laboratory, School of Electrical and Computer Engineering
College of Engineering, University of Georgia, Athens, GA 30602, USA

Abstract

Optical technologies can be found in many aspects of our daily lives. We have developed three experiments using items that can be found in a toy box or around the house to demonstrate and explain optical concepts. Videos of the experiments, their principle, and applications are available on our YouTube channel. The first experiment uses moldable putty to make a shapeable lens and light guide to observe refraction and total internal reflection respectively. The putty's characteristics allows for hand molding into different shapes to observe how light propagation is changed within the putty in real time. The second experiment is to learn about color absorption and reflection. The color pattern of clothing would change depending on the color of light that is used to illuminate it. The experiment illustrates how optical communication can use different colors to support multiple users. The third experiment uses a bubble to illustrate light interference, the principle behind eyeglasses coating. Different colors are seen at different locations on the bubble due to light interference. The above experiments can be carried out at home or at school through our outreach program. During our school outreach, we relate the above hands-on experiments with two demonstrations. The first demonstration is a laser-transmitted audio system that explains how electrical signals can be transmitted using optical fibers. While the second allows for the observation of how laser light is guided within an optical fiber. The toy-based experiments are a fun approach to introduce complex concepts to students.

Optics outreach, interference, refraction, total internal reflection, optical fiber, at-home experiment

1. INTRODUCTION

Optics play a crucial role in many of the technologies we use and observe on a daily basis. For example, light is used in optical fibers to transmit data across distances that can span the entire world. Making the internet possible. Furthermore, optics are fundamental to the construction of lenses. Helping people to see better and magnifying small objects not visible to the naked eye. We observe both ray optics and wave optics phenomenon everyday, such as the wavy images observed above hot asphalt and the rainbow color on the surface of a bubble. Light is essential to many of the technologies that we rely on every day. Its properties and behaviors have been harnessed to improve and enhance our lives in countless ways.

To help our next generation relate to light-based technologies that we use daily, easy and accessible hands-on experiments can help engage them in learning more about optics through concrete examples of optical phenomena. Physical experiments can help kids develop a better understanding of the properties of light and the ways in which it interacts with different materials – it is educational, fascinating and fun. Conducting experiments at home allows students to creatively design and carry out their own investigations, make thorough observations, and draw logical conclusions based on their own experiences. Conducting experiments using everyday items would help students learn through play and reduce the mental hurdle for students who are “experimentally anxious” as they are using items they play with every day. Furthermore, toybox based experiments overcome the financial barrier that students may face – there would be no need for purchasing any science and engineering experiment kits which are usually very expensive. Additionally, a follow-along video on how the experiment is conducted, the principle behind it, and applications related to our daily lives would be beneficial to help strengthening one's understanding and connecting the experiment to real life. Lastly, some more complex optics experiments can be conducted at school using low-cost components to bring the at-home experiment closer to real life applications.

*Corresponding author email: mfok@uga.edu

2. TOY BOX OPTICS: AT-HOME EXPERIMENTS

Toy box optics focus on using simple toys that kids may already have at home for conducting optics experiments and allowing them to observe various optical phenomenon. This section introduces three toy-based experiments that can be conducted at home: (1) Moldable putty lens (2) Color fashion (3) Rainbow bubble; covering optical phenomenon such as refraction, total internal reflection, interference, how color absorption and reflection works, as well as color adding and subtracting.

2.1. Moldable putty lens and light guide

A popular toy among elementary school students, putty is a toy that is stretchable, moldable, and reusable. Clear putty is one type that has a transparent appearance or contains a certain shade of color, as shown on the right of Figure 1(a). In this at-home putty lens experiment, a student would begin by using their fingers to mold the putty into a convex and concave lens. An example of a putty-based convex lens is shown in Figure 1(b). Once the putty lens is made, the student can use any light source to observe refraction. If the student does not have a narrow beam light source (e.g. laser pointer), they could tape the output of a single LED flash light to leave just a slit. A black sharpie could be used to color on the tape to reduce light leakage. The student would first shine the light source at the central axis of the lens. As the light source is moving away from the normal, i.e. middle point of the lens, the beam of light would bend away from the central axis in a convex lens, as shown in Figure 1(c), while the beam would bend towards the central axis in a convex lens, as shown in Figure 1(d). If the students have two light sources, then the two light beams can be directed to the putty lens in parallel and can be used to illustrate how lenses are used for correcting vision and for magnifying objects in a microscope. Furthermore, multiple putty lenses can be used next to each other to experiment with how light is refracted as it travels through different lenses.

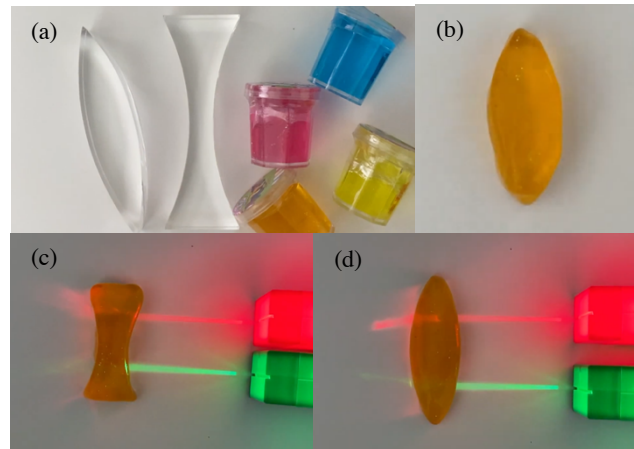


Figure 1: Moldable putty lens experiment. (a) Lens and clear putty (b) An example of a convex lens made of clear putty (c) Light is diverted by a putty concave lens (d) Light is focused by a putty convex lens.

Once students are comfortable with the concept of refraction in the putty lens, they can move on to molding the putty to make a light guide allowing for the observation of light propagation in optical fibers. The student would first mold the putty into a long cylinder as seen in Figure 2(a). Then, the student can launch a narrow light beam at angle to the input and adjust the incident angle until total internal reflection occurs as shown in Figure 2(b). While changing the incident angle, students can observe the change from refraction to total internal reflection. This experiment can be used as ray optics explanation of fiber optic communications and how certain types of optical fibers use total internal reflection to guide light through optical fibers.

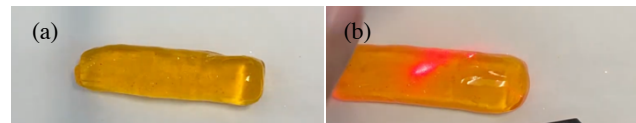


Figure 2: Moldable light guide experiment. (a) Putty is molded into a long cylinder light guide (b) Total internal reflection occurs inside the light guide.

2.2. Color Fashion

From the famous Newton's prism experiment, it has been shown that white light is composed of a variety of colors. The colors we observe in objects around us result from materials absorbing and reflecting different wavelengths of light. In the color fashion experiment, students will need a dark place, such as a closet, and a few pieces of clothes or fabric with multi-color patterns. A good example of a multi-color fabric is shown in Figure 3(a). In this experiment, a flashlight is being used as the light source. Ideally, the students would have access to multiple color LED flashlights. We will need one red, one blue, and one green LED flashlight. If colored flashlights are not available, students can add color to the output of a white light flashlight by adding transparent tape, then using a red/blue/green sharpie to add color to the transparent tape.

Once the colored flashlights are ready, the student would shine the light onto the fabric/clothes in turns. When blue light is used, only the blue color will show up on the fabric while the rest would look black (Figure 3(b)). On the other hand, when red light is used, only the red color will show up on the fabric while the rest looks black (Figure 3(c)). This is because when only blue light is provided, the parts of the fabric that are blue can reflect the blue light, while the non-blue parts of the fabric are absorbing the blue light – making them appear black as no light is reflected. Next, the student can shine all the three color of light onto the fabric, and the

“normal” color combination should show on the patterned fabric, similarly to Figure 3(d). Since different colors can be used to represent different patterns on fabric, the combined color pattern is similar to wavelength division multiplexed optical communication systems. Where different colors can be used to represent different information streams that can be combined into one coherent light ray and transmitted in an optical fiber.

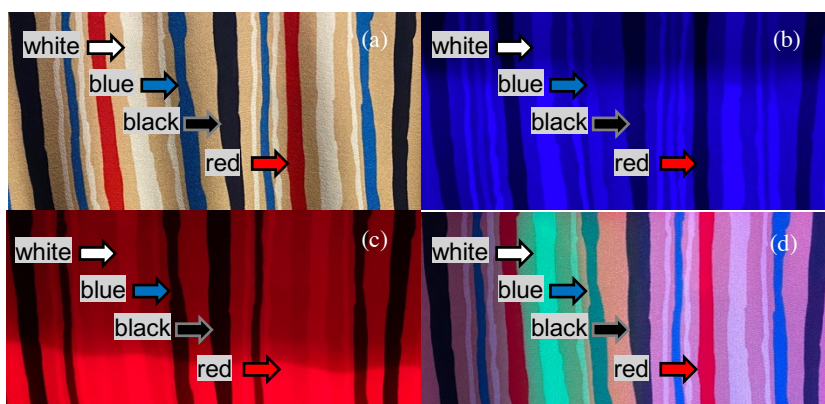


Figure 3: Color Fashion experiment (a) pattern fabric under white light (b) pattern fabric under blue light (c) pattern fabric under red light (d) pattern fabric under mixed color light.

Using the three colored flashlights, students can also experiment with color adding. First, the student can pick a specific colored flashlight and shine the light onto a white sheet of paper. The paper should only show the color of that particular flashlight. Next, the student should make a guess of what would happen if all three colored flashlight are shined onto the paper. Then, the student should continue the experiment by shining all three colors on to the same spot of the paper. If one of the flashlights is stronger than the others, then the stronger flashlight should be moved further away from the paper. When the strength of each light is balanced, the student should see white at the area where all the three light beams are overlapping – this is called color adding. Each color flashlight has its own energy corresponding to its color. The white paper reflects all colors when the three primary colored flashlights are used. Therefore, all the energy from each color is reflected. This color mixing concept is quite different from when one mixes different colors of paint. Paint itself does not give out energy. When a white light is applied to red paint, then it would absorb all colors except red. If white light is applied to blue paint, it would absorb all colors except blue, just to list a few as an example. As one could imagine, multiple colors of paint are added and mixed together, more color energy would be absorbed, preventing the reflection of light. As a result, the color of black is seen when mixing multiple paints of different colors together – this is called color subtraction. On the other hand, when mixing light of different colors together, white color is seen – this is called color addition.

2.3. Rainbow bubble

Every kid has likely enjoyed playing with bubbles. Blowing bubbles outdoors is fun and they look pretty as they display a rainbow-like color under sunlight. By conducting this experiment, students can gain an understanding of the principle behind the appearance of rainbow-like colors on bubbles. A bubble’s wall is extremely thin - in the order of 10 to 1000 nanometers (10^{-9} meter) and is about 500 times thinner than human hair. Although a bubble’s wall is thin, it consists of multiple layers of soap on the outside and inside with an ultra-thin layer of water sandwiched in between. When light hits a bubble, some of the light is reflected back to our eyes from the outer layer, while some of the light is reflected back to our eyes from the inner layer, which is less than tens to hundreds of nanometers away from the outer layer. Therefore, these two reflected light rays will arrive at our eyes with a delay between them, which is comparable to the size of the visible light wavelength. The two sets of waves interfere with each other. The colors that are added together look brighter while the other colors that cancel each other out are removed. The colors that can be added depend on the thickness of the soap and water layers – the bubble’s wall thickness. Hence, bubbles appear to change color as they drift, owing to the alteration in their walls thickness. Aside from the rainbow-like coloring of bubbles, interference is also the optical phenomenon responsible for the anti-reflection coating of glasses and the beautiful color schemes seen on butterflies and peacocks.

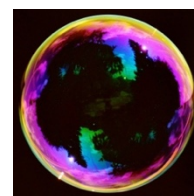


Figure 4: Rainbow color observed in a bubble.

3. SCHOOL DEMONSTRATION

In section 2, several at-home experiments have been introduced for demonstrating optical phenomenon. Such as refraction, total internal reflection, interference, as well as color adding and subtracting. To go further into real life applications of lasers and fiber optics, two more experiments that can be used at school are introduced.

3.1. Laser-transmitted audio system

A laser-based audio transmitter and receiver can be constructed using readily available components found around the house or online. Items required to construct both circuits include one 3.5mm audio cable, a small solar panel, a battery/battery pack capable of supplying 1.5V, a $1000\Omega:8\Omega$ transformer, and either a breadboard or protoboard. The choice between the breadboard or protoboard is dependent on if the user would like to solder the components together. The laser diode can be purchased or removed from a laser pointer. For constructing the audio transmitter, the components are to be wired together as seen in Figure 5(a). It is important that the cathode of the laser is connected to the positive terminal of the 1000Ω side of the transformer to ensure proper modulation. Figure 5(b) provides the circuit diagram for the audio receiver circuit. Once constructed, the user should be able to hear music from the receiver when the laser is pointed directly at the solar panel.

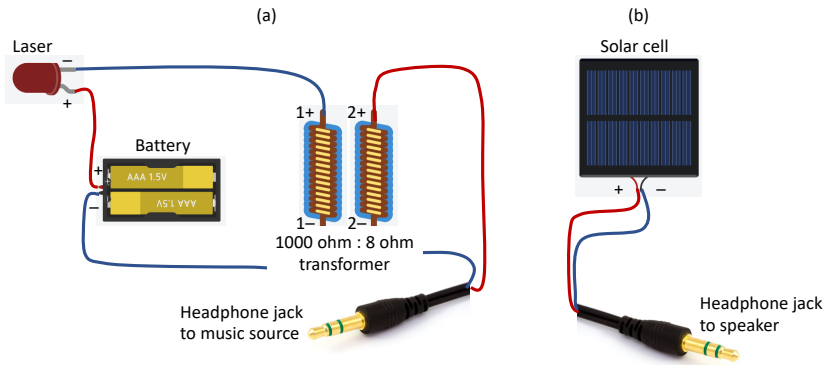


Figure 5: (a) The circuit diagram for the laser audio transmitter circuit. (b) The circuit diagram for the laser audio receiver circuit.

The principle behind the experimental setup focuses on the modulation of a laser diode using an electrical signal. Students are able to see the laser's intensity change as the audio plays in real time. While traditional fiber optic communication systems do not use an air medium for transmission, the experiment provides the opportunity to see what happens within an optical fiber-based communication system. Additionally, the experimental setup can be used to highlight the care required when selecting components for an optical communication system. The solar panel can be exchanged with a more sensitive PIN photodiode to show the effects a photodetector has on the reconstructed audio signal.

3.2. Transmitting visible light in optical fiber

In section 2.1, a moldable putty light guide experiment is used to illustrate the theory behind fiber optic communications. To allow a more realistic demonstration of light guiding in fiber optic communication systems, a visual fault locator for fiber optic network testing and a piece of 900um single mode or multimode fiber patch cord can be used to demonstrate data transmission in an optical fiber. Both the visual fault locator and the fiber patch cord should have FC/APC connectors for easy connectivity. The visual fault locator emits red laser beam and collimates into the fiber patch cord. The other side of the patch cord should be pointing towards a table or a wall, where the red laser output can be observed. The visual fault locator can be turned on and off to simulate amplitude modulation and the laser output can be seen at the other end of the optical fiber. Illustrating how light information is transmitted through the optical fiber. Another way to demonstrate how light travels within a fiber optic patch cord is by bending the optical fiber. The demonstrator can bend the optical fiber to a circle with diameter of 2-3 cm to allow red laser light to escape via radiation. An example is shown in Figure 6. The optical fiber will change from white to red due to the escaping laser light. The principle of light radiation due to bending will also be explained.

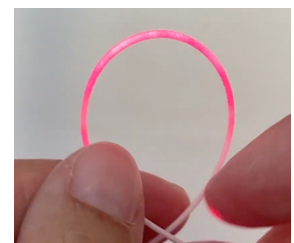


Figure 6: Laser light escape the optical fiber due to small bending radius of the fiber.

This experiment can be used as a basis for a fiber optic sensing experiment. Since light escapes an optical fiber if the bending radius is too small, the amount of light that is transmitted through the optical fiber would change. Therefore, an

optical fiber can be embedded on an object and any physical change to the object would bend the optical fiber. As a result, optical power loss due to bending would be seen and the amount of power loss can be used to determine the physical change in the object.

4. ONLINE MATERIALS

To provide a fun and engaging experience for students, videos that demonstrate and explain the at-home experiments are available on an educational YouTube channel – Play with Light, as shown in Figure 7(a). The videos provide follow-along directions and they discuss the working principle behind the optical phenomenon in the experiments. Additionally, the videos relate the phenomenon to real-life applications that kids are familiar with. The at-home experiment videos form the first series of videos on the YouTube channel that students can use as they do the experiment at home or as follow-up videos after watching the school demonstrations. Figure 7(b) is an example of the at-home experiment video. The second video series on the Play with Light YouTube channel is the Research Series. Videos of several research projects conducted in the Photonics and Soft Robotics Research Lab at University of Georgia are included to connect the general public with research activities in the field. The research series provides an accessible view into optical research and allows the public a better view into how the laboratory’s research may help improve their lives. Figure 7(c) shows an example of a research series video that introduces a soft robotic gripper with fiber optic sensors that mimic twining plant.



Figure 7: (a) Play with Light YouTube Channel (b) follow-along moldable putty lenses (c) Research series.

5. SUMMARY

This paper aims to present accessible and interesting optical experiments that help explain the concepts of optical technologies present in various aspects of our daily lives. The at-home experiments introduced are created using items found in toy boxes or around the house. Companion videos to the experiments are available on our YouTube channel. Where you can learn about the principles and applications of each experiment.

The first experiment is based on moldable putty, which is used to create a shapeable lens and light guide. By hand-molding the putty, you can observe refraction and total internal reflection in real-time and see how light propagation changes within the putty. The second experiment focuses on color adding and subtraction. By illuminating multi-color fabric with different colored flashlights, you can observe changes in color patterns. The third experiment involves using bubbles to explain light interference, the principle behind coatings on eyeglasses. The bubble displays different colors in different locations due to light interference based on different bubble wall thickness. These experiments can be carried out at home or school through our outreach program.

In addition, we also provide two demonstrations during our school outreach program. The first is a laser-transmitted audio system that explains how electrical signals can be transmitted using optical fibers. The second demonstrates how laser light is guided inside an optical fiber. These toy-based experiments offer a fun way to introduce complex concepts to anyone interested in optics.

6. ACKNOWLEDGMENT

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7. REFERENCES

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