Outreach experiments guide for an optic show to pre-college level by Medellin student chapter

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ABSTRACT

There is a lack of knowledge among the community that prevents them from pursuing a career in the science of light. Due to the importance of introducing optics and photonics fields and their relevance in both, industry, and academy to pre-college students, outreach activities such as showing optical experiments become relevant. The method used to present science to students impacts their perspective directly; therefore, an adequate optics show oriented to the comprehension of pre-college students is required to improve the knowledge transmission. Here we present how an optics show is carried out by our student chapter at Universidad Nacional de Colombia, Medellin campus, along with recommendations hints and suggestions, as well as a useful guide for beginners in outreach. The explanation methodology and the needed materials and components and setups to perform common optics phenomena experiments such as diffraction, color theory, polarization, fluorescence, phosphorescence, and optical illusions are presented.

Keywords: Outreach, Optics show, Experiments, College level, Student chapter

1. INTRODUCTION

Over the years, there has been an evident reduction in the number of new students entering university programs in the STEM areas and an increase in traditional programs such as medicine, administration and law, as well as audiovisual communication, marketing and journalism.[1]

Recently a public university in Colombia has announced the closure of academic programs due to the absence of new students, being mostly academic programs focused on STEM, some of them are: bachelor's degree in physics and environmental engineering. This represents a serious situation for the technological and scientific development of the country.[2]

It is worth to establish a relationship between student desertion and basic sciences, where the most influential points and the convergence of these two topics are analyzed. In this study [cite] the author presents some reflections and alternatives, including relevant statistical information, which aims to improve teaching strategies both in the population that accesses higher education and those that do not. Clearly, science outreach is proposed as an alternative solution for the dissemination of science and technology, for all types of audiences.[3]

Optical shows, as scientific outreach, are activities that allow people to have an approach that motivates, generates curiosity and ultimately stimulates the desire to delve deeper into the phenomena discussed, which is why such activities are strategic to be applied in students of secondary school, who are in the process of incorporation into

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a university life. Optical displays allow strengthening concepts and creating connections between experimental experiences and previously seen theoretical models, in addition to leveling or adjusting the knowledge presented so that it can be more easily remembered and understood. This type of outreach activities are transversal to all areas of knowledge, both as strategies to promote curiosity and as a complement to lines of study proposed in the classroom.[4]

2. OPTICS SHOW GUIDENCE

An optics show is an activity of scientific divulgation, where the main objective is to bring knowledge that could be complex to people who are not experts in the subject or who ultimately know nothing about the area, in an accessible and easy way to understand. These activities usually have more of an informative approach, and not a teaching method, because although something can be learned, there may not be a social appropriation of knowledge. Additionally, the optics shows are not rigorous in terms of phenomena or the mathematical development of the topics.

Before performing an optics show it is necessary to take into consider the phenomenon or topic to be explained, then it is important to know the materials that will be needed for its execution and it is also relevant to take into mind the environmental conditions that are required for the execution of the experiment, for example if a dark or illuminated environment is needed. Considering the above, it is necessary to consider the audience to whom the show is addressed, this is essential because explaining to a child, an adult, an expert on the subject or someone from another area of knowledge is very different and if the right language is not used, it can become an uncomfortable experience and the knowledge that you want to bring may not be digested correctly.

There are too many ways to organize an optics show; a simple way to do this task is to separate the experiments in accordance with their most related optics phenomena, and, again, there are many ways to organize the experiments because some of them have different phenomena in just one experiment, so the criterion to choose the better place for a particular experiment depends on the order followed in the show and their role with other experiments. An order for the experiments is proposed in this paper, but it is not required; it is simply a useful guide. The phenomena used for this purpose are

- **Diffraction**: It is shown that the light behaves like a wave with impressive diffraction experiments.
- **Color theory**: With these experiments, it covers the way humans perceive light with their eyes and how different colors are a consequence of this.
- **Polarization**: here it is shown how light can be "ordered" in some orientation and the possible applications of this property.
- **Fluorescence and phosphorescence**: These experiments reinforced the particle-wave light duality and how it is possible to use each of these behaviors in specific situations.
- **Optical illusions**: Here it illustrated how the way humans perceive light could trick our eyes.
- **Geometrical optics**: Here it is shown the light like rays and particles in the classic way, normally this is present before diffraction optics to realize their different conceptions of light.

The following subsections shows the different experiments that are usually carried out by our student's chapter; alongside a the materials needed, the experimental procedure, and a brief explanation of the phenomenon to be show.

2.1 Diffraction

Diffraction is the physical phenomenon that occurs when waves encounter a small obstacle or irregularities on a surface, resulting on the deviation of the wave in a specific pattern. A classic example is when looking at a CD near or through a light source, observing a band of different colors.

2.1.1 Slits vs Light

Materials:

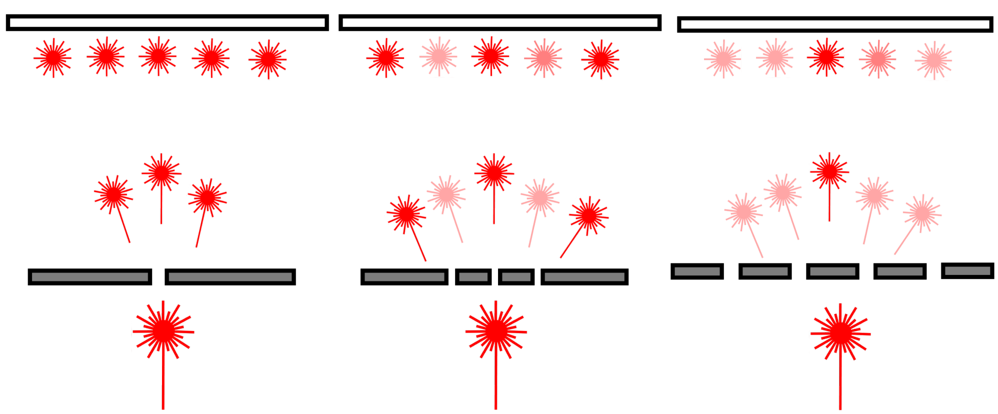
- A laser
- Diffraction gratings with 500 lines/mm, 13500 lines/in, and 25400 lines/in
- Diffraction glasses

Procedure

Point the laser at the different gratings available with a solid background in order to be able to see the patterns. After analyzing one pattern, change to next diffraction grating.

What phenomenon is observed?

During the slits experiment it is demonstrated that, given the diffraction patterns, light has an ondulatory behavior. This is, light is a wave. Contrary to previous thoughts that considered light as ray. This can be explained as it follows: we have a grid and a laser. Let's consider that from the laser light is emitted in straight line, or a "ray". When the light beam interacts with the grid, we see many points of light in the background, as if there were more lasers pointing in the same direction. Actually, what happens is that the ondulatory behavior of light arises, and the light waves interact with each other, like waves in the water, reorganizing the intensity across the space. This reorganization produces constructive or destructive interference. This means, the intensities are added or canceled, thus observing several points on the wall. This result is known as diffraction, Figure 1. The amount of luminous points (principal maximums) on the solid background will depend on the distance between the diffraction grating and the background, alongside the amount of slits (lines) of the diffraction grating, as shown in Fig. 1 . The amount of dimmer points (subsidiaries maximums) also depend on the amount of lines, following the empirical relation of $dimmerPoints = N - 2$, where N is the amount of lines.



(a) (b) (c)

Figure 1. Conceptual sketch of a diffraction grating experiment. The dimmer points represents subsidiaries maximums, while the luminous points represents principal maximums. (a)-(c) displays the relation between the dimmer points and the number of slits.

2.1.2 Psychedelic Record

Materials

- Paperboard
- 6 tongue depressors
- Cutter

- Hot silicone
- 1 CD
- 1 flashlight
- 1 candle
- Scotch tape

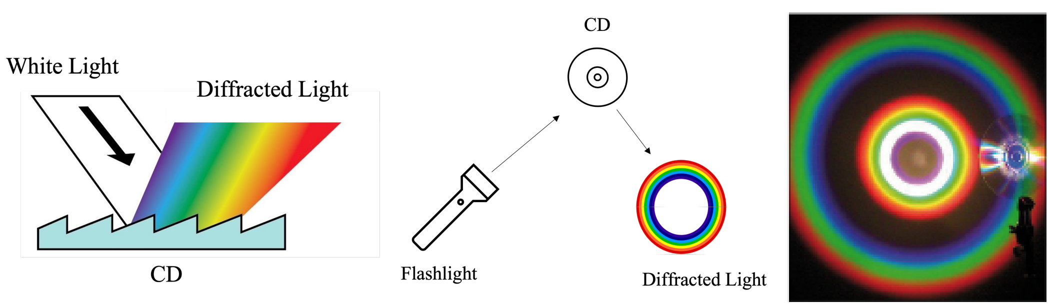
Procedure

First, we proceed to separate the plastic layer that is attached to the CD and remove the rest of the aluminum using adhesive tape. Then, three tongue depressors are glued one on top of the other in a line along each other, thus forming a "mobile". A cardboard rectangle is cut out and two tongue depressors are glued parallel to the center, separated by exactly the same measurement as the width of the mobile that has just been created. A tongue depressor is glued perpendicular to one end of the mobile. Secondly, the CD is fixed perpendicularly to the mobile using silicone and a cardboard circle is cut out to stick it in the center of the CD and cover the central circle. Finally, a flashlight is placed so that the focus is at the height of the center of the cardboard circle.

To perform the experiment, the light of the flashlight is made to impinge the mobile, and the mobile is moved towards and away from the flashlight, Figure 2(b). Then the flashlight can be changed to a candle and the experiment repeated.

What phenomenon is observed?

During this experiment diffraction arises due the transmission of light through slits of size comparable to the wavelength. Here, the CD will play the role of a diffraction grating. CDs are composed by many channels in the form of spiral rings. These channels resembles a diffraction grating , as depicted in figure 2(a)[5] . As the separation between rings is very small, it is able to separate white light into its different spectral components, which happens to be the colors of the rainbow. This separation is produced because when light is reflected by a grating, as the one depicted in figure 2(a), the reflection angle depends on the wavelength (color) of the light, the period of the grating, and the incidence angle. This is known as Bragg's Law. If we change the distance of the disk and the light source, we can see variations in color, since the incidence angle of the light is being changed. This experiment has been previously reported,[6] and its amazing result is shown in figure 2(c).



(a) (b) (c)

Figure 2. Diffraction through a CD. (a) Conceptual sketch of the working principle of a diffraction grating, adapted from Edmund Optics.[5] (b) Conceptual sketch of the experimental procedure. (c) Experimental result, figure taken from Ivanov *et al.*[6]

2.1.3 Diffraction through human hair

Materials

- Laser
- A hair

Procedure

Place the laser several meters away from a solid backgrounf. Between them the hair is placed, making sure that the distance between the laser and the hair is less than 1 meter. Having the assembly ready, we proceed to visualize the interference (diffraction) pattern produced by the hair. This simple experiment, summarized in figure 3, resembles the double slit experiment used by Young to test the wave-like behavior in his seminal work.

What phenomenon is observed?

Given the thinness of a hair, which similar to a common diffraction slit, the laser light is diffracted. This is, it deflects its straight path when it hits the obstacle of similar dimensions to its wavelength. The result of this can be projected into a white surface. In the generated image a pattern can be distinguished in which there is a strongly illuminated maximum and at its sides, separated by dark areas, there are other maxima. This simple experiment can be used to calculate the diameter of a human hair with the following equation,

$$d \approx \frac{L\lambda}{w},$$

where d is diameter of the hair, L is the distance between the hair and the screen, λ is the wavelength of the laser beam, which is commonly reported in the device, and w is the distance between the centers of the luminous points of the resulting pattern, Fig. 3. For this experiment the hair can be changed by a home-made single slit, using a soda can and a cutter. With this, the relation between the separation of the luminous points and the width of the slit can be deducted.

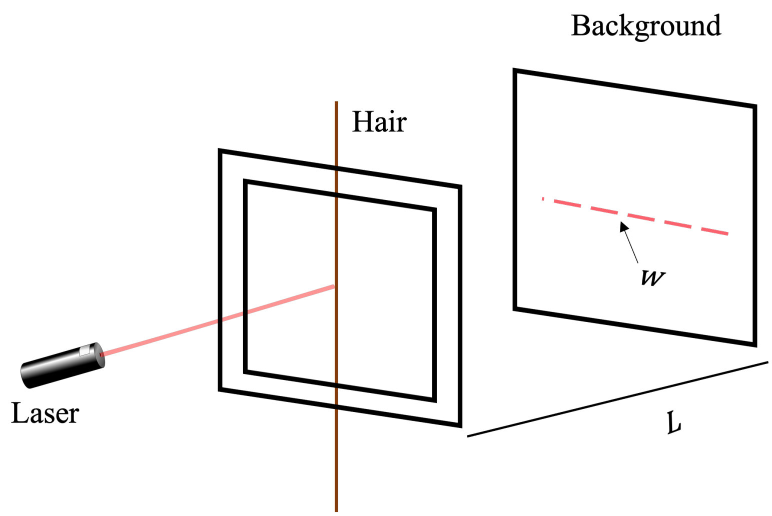


Figure 3. Conceptual sketch of a double slit experiment carried out with a human hair. L is the distance between the hair and the solid background. w is the distance between luminous points.

2.2 Color Theory

White light is composed by the superposition of all colors. Even so, white light can be produced with sources composed by primary colors as red, green, and blue (RGB). The color theory explains how these colors interact with each other and how the idea of colors is a visual perception that occurs in the brain when processing reflected light. These colors, when combined at a certain angle of light and according to the inclusion of each of these colors, can produce a wide range of colors including white. This mixture of colors is called additive synthesis.

2.2.1 Discrete vs Continuum Spectrums

Materials

- Red, green and blue LED bulbs
- Diffractive glasses

Procedures

The first step to perform is to turn on the RGB bulb, then the viewers are asked to put on the glasses in order to appreciate the experiment. The first thing they will observe when putting on the glasses are the multiple focal points, this is thanks to the surface of the lenses that disperses the light allowing us a clear vision of the step to be performed. With the glasses on, we proceed to mix the different colors with the help of a remote control in which the participants of this activity will be able to see how the intensity and combination of these colors (red, green, and blue) create the rest of the colors. Then, with the glasses on, it is looked into a different white light source as a reflection of the sun (do not look at the sun directly). The procedure of the experiment is shown in Figure 4.

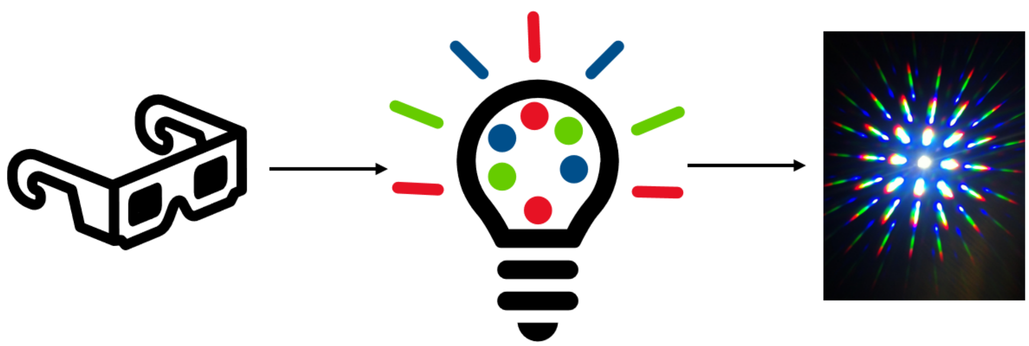


Figure 4. Diffraction pattern that can be observed with the glasses looking at the light bulb.[7]

What phenomenon is observed?

The diffractive glasses use special lenses to diffract light and create patterns of colors in the visual field. In this case they are use to separate the different colors of the spectrum. In a three-dimensional plane, colors can be used to create depth and realism. These bulbs use light-emitting diodes (LEDs) of three different colors (red, green, and blue) to create a wide range of colors and shades. Furthermore, it can be seen that the light generated by an LED have a discrete spectrum. This is, the transition from red to green and then to blue is very strong; contrary to a continuum spectrum, like the one generated by the sun, which would look smooth, as a rainbow.

2.2.2 Trichromy

Materials

- Red, green and blue bulbs
- Paper

Procedures

For this experiment, it is necessary to use three RGB bulbs, each representing a color (red, green, and blue). It is also necessary to have a piece of paper with a rectangle in the center to produce a shadow. Now, the light from the bulbs is combined at the piece of paper and different combinations can be seen.

What phenomenon is observed?

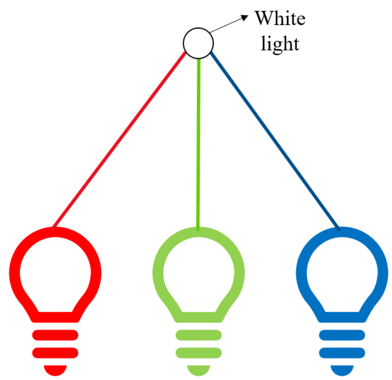


Figure 5. Red, green and blue combination.

When the shadow is produced, these three colors will begin to combine at a certain angle of light, resulting in the formation of other colors. This allows for the combination and use of these colors to create different visual effects. Furthermore, here is proved that with red, green and blue light all colors can be created, being the principle of the RGB system. Figure 5 shows the phenomenon.

2.2.3 Light absorption

Materials:

- Red light.
- Blue light.
- Green light.
- Green glass bottle.

Phenomena: Color filters.

Procedures:

The red, blue and green light illuminated the bottle, while the blue and red light are completely absorbed by the bottle, the green light is the only wavelength that crosses it. The bottle is a green filter. The procedure is shown in Figure 6.

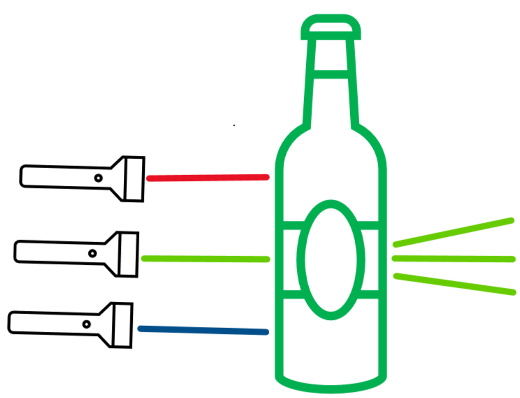


Figure 6. Behavior of red, green and blue light through a green bottle (color filter).

2.3 Polarization

Polarization is a property which helped to establish wave theory of light. Light is a transverse electromagnetic wave, i.e., it oscillates on a perpendicular angle from the direction of propagation of the wave. Then the polarization of light is associated with the direction of oscillation of the electric field of the wave. Furthermore, Polarization is one of the most mathematically complex light phenomena, given its intrinsic vectorial formalism. If we keep track of the movement of the electric field vector in time a couple of drawings can be seen, these drawings define the name of the polarization type we consider; namely linear, circular or elliptic. The most basic type of polarization is linear, and the other ones can be explained through it. Linear polarization sheets are made of long polymer chains that can absorb energy from the electromagnetic wave in the opposite direction the chains are oriented. If linearly polarized light passes through a linear polarization sheet oriented on a 90° about the polarization direction, no light will pass the sheet, but if the orientation is 0°, then all incident light will pass. The angles between 0° and 90° will have light intensity passing through the sheet that will take values given by Malus' Law.

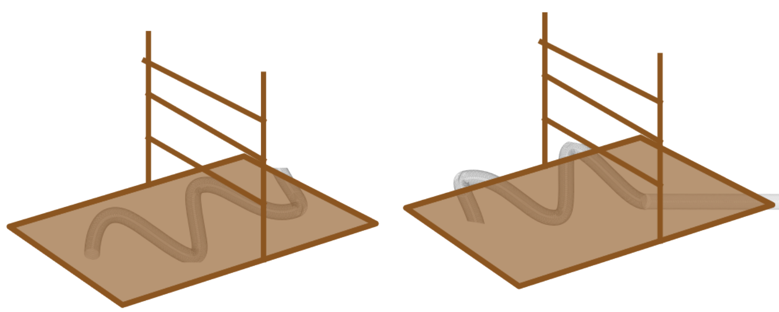
2.3.1 Oscillation of a electromagnetic wave

Materials

- One wood shelf.
- One slinky.

Procedures

The slinky is used to generate transverse waves in three moments, each of them will have horizontal, vertical and an intermediate direction movement. The shelf would be used as an obstacle along the slinky, after the wave passes through the shelf its movement will be restricted according to the direction the shelf is oriented (Figure 7).



(a) (b)

Figure 7. (a) Horizontal direction movement and (b) vertical direction movement.

What phenomenon is observed

The movements of the slinky can be used to explain how a electromagnetic wave oscillates. Given the different movements that are given, the polarization of light can be illustrated with ease.

2.3.2 Malus' Law

Materials

- Two linear square polarizer layers

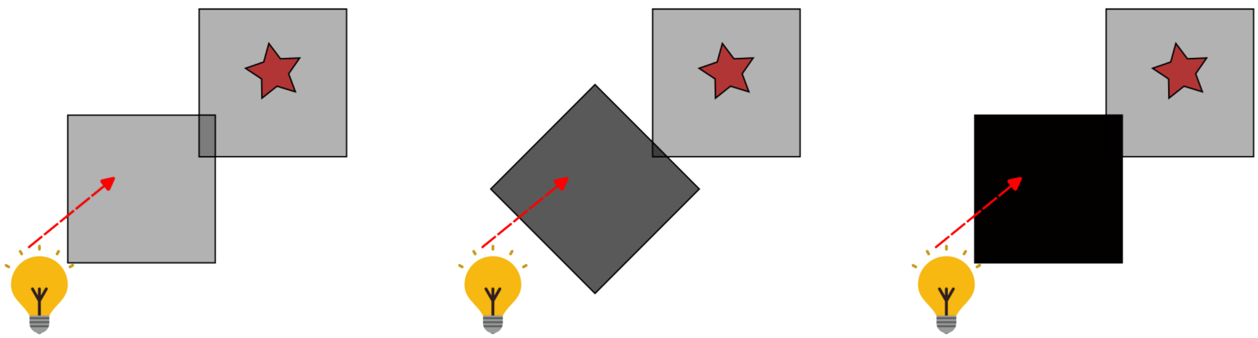
- One light bulb or another non polarized source
- One random object

Procedures

The two polarization layers are placed one in front of each other. At first, the orientation of the polymer chains will be the same for the two of them. Then, looking directly through the layers, one of them will be rotated showing how the changes of light intensity will let see or not see the object.

What phenomenon is observed

This experiment shows the intensity dependence explained by the Malu's Law. In Figure 8 the phenomenon can be observed.



(a) (b) (c)

Figure 8. Light propagation through two polaroids. (a) parallel direction of polarization, (b) rotated polarization angle and (c) orthogonal direction of polarization.

2.3.3 Magic box

Materials

- One black carton box with a removable cover up
- Four linear square polarizer layers of 3 cm side
- One transparent ruler

Procedures

The public will be asked to observe the inside of the box through the polarizers, which will seem to have a dark wall. The ruler shall be pass to a lateral cut in the box, passing also through the wall, making the public realize that there is not such thing as a physical wall in the box when the box it is opened. Figure 9.

What phenomenon is observed

As the two polarizers are perpendicular, from the point of view of the public there is a black wall, given the null light transmission through them. But un reality, it is just an illusion created by the polarization of light.

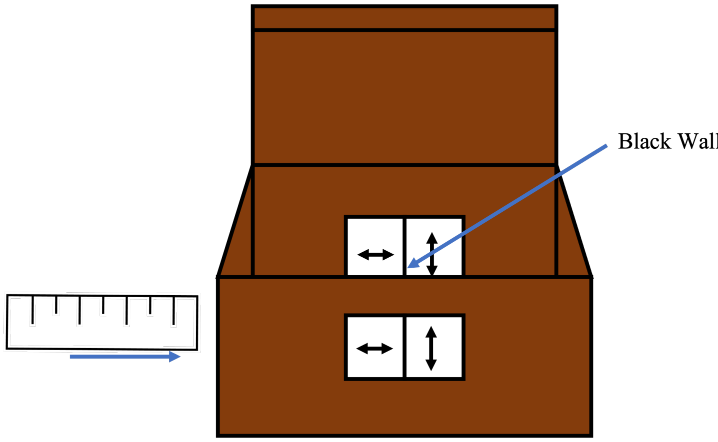


Figure 9. Conceptual sketch of the magic box experiment. The black wall is generated because of the perpendicularity of the two polarizers of the box.

2.3.4 Vectorial properties of light

Materials

- One laser pointer
- One white screen
- One rectangular bar with four transversal little cuts

Procedures

Two linear polarizers will be placed on the cuts of a rectangular bar with 90° between their transmission axes. A third linear polarizer will be placed at 45° in the middle of the two already mentioned. Finally, the white screen will be placed at the last cut. From the experiment of the Malus' law, one can think that if a laser pointer is used to light the system from the first polarizer to the screen, when the 45° polarizer is missing, the screen will not be illuminated, Fig. 10(a). But, what if the third polarizer is placed? (Fig. 10(b)).

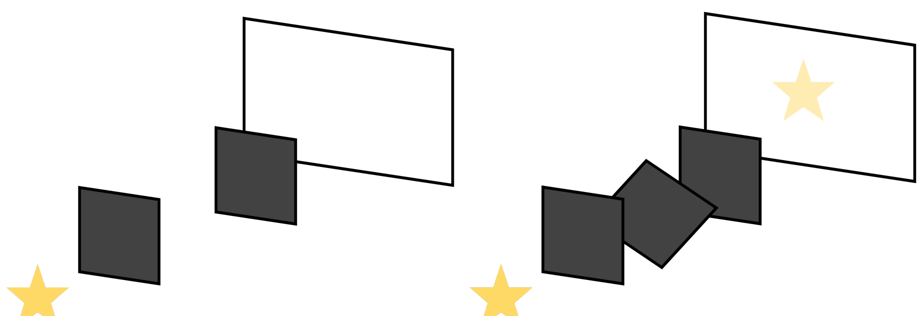

(a) (b)

Figure 10. Experimental demonstration of the vectorial behavior of light. (a) when two perpendicular-oriented linear polarizers there is no transmission of light, but (b) when another polarizer at oriented at 45º, a diagonal polarization state is generated and there is transmission.

What phenomenon is observed

According to Malus' Law, and the vectorial nature of the polarization, it can be shown that adding this 45° polarizer will allow the transmission of diagonal linearly polarized light, that will be allowed to be transmitted through the second polarizer placed at 90°.

2.4 Fluorescence and Phosphorescence

Fluorescence and phosphorescence are two optical phenomena involving light interaction with certain materials. These materials absorb luminous energy and re-emit it in the form of lower-energy light after the excitation of their electrons. In fluorescence, the material absorbs energy and then emits part of that energy as visible light. When the excitation source ceases, the light emission stops almost immediately. In the case of phosphorescence, the material absorbs and stores energy and later gradually emits it over an extended period, even after removing the excitation source. The main difference between the two phenomena lies in the duration of light emission and the process by which electrons return to their original energy levels.

2.4.1 Explanation of the light spectrum

Materials:

- Spectrum informative sheet

Explanation

The figure 11 shows light classification into different types of electromagnetic waves based on their energy, frequency, and wavelength, which are closely connected. The longer the wavelength, the lower the frequency and energy. This image illustrates that visible light is only a small part of the electromagnetic spectrum, while humans utilize other spectrum regions for various purposes. Ultraviolet light can excite electrons in materials, making it suitable for observing and analyzing the phenomena studied. However, it is important to take appropriate safety measures to protect oneself from excessive exposure to this radiation. In summary, classifying light into different types of electromagnetic waves according to their energy, frequency, and wavelength helps us understand how they interact with matter and how they can be used for various purposes.

2.4.2 Sunscreen

Materials

- Physical sunscreen.
- Chemical sunscreen.
- Paper sheet.
- Violet light source.

Procedure

Applied both sunscreens on the paper sheet and illuminate with the violet light source.

What phenomenon is observed?

This experiment demonstrates how two types of sunscreen work: physical and chemical. A brightness is observed when the violet light illuminates the physical sunscreen; instead, the chemical sunscreen turns dark under this illumination. This difference is due to the way the ingredients of each sunscreen interact with high-energy ultraviolet light, which is harmful to our skin. Although both sunscreens prevent ultraviolet light from reaching our skin, they do so through different mechanisms: the physical sunscreen reflects the light rays, making it appear "bright" under ultraviolet light, while the chemical sunscreen absorbs the light rays without re-emitting them, causing it to appear black as is illustrated in Figure 12.

If desired, instead of using a sheet of paper, can be used a participant who has applied sunscreen before.

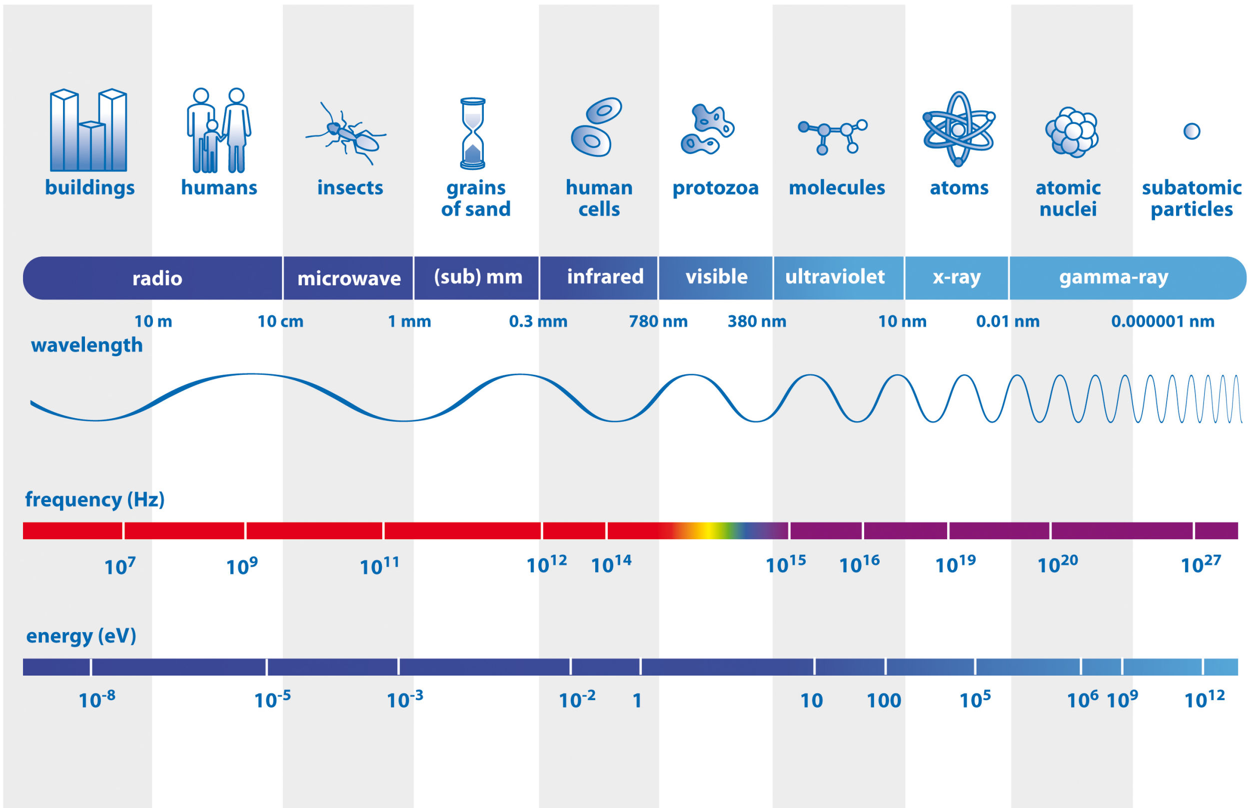
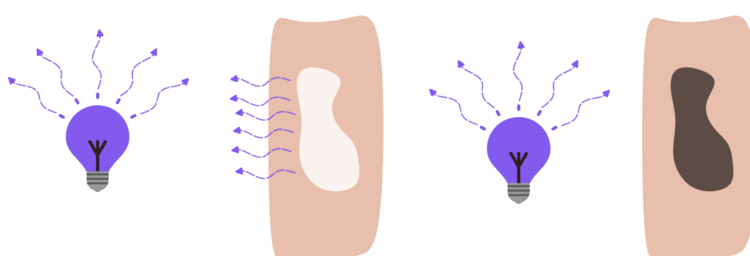


Figure 11. Spectrum informative sheet. Figure taken from ESA / AOES Medialab.[8]



(a) (b)

Figure 12. (a) Effect of physical sunscreen and (b) effect of chemical sunscreen.

2.4.3 Fluorescence with face painting

Materials

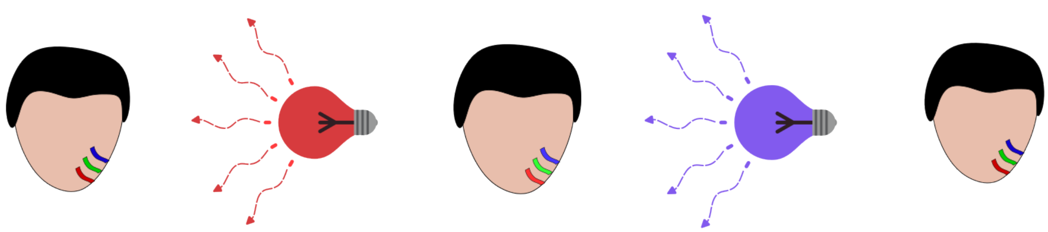
- Fluorescent face painting.
- Violet light source.
- Red light source.

Procedure

Applied different fluorescent face painting on the participants faces. Later, illuminates using a violet light source and see what happens.

What phenomenon is observed?

In this experiment, we demonstrate fluorescence using face paints (Figure 13). Firstly, the red light is used to illuminate the face paints to show no effects on the paints, given that this light does not have sufficient energy to move electrons to a higher energy level. Then, the violet light is used in the same way, showing, in this case, the brightness of the paints, as this light has enough energy to excite the electrons to a higher energy level. Violet light, having more energy, can excite the electrons of the atoms that make up the face paints. This excitation occurs immediately and only when the light source is in direct contact with the face paint. If the light is removed, the face paints stop emitting light instantly. It is important to note that this differs from a phosphorescent phenomenon, where the energy is gradually released over an extended time.



(a) (b) (c)

Figure 13. (a) Face painting with red light, (b) face painting lighted with violet light and (c) face painting few seconds after violet illumination.

2.4.4 Phosphorescence with hair beads

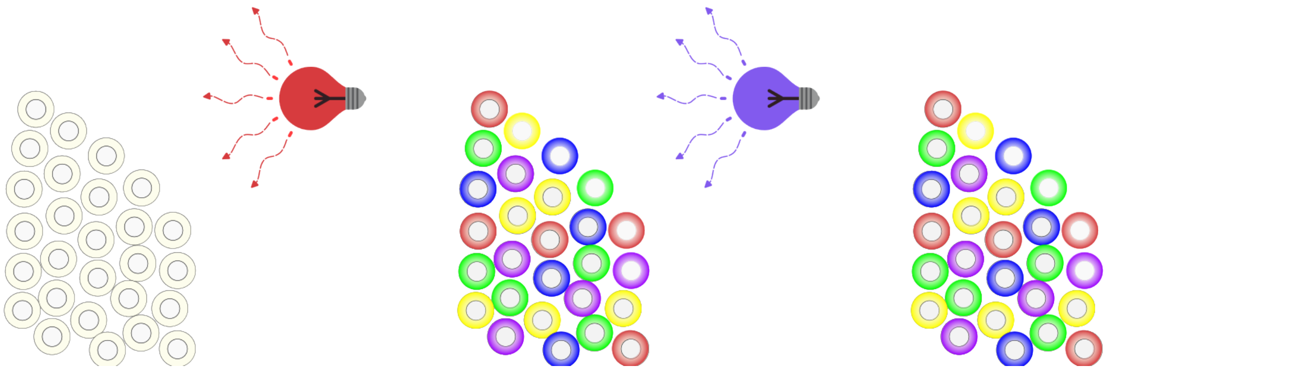
Materials:

- Hair beads,
- Violet light source.
- Red light source.

Procedure

Illuminates the hair beads using a violet light source and see what happens.

What phenomenon is observed?



(a) (b) (c)

Figure 14. (a) Hair beads with red light, (b) Hair beads lighted with ultraviolet light and (c) Hair beads few seconds after ultraviolet illumination.

As in the previous experiment, the changes in a material are analyzed. In this case, phosphorescent hair beads are used. The incidence of red light over the hair beads does not present any change. However, exposure to a violet light source generates hair beads to change from a pale white to various vibrant colors as is shown in Figure 14. These hair beads are made of a material capable of absorbing the energy of ultraviolet light and exciting its electrons. This excitation causes the electrons to change their energy level and subsequently seek to stabilize back to their original level. During this process, the electrons release excess energy in the form of light, and they do so over an extended period, allowing the effect to be visible for a longer time. This phenomenon is only observed with violet light because, unlike red light, it has a shorter wavelength, which means a higher frequency and energy. This additional energy is sufficient to excite the electrons of the phosphorescent material.

2.5 Optical Illusions

An optical illusion is an image captured by our eyes that, upon reaching our brain, is interpreted differently, generating a distortion of reality.

2.5.1 Real image projection

Materials

- Two semi-spherical concave mirrors. One mirror need to has an hole as is illustrated in Figure 15
- A object to placed on one of the mirrors.

Procedure

Place the object of interest on the complete mirror and cover it with the holed mirror, as shown in Figure 15 . Then observe what happens.

What phenomenon is observed?

The rays from the object reach the upper mirror and are reflected in the lower mirror. The lower mirror reflects the rays again so that they converge at the hole of the upper mirror, forming a floating image of the object. This image seems like the object is standing over the mirror aperture generating an interesting visual effect.

2.5.2 Perceptive illusions.

Materials:

- Sheet with the print of the image.

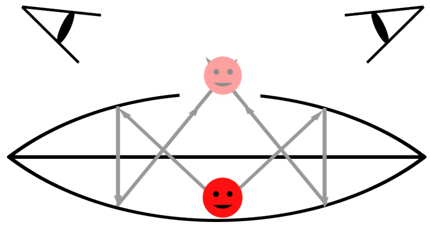


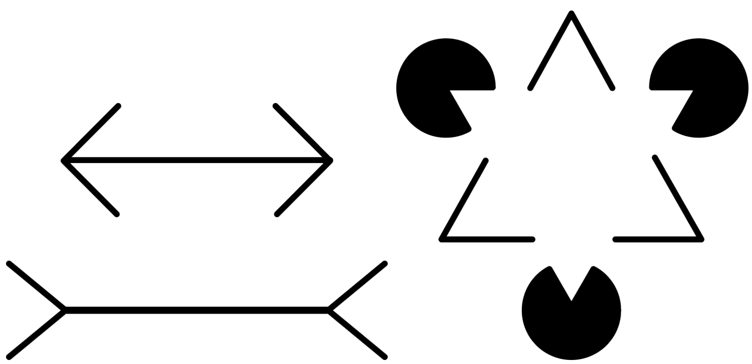
Figure 15. Ray tracing of the real image.

Procedure

Observe the Figure 16 and describe what is seen.

What phenomenon is observed?

- **Müller-Lyer illusion:** The arrows on the lines create an optical illusion concerning their position. When these arrows point outward, the brain perceives the line as shorter and resembles the edge of a building, but when they point inward, it is perceived as a long line and looks like the corners of a room.
- **Kanizsa Triangle:** This effect is known as an illusory or subjective contour. The circles and the surrounding triangle create an imaginary contour of the triangle.



(a) (b)

Figure 16. (a) Müller-Lyer illusion and (b)Kanizsa triangle

2.6 Geometrical optics

Geometrical optics studies the behavior of light, considering its propagation as rays and evaluating how the direction of propagation changes due to the incidence in a translucid medium like refraction or a specular surface like reflection, or even both of them occurring at the same time.

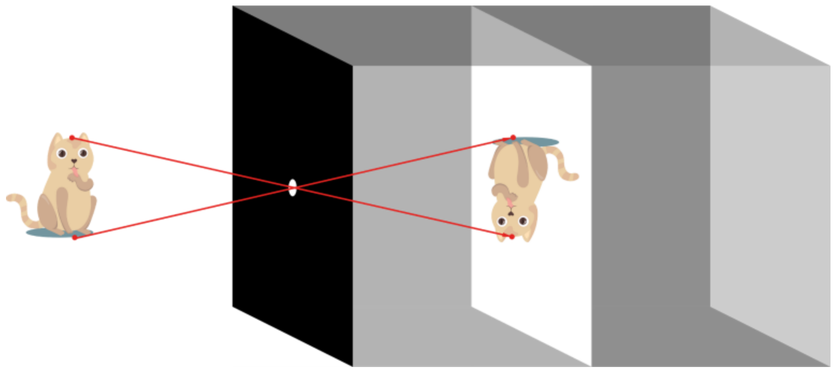
2.6.1 Pinhole camera

Materials

- Carton box.
- Black tape.
- Aluminum foil sheet.
- Pin.
- Sheet of paper.
- Luminous object or light source.

Procedure

Take the aluminum foil sheet and make a hole as small as possible using the pin. Then, cut a hole in the carton box and paste the aluminum foil into the hole there. Place a screen with a sheet of paper inside the cardboard box and cut out the back to observe the screen from behind. Place the luminous object or light source in front of the hole and observe. Figure 17 shows a schematic of a pinhole camera.



(a)

Figure 17. Schematic of pinhole camera

What phenomenon is observed?

A pinhole camera is the simplest image formation system, given that microscope objectives or lenses are not utilized. Only a small hole is needed to generate an image. An illuminated object is located in front of the hole. The rays of the object are propagated through the hole, and an image is formed in a plane on the other opposite side of the object. The brightness of the light that passes through the hole, a darkness box covering the image plane, can be placed to enhance the visualization. If a photosensitive material were placed in the image plane, a photograph of the object could be recorded. Additionally, for the image process, the size of the hole is an important parameter; the smaller the hole, the better the quality of the image but the less the intensity of it.

2.6.2 Bending light using...

Materials

- Water glass.
- Pencil.
- Thick acrylic film.
- Mirror.
- Convergent and divergent glass or plastic lenses.
- Two prism.
- Laser or lineal light source.

Preferable in a dark room.

Procedure

Illuminate the different optical elements from various incidence angles and observe how the light is bent depending on the material. Additionally, illuminate a prism and lenses uniformly with a plane wave to see a color scattering of light.

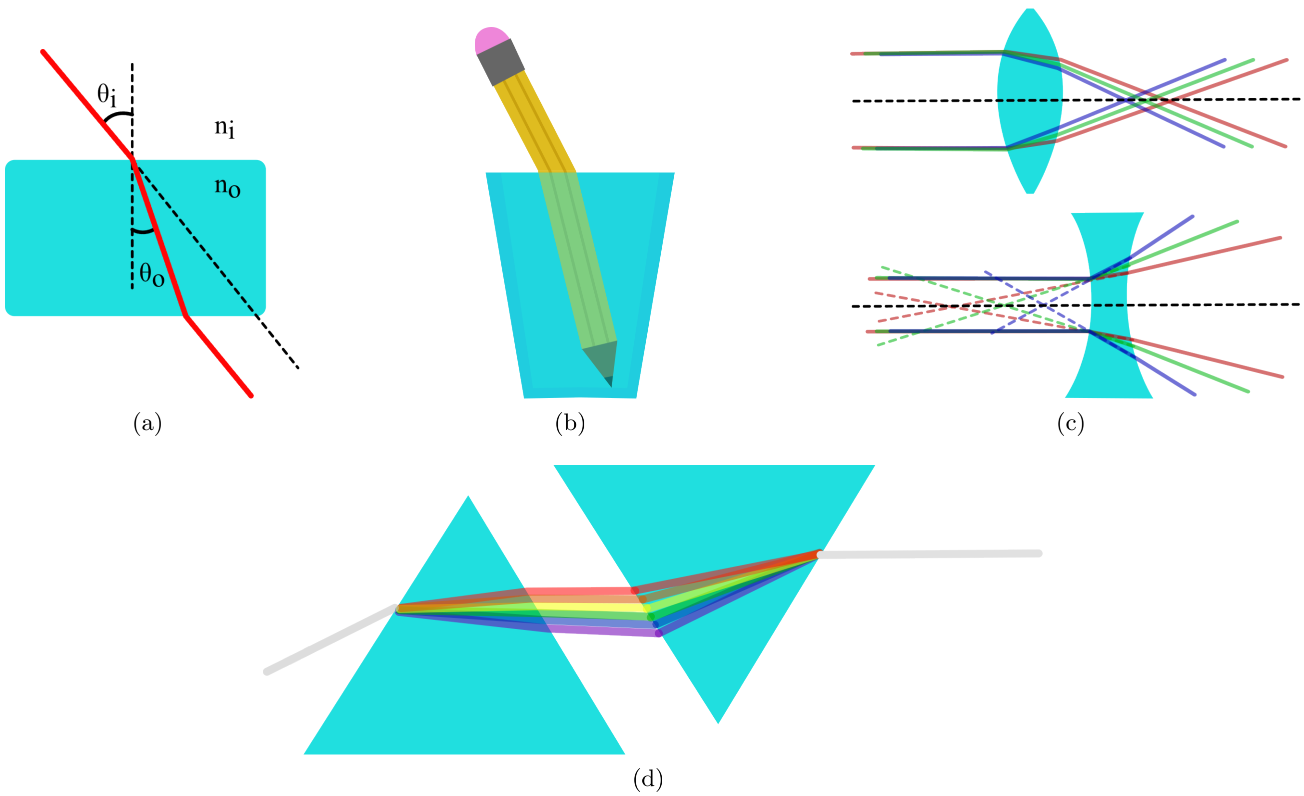


Figure 18. Snell law experiments (a)A parallel faces film, (b) Seen the refraction of a pencil in a glass of water, (c) Rays of different wavelength through convergent and divergent lenses. (d) Scattering light through two prisms.

What phenomenon is observed?

When an incident ray of light, with an angle θ_i respect to the normal, passes from a medium with refractive index n_i to another medium with refractive index n_o, as is shown in Figure 18(a), the angle of the ray at the exit of the second medium is determined by this simple equation

$$n_i sin\theta_i = n_o sin\theta_o$$

For the following experiments this equation, known as Snell law, is utilized over different surfaces to understand how the rays or light are bending when they pass through different mediums.

- **Bending light using an acrylic film:** When an incident ray passes from the air through a medium such as water, glass, or in this case, acrylic, the angle of the ray will change depending on the relationship between the refractive indices of the materials and the incident angle. In this particular case, since the acrylic film has parallel faces, the angle of the ray becomes the same as when it entered the material when it exits as is shown in Figure 18(a).
- **Bending light using a glass of water:** Introducing a pencil into a glass of water should be the simplest and most illustrative experiment of how light is bent as is shown in Figure 18(b). The rays that emerge from the pencil and reach our eyes take different ways depending on the surrounding medium they have to pass through, as in the previous experiment.
- **Bending light using lenses:** Lenses surfaces are commonly not flat, but instead, they have a curved surface, often spherical. When parallel rays of light pass through the lens, they are refracted and bent towards the focal point, in the case of converging lenses. If the lens is diverging, the rays do not converge, but instead, a projected line is drawn that appears as if all the rays diverge from an imaginary point. Additionally, Figure 18(c) show how the focal point change its position depending on the wavelength.

- **Bending light using prisms:** Chromatic dispersion occurs when a beam of white light crosses a prism. White light combines all the visible wavelengths of ligh. When it passes through a prism, the change of material will change the refracted angle of light, and as was seen in the previous experiment, the deviation angle of the light depends on the wavelength. For this reason, it appears as if the beam of white light breaks down into all wavelength colors. As is shown in Figure 18(d), if another inverted prism is placed to receive the scattered light at the exit of the first prism, it is possible to combine the wavelengths to form white light again.

- **Bending light using a mirror:** Reflection is an optical phenomenon in which a light ray bounces back in the same medium when it encounters a specular material.

2.6.3 Fake hologram!

Materials

- Cell phone
- Clear acrylic of a CD case

Procedure

Cut the CD case to form the inverted truncated pyramid shown in Figure 19. In order to use the pyramid correctly, make sure that the angle of the sides is 45°. Next, click the YouTube link or search for a similar video if it is wanted. Play it in full-screen mode. Once the pyramid and video are ready, place the pyramid over the cell phone and locate it at the center of the four images. Finally, look through one side of the pyramid, as illustrated in Figure 19.

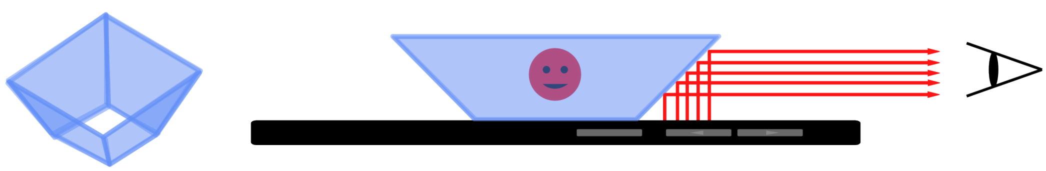


Figure 19. Reflective projection over an plastic pyramid

What phenomenon is observed?

The light from the cell phone screen is incident on the acrylic film at a 45° angle. The light is both transmitted and reflected, but for this experiment, we are interested in the reflected light, which also has a 45° angle. When the pyramid is directly looked at, as in Figure 19, the cell phone image is reflected and appears to be floating due to the transparency of the acrylic material. If the object seems to be in 3D, the floating image creates the illusion that one is watching a hologram.

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DISCLOSURES

The experiments mentioned in this guide for optical shows are a compilation of selected experiments, some of which may be included in the OSA Suitcase[9] or Light Blox kit.[10]

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