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The Optical Society

100
Since 1916

A collection of optical science activity kit components is displayed on a black surface. In the upper left, a clear plastic box is open, revealing a black cylindrical lens and a small yellow and black component. To its right is a small, colorful, rectangular object with a rainbow spectrum. Below these are two small, clear plastic containers, one red and one green, each with a black cord. In the lower left, a pair of eyeglasses with large, clear lenses is visible. A black box with the word 'PEPPER' in white letters is partially visible in the center. The background is a solid black surface.

EXPLORE OPTICS

OSA ACTIVITY GUIDE

REFLECTION WITH REFLECT VIEW

Reflections are everywhere. When you look at yourself in the mirror, or in a big window, you're observing the wonder of reflection! So how do reflections work? Do they have rules?

Reflection

Light travels in straight lines. It moves freely through the open air, but when it comes across an obstacle, it can't move around it. So what does it do

A lot of the time, the light bounces off the object. This is called reflection, and it's how we see! Take a look at Figure 1. When light from the sun or your overhead light bounces off an object and into your eye, your eye "sees" the object. Have you ever been in a room so dark you can't see your own hand in front of your face? This is because without light, your eye can't tell an object is there!

When light from an object bounces off a reflective surface like a mirror or a window, you see the object on the other side of the glass. This reflection is called a virtual image. Virtual means fake or appearing to be real. This is because the object is not really there - when you look in a mirror, the reflection makes it look like you're standing in front of yourself, but you're not really there!

Virtual Images

The virtual images created by a flat mirror or piece of glass follow some very strict rules, as shown in Figure 2. Take a look at yourself in the mirror. Notice how far from the mirror you're standing. How far does your reflection seem to be standing from the mirror, on the other side?

You should notice that your reflection is the same distance from the mirror as you are! This is because a virtual image is always the same distance from a flat mirror as the real object. Your virtual image is also the same size as you are.

Big Idea

Demonstrate the concept of reflection and the formation of virtual images by drawing mirror images with the Reflect View.

What You'll Need

- 1 Reflect View
- 1 Lazr finger
- A ruler
- A mirror

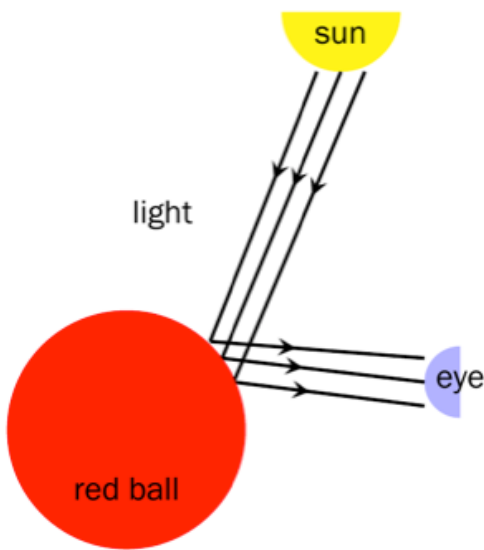


Figure 1: How We See

Now lift your left hand, and wave at yourself. Which hand is your reflection waving with? You'll see your reflection is waving with its right hand. The virtual image is inverted, or swapped around - left becomes right!

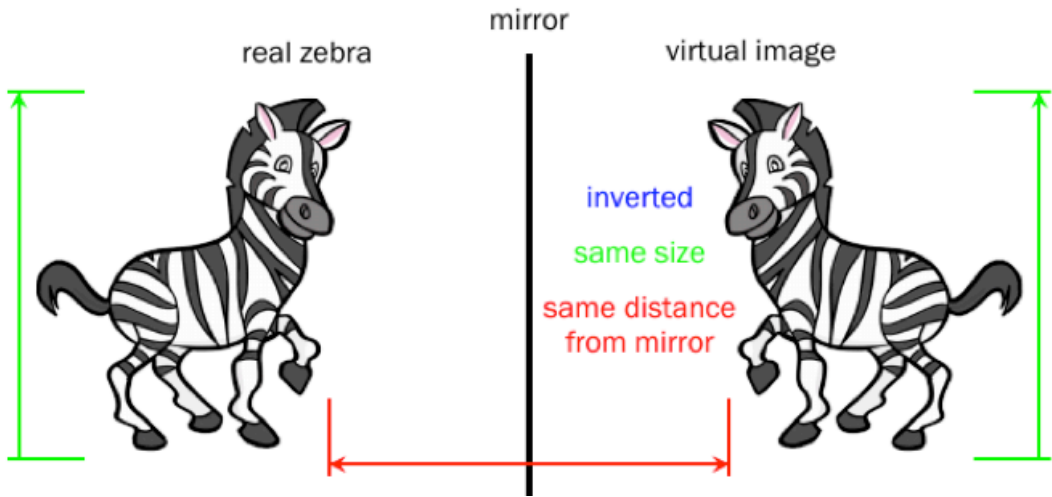


Figure 2: Properties of a Virtual Image

Virtual Images in Real Life: Ambulances

Emergency vehicles like ambulances tend to have AMBULANCE written clearly on the front of the vehicle. However, it's often written backwards!

When an ambulance is trying to make its way through traffic, it sounds its sirens. If you're a driver in front of the ambulance, you'll look back in your rear view mirror to see what the sirens are about. The virtual image of the ambulance will be backwards, however. If the word "ambulance" is backwards to begin with, the mirror will swap it the right way around, and the driver will know to move out of the way for the ambulance!

ACTIVITY SHEET

Reflection with Reflect View

We’re going to use the Reflect View to reflect pictures and words, and see for ourselves how virtual images work!

- 1. Write your name in the blank slot on the worksheet.
- 2. Place the Reflect View on the dotted line. Make sure the stand is facing upwards and the bevelled (stepped) edge is towards to.
- 3. Lean slightly to the left, until the star on the right matches up with the reflection of the one of the left.
- 4. Reach your arm around to the right hand side and trace the reflections you see on the Reflect View onto the paper.

What do you notice about the words/images on the right hand side? Measure the distance between each matching word or picture and the dotted line. What does this tell us about virtual images?

The words/images on the right hand side are the same size as those on the left, but they are inverted. They are also the same distance from the dotted line as those on the left.

- 5. Fold the paper in half along the dotted line. Holding the folded paper up, shine the light of the Lazr finger against the back of the paper, towards you. You should see both halves of the paper at once now.

What do you notice about the words/images on both halves? Do they match up? Don’t they?

The words/images match up. This confirms what we learnt above about virtual images formed by flat mirrors!

- 6. Unfold the paper and stand in front of the mirror, holding the paper in front of you. Observe the worksheet’s reflection in the mirror.

What do you notice about the words on the right hand side/traced side?

In the mirror, the words on the right hand side are the right way around, and those on the left are backwards. The reflection of the right hand side is inverted, so it has turned it the right way around again!

ACTIVITY SHEET

Reflection with Reflect View



Hello!

My name is



Draw your own picture in the box!



Figure 2: How objects have color

COLOR WITH M&M’S

Color is everywhere. Just this morning, you had to choose what color shirt or shoes you were going to wear. So what gives an object its color? Why are some things red and others blue?

Color Starts With Light

To understand why objects have color, we need to understand where light gets its color.

Light is a wave, and so has a **wavelength**. Take a look at Figure 1. The blue light has a longer wavelength than the red light. Wavelength is what gives light its color.

Reflection

So what gives an object its color? The simple answer: light!

Without light, an object has no color. This is because without light, we can’t see! When you look at a red object, what you’re actually seeing is red light bouncing off the object and into your eye. The bouncing of light off an object is called **reflection**.

White Light

When you see a red ball, however, there’s no red light shining on it, is there? Instead, there’s only the “clear” light coming from the sun or the light in your room. This “colorless” light is called **white light**.

White light is actually a mixture of the three primary colors of light: red, blue and green. These three colors can be mixed in different ways to form every color of light imaginable - the same way that we can mix the three primary colors of paint to make other colors! This is why you can see all the colors of the rainbow under sunlight - all the colors are in the white light, ready to be reflected!

Big Idea

Demonstrate how color is due to reflection and absorption of light by sorting M&M’s under colored lights.

What You’ll Need

- 3 Lazr fingers/Light BLOX: Red, Green, Blue
- 1 White Lazr finger
- A packet of M&M’s

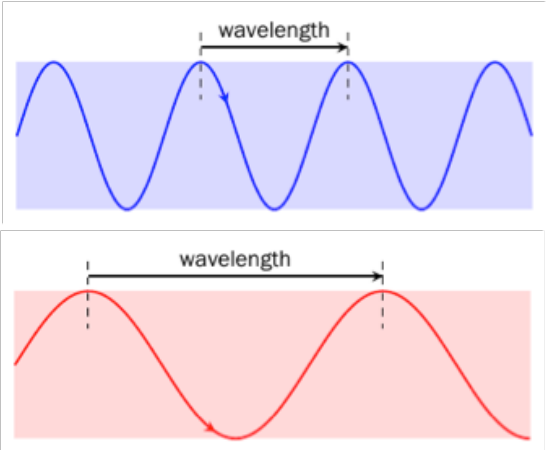


Figure 1: Wavelength gives light color

Absorption

Let’s go back to the red ball. Say we take a look at it under sunlight, like in Figure 2. We now know that it looks red because the red wavelength in the white light is reflecting off the ball and into our eye.

But wait - we said white light is made up of all the colors of light. So what happened to the rest of the light? Where did the blue wavelength of light go, for example?

The left over light that wasn’t reflected off the ball was trapped inside the ball. This is why it couldn’t be reflected back for us to see. This is called **absorption** of light. A black object, for example, absorbs all the light you shine on it, and reflects nothing back - this is why it has no color! White objects reflect all the colors, and absorb none.

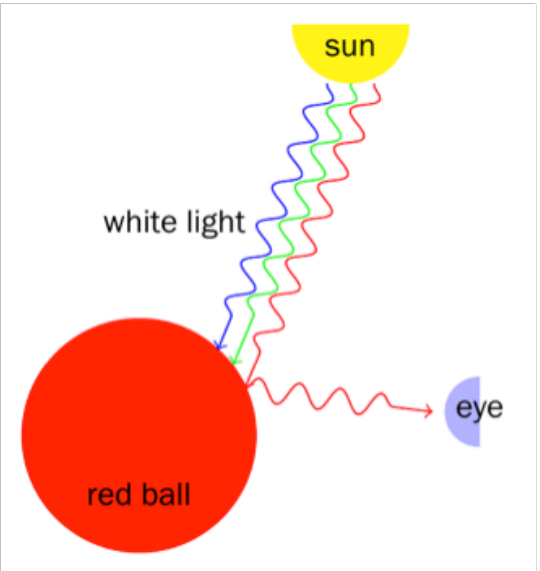


Figure 1: Wavelength gives light color

Colors in Real Life: Colorimetry

Scientists can use a device called a colorimeter to find out what a liquid mixture is made of. Different substances absorb certain wavelengths, or colors, of light. If scientists know the ingredients mixed together, they can figure out how much of each ingredient there is in the mixture by shining light at it.

The colorimeter measures how much of a specific wavelength of light is absorbed by the mixture, and can use this measurement to work out how much of a specific substance is in the mixture.

ACTIVITY SHEET

Color with M&Ms

We’re now going to see just how much light affects our ability to see color by sorting M&Ms under colored light!

- 1. Mix up the M&Ms, and place them in the centre box of the worksheet.
- 2, Switch off the overhead light and darken the room as much as you can.
- 3. Switch on the white Lazr finger and hold it over the unsorted M&M’s. Sort them into each of their labelled color boxes.
- 4. Switch off the Lazr finger and turn on the overhead light again.

Were the M&M’s in the correct boxes? Why/Why not?

Under the white light, all the M&M’s should be sorted easily and correctly. This is because the white light contains all the colors of light needed to see each of the M&M’s.

- 5. Place the M&M’s in the unsorted box again and repeat the experiment using the red Lazr finger

Were the M&M’s in the correct boxes when sorted under the red light? Why/Why not?

You probably found that some of the colors were in completely the wrong boxes! Others looked exactly like each other, but when you saw them under the white light again, they were completely different.

- 6. Repeat the experiment again using the green and then the blue Lazr finger, respectively. (This order is recommended, since the results just get crazier!)

Were the M&Ms in the correct boxes when sorted under the green or blue lights? What does this tell us about how color works?

Under the colored lights, the M&M’s were probably more difficult to sort. Like with the red light, a group of colors could all look exactly the same. Sometimes an M&M could look definitively like one color under a certain color light, but when the white light is switched on, it’s another color entirely! This is because the wavelength of light making up the main part of the M&M’s color wasn’t present, so it could not be reflected, and you could not see it.

ACTIVITY SHEET

Color with M&Ms

RED

YELLOW

BROWN

UNSORTED

BLUE

ORANGE

GREEN

TRANSMISSION WITH GUMMY BEARS

Take a look at a gummy bear. Now compare it to something solid, like a table or your shoe. You'll notice it's slightly different - if you look closely, you can see inside it. Why do you think this is?

Reflection and Absorption

Light travels in straight lines. When it comes across an object, then, it can't move around it. So what does it do?

The first thing it can do is bounce off the object. This is called **reflection**, and shown in Figure 1. This is what allows us to see the objects around us: light from the sun or a light bulb bounces off the object and into our eye. This is why we can't see in the dark - there's no light to bounce into our eyes!

Light can also become "trapped" inside an object, as shown in Figure 2. This is called **absorption**. This light does not reach our eyes after it's been absorbed, so we don't see it.

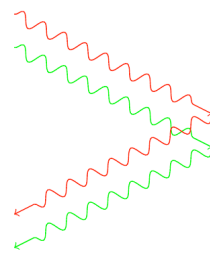


Figure 1: Absorption of Light

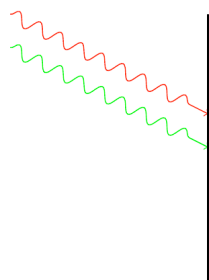


Figure 2: Reflection of Light

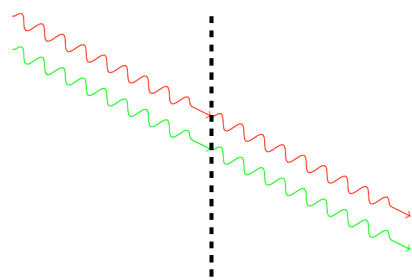


Figure 3: Transmission of Light

Transmission

Sometimes light is neither reflected nor absorbed, however. How else would we see the trees outside the window, or what cool drink we have in our glass?

When light passes through an object, it's called **transmission**. This is shown in Figure 3. Objects that allow light to pass through them are called **transparent**. Objects that don't allow any light to pass through are called **opaque**.

Big Idea

Demonstrate the concept of transmission while exploring color by passing different colors of LED and LASER light through gummy bears.

What You'll Need

- 1 White Lazr finger
- 1 Red LASER pointer
- Four gummy bears: red, green, clear & black
- A white surface

White Light and Color

Color depends on the wavelength of light. Red light has a different wavelength to blue light, for example. The light coming from the sun or a flashlight is called white light. It looks clear, or invisible, but it actually consists of a mixture of red, blue and green light. Together, these three primary colors of light can mix to create any color of light imaginable!

When an objects looks red under white light, the red wavelength of light is being reflected off the object and into your eye. The blue and green wavelengths are absorbed by the red object, and we don't see them.

Transparency

Clear substances like glass let all wavelengths, or colors, of light through. A small amount of light is sometimes reflected, as well. Think about when you see your reflection in a window: a person standing outside would still be able to see you through the window, but you can see yourself as well.

Some objects allow transmission of only certain wavelengths of light. These substances are colored, like the Reflect View, or colored cellophane. Consider a blue sheet of plastic, like in Figure 4. It allows blue light to be transmitted, but absorbs all the other wavelengths of light. Some of the blue light is also reflected, however; that's why the sheet looks blue.

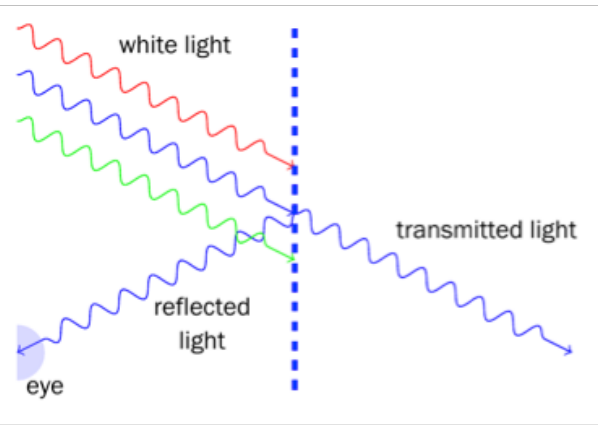


Figure 1: Selective Transmission

Selective Transmission in Real Life: 3D Glasses

There are many ways to create and view 3D movies these days. One of the oldest methods use a pair of glasses with one red lens and one blue lens. The movie plays two images at once: one in blue, and the other in red. The images are of the same object, at slightly different angles.

Naturally, you would see an object from slightly different angles with each eye, since they're a couple of inches apart - this is what allows your brain to judge if something is 3D. The glasses allow only one of the images to enter each of your eyes - the blue image through the blue lens, and the red image through the red lens. This way, your brain is tricked into thinking that it's looking at a real 3D object!

ACTIVITY SHEET

Transmission with Gummy Bears

We’re going to shine light through transparent gummy bears to see how light is reflected and transmitted.

- 1 Place each gummy bear on the white surface.
- 2. Shine the red LASER pointed through the each gummy bear in turn. You may have to hold it quite close to the gummy bear; not further than 2 cm away.

Does light pass through the red gummy bear? What color is it? Is any light reflected?

The light from the red LASER pointer passes through the red gummy bear. Some of the light might also be visibly reflected against the white surface.

Does light pass through the green gummy bear? What color is it? Is any light reflected?

The red light does NOT pass through or reflect off the green gummy bear. This is because the green gummy bear absorbs red light, and transmits/reflects only green light.

- 3. Now, shine the white Lazr finger at each of the gummy bears.

What do you notice about the white light when it passes through the red and green gummy bears?

The white light passes through both the red and green gummy bear, but appears as red and green, respectively. This is because the red gummy bear, for example, transmitted and reflected the red part of the white light (remember, white light consists of ALL the colors of light) but absorbed the rest of the wavelengths.

What do you notice about the all the results from the clear gummy bear, specifically? What do you notice about the black gummy bear, specifically?

The clear gummy bear allowed all of the lights to pass through it unchanged. It is completely transparent. The black gummy bear didn’t allow any light to pass through it. This is because it absorbed ALL the wavelengths of light, and is opaque.

CHALLENGE: SPECTRA OF COLORED LEDS

Spectrum of Light

Colored light is not always what it appears. A red LED does not consist of only red light - instead, it consists of red, yellow and orange light as well. We can view the colors of light that a beam of light consists of - its spectrum - through a diffraction grating, as shown in Figure 1.

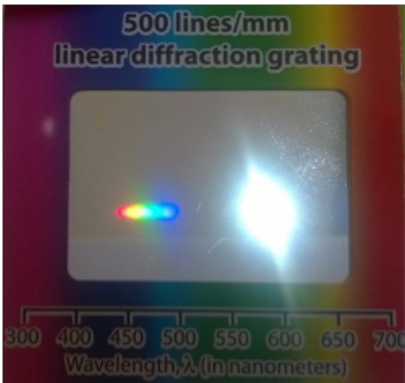


Figure 1: Spectrum of White Light through a Diffraction Grating

Selective Transmission

Certain transparent objects allow only certain wavelengths, or colors, of light to pass through them. This is known as selective transmission. A blue piece of cellophane, for example, transmits only blue light, and absorbs all the other wavelengths. It also reflects blue light, which is why it appears blue to us. This is shown in Figure 2.

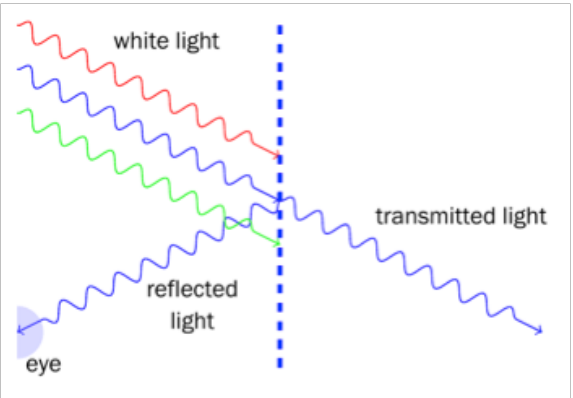


Figure 2: Selective Transmission of Blue Light

Big Idea

Explore the spectra of colored light further using knowledge of selective transmission.

Related Activities

- Activity 3: Transmission with Gummy Bears
- Activity 7: Monochromatic LASER Light

What You’ll Need

- 2 Lazr fingers/Light BLOX: Green and Blue
- Red Laser Pointer
- Reflect View
- Diffraction Grating
- A blank wall/screen

ACTIVITY SHEET

Spectra of Colored LEDs

We’re now going to use what we know about selective transmission to confirm that colored LED light consists of a varied spectra.

Place the Reflect View about 5-10 cm from the wall/screen.

Shine the red LASER pointer at the Reflect View. What do you see?

The red LASER passes through unhindered, since the Reflect View reflects/transmits red light.

Shine the blue Lazr finger at the Reflect View. What do you see?

Can you think why this is? Use the diffraction grating to view the spectrum of the blue light and speculate.

No light passes through the Reflect View, since blue light does not have a red component.

Shine the green Lazr finger at the Reflect View. What do you see?

Again, use the diffraction grating to view the spectrum of green light and say why you think this is.

A small amount of red light passes through the Reflect View, since green light has a red component.

WHITE LIGHT & SHADOWS

Do you sometimes feel like you’re being followed? Don’t worry, that’s just your shadow! So how does your constant companion work? Does your shadow every change? And if so, why?

White Light

The light created by the sun is called **white light**. It’s the same kind of light you get from the room lights, a flashlight, or the white Lazr finger. It may look clear, or invisible, but that’s not the case at all!

White light actually consists of a combination of the three primary colors of light: red, green and blue. Just like paint, you can combine these colors to make every color of light imaginable!

How Light Travels

A ray of light will always travel in a straight line. When you put a bunch of rays together, you get a beam of light. Light sources, like flashlights, emit beams of light. When a beam of light leaves a light source like an LED or a Light BLOX, the rays starts to spread out, and move further away from each other.

When a ray of light hits an object, it can’t move around it - light can’t bend or curve around an obstacle. If the object is transparent, the light passes through the object, or is transmitted. If the object is not transparent, but rather opaque, a shadow is formed.

Shadows

When light encounters an opaque object, it cannot pass through it. Therefore, it must be either reflected, absorbed, or both. In either case, the light never makes it to the other side of the object.

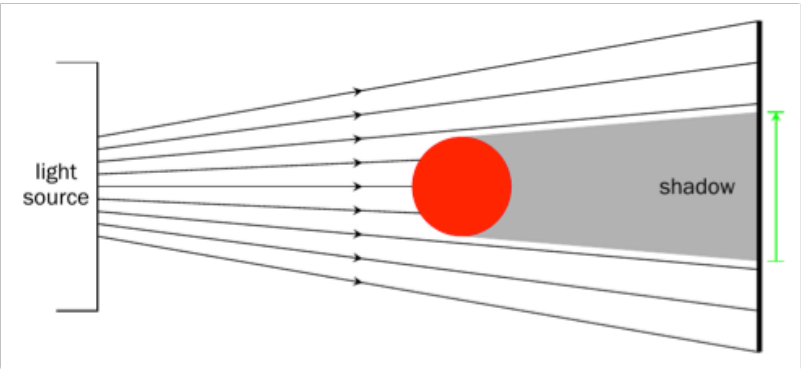


Figure 1: How a Shadow is Formed

Big Idea

Explore the nature of white light and shadows by creation and manipulation of both.

What You’ll Need

- 3 Lazr fingers/Light BLOX: Red, Green and Blue
- 1 White Lazr finger
- A long, thin object, like a LASER pointer or pencil
- A blank screen or wall

Take a look at Figure 1. You can see a bunch of light rays leaving the light source on the left. They travel in straight lines, and when they meet the red ball, they are reflected or absorbed. The space behind the red ball, however, now has no light rays, and is dark. This is a shadow.

The size of a shadow will change depending on how far it is from the light source. Take a look at Figure 2. The red ball is far away from the light source, and by the time the light rays are blocked by the ball, they are very far apart and only a small area is left without light. This produces a small shadow.

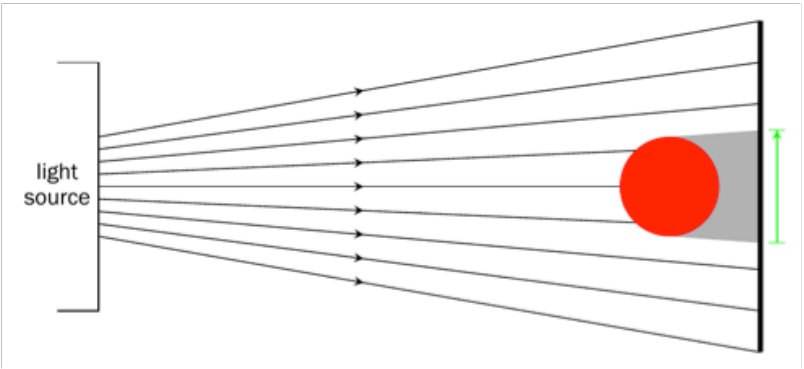


Figure 2: A Small Shadow

Now take a look at Figure 3. Here, the ball is close to the light source, and the light rays are still very close together. This way, the ball blocks a lot of light rays, and a large shadow is formed.

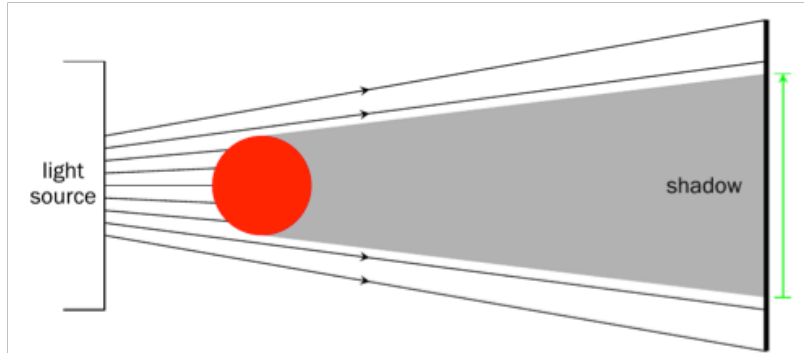


Figure 3: A Large Shadow

Shadows in Real Life: Sundials

A sundial is a device which tells the time of day using only a shadow from the light of the sun. It dates back to the ancient Egyptians, and can still be used today!

The sundial consists of an upright piece of metal (called a gnomon) attached at exactly 90° to another sheet of metal or stone. Carved into the stone or metal sheet are markings like one would find on a clock - every hour, or even minute, is shown. When the sundial is facing in the right direction, the shadow cast by the gnomon from the sun will point at the time of day!

ACTIVITY SHEET

White Light & Shadows

First, we’re going to create our own patch of white light to see what it’s made of!

- 1. Darken the room as much as you can.
- 2. Switch on the red, green and blue Lazr fingers, or Light BLOX.
- 3. Try to create a patch of white light on the blank screen or wall, using only these three lights. You can combine them in any way you want. Use the white Lazr finger as a guide for the kind of light you’re looking for.

What did you need to do to create white light? What is white light made of?

To create white light, you have to shine all three lights on the same patch of screen at the same time. When you combine the red, blue and green light, you get white light!

Now, let’s create a shadow and see if we can figure out how it works.

- 4. Place the long, thin object about 3 inches in front of the white screen. You’ll want the object to stand up straight.
- 5. Switch on the white Lazr finger, and shine it directly onto the object, towards the screen. Hold the light about 2 inches from the object.

Try to make the shadow bigger, then smaller, by moving the LIGHT. What do you have to do to make this happen?

To make the shadow bigger, you have to move the light closer to the object.

Now try to change the size of the shadow by moving the OBJECT. What do you have to do?

To make the shadow bigger, you have to move the object closer to the light. The same principle applies as above: the closer the object and the light, the bigger the shadow.

Make the shadow move to the left of the screen. What did you do? How can you make the shadow move to the right?

To make the shadow move to the left, you have to move the source of light to the right, and vice versa.

CHALLENGE: TRANSMISSION & SHADOWS

Shadows

Shadows are an absence of light. Light travels in a straight line, and when it meets an obstacle, cannot move around it. The light is then either reflected, absorbed, or transmitted. If the object is transparent, and the light is transmitted, the light will continue on its path on the other side of the obstacle. If the object is opaque, however, the light is either reflected, absorbed, or both. Either way, the light does not make it to the other side of the object, and a shadow is formed.

Selective Transmission

Some transparent objects allow only certain wavelengths, or colors, of light to pass through them. This is called selective transmission. A red piece of plastic, like the Reflect View, will allow only red light to pass through it. All other wavelengths of light will be absorbed, or blocked.

Big Idea

Explore the formation of shadows by selectively transparent objects using knowledge of selective transmission.

Related Activities

Activity 3: Transmission with Gummy Bears

Activity 4: White Light and Shadows

What You'll Need

- 2 Lazr fingers/Light BLOX: Red and Blue
- 1 Reflect View
- A long, thin object, like a LASER pointer or pencil
- A blank wall/screen

ACTIVITY SHEET

Transmission & Shadows

We're now going to use what we know about selective transmission to create shadows using selectively transparent objects.

1. Place the Reflect View about 5-10 cm from the wall/screen.

Start out by shining the red Lazr finger at the Reflect View. What happens?

You should see that the red light passes through the Reflect View, and shines on the screen behind it.

2. Stand the pencil vertically next to the Reflect View.

Shine the red light at the pencil on its own. What do you see? Is this what you expected?

The pencil casts a shadow on the screen behind it. Regardless of the color of the light, the opaque pencil allowed none of the light to pass through it.

3. Move the pencil so that it stands between you and the Reflect View.

Shine the red Lazr finger at the pencil and the Reflect View together. What do you see on the screen?

You'll notice that the red light passes through the Reflect View unhindered. The pencil blocks the light, however, and a shadow of the pencil is formed on the screen.

Now shine the blue light at the Reflect View and pencil together. What do you see?

This time, the entire Reflect View casts a shadow! None of the blue light makes it to the other side of the Reflect View, since the Reflect View absorbed all the blue light, and would only allow red light to pass.

PEPPER’S GHOST

Think about the last time you stood in front of a window at night, while the lights in your room were on. What did you see?

What Is Pepper’s Ghost?

By reflecting a real person against a pane of glass, one can create the image of a ghost floating in “mid-air”. This is called Pepper’s Ghost, and it’s been around for ages!

History of Pepper’s Ghost

Pepper’s Ghost was first mentioned over 400 years ago, but not demonstrated until an inventor named Henry Dircks created the Dircksian Phantasmagoria in 1862. This was a device that theaters could use to make ghosts appear and disappear on stage at a moment’s notice. Sadly, it was a complicated trick that required theatres to be completely rebuilt.

When a professor named John Pepper realized that the illusion could be more simply created, the Pepper’s Ghost that we know today was developed. Pepper first showed off the new trick during a performance of Charles Dickens’ *A Haunted Man*. The illusion was such a huge success that it was nicknamed Pepper’s Ghost, instead of after its original inventor Dircks.

Pepper’s Ghost has since been used in theatrical productions, magic shows and haunted houses - and is still in use today!

Reflection and Virtual Images

When you look at yourself in the mirror, your reflection is called a **virtual image**. When something is virtual, it appears to be real, but isn’t actually - your reflection looks just like you, standing in front of you, but you’re not really there! Virtual images created by plane mirrors, or flat mirrors, follow very strict rules. These virtual images are always as far from the mirror as the real object being reflected, and horizontally inverted - left and right are swapped around. They’re also the same size as the original object!

Big Idea

Demonstrate the formation and properties of virtual images by creating a Pepper’s Ghost with the Reflect View.

What You’ll Need

- 1 Reflect View
- 1 White Lazr finger
- A printed picture with a black background
- A smartphone

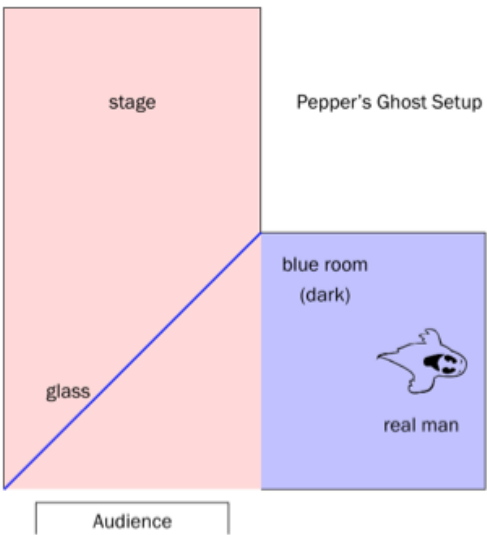


Figure 1: Setup of Pepper’s Ghost

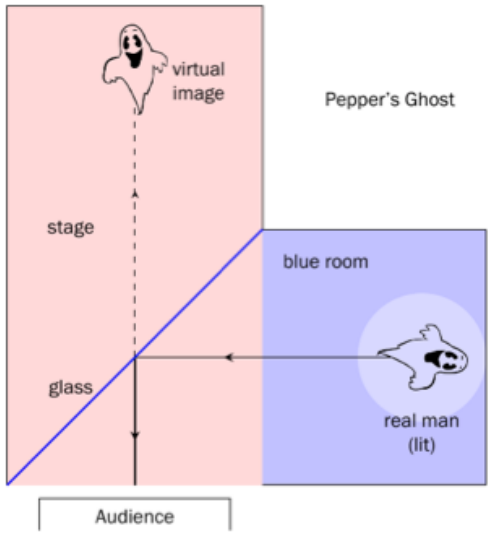


Figure 2: Pepper’s Ghost in Action

How Pepper’s Ghost Works

One of the ways that **Pepper’s Ghost** was created was with a special stage, shown in Figure 1. The stage consisted of two parts: the visible stage (in pink), and a room to one side, hidden from the audience’s view (in blue). The hidden room was called the “blue room”, and this is where the person dressed as a ghost would stand. The blue room was painted a dark color; usually black.

A sheet of glass was placed at a 45° angle between the stage and blue room. When the blue room was dark and the stage well-lit, the stage seemed empty - think about when you stand in front of a window when it’s sunny outside. Can you see your reflection? No, only the objects outside!

Then, when the stage lights were dimmed and a spotlight lit over the man in the blue room, his reflection became visible in the glass. Since the audience couldn’t see the real man, it appeared as though a ghost was floating on the stage!

Pepper’s Ghost in Real Life: Disneyland’s Haunted Mansion

The ballroom of Disneyland’s Haunted Mansion is one of the largest examples of Pepper’s Ghost in action. As guests travel through the haunted room, they’re actually looking down into an empty ballroom covered by a gigantic sheet of glass.

Hidden from the guests’ view, robotic “ghosts” dance and dine in a black recreation of the ballroom. As they’re lit in the fake ballroom, they appear dancing in the real ballroom, and disappear just as quickly when they move away from the lights.

ACTIVITY SHEET

Pepper’s Ghost

We’re now going to create an old-fashioned Pepper’s Ghost. For these activities, you’ll want to darken the room you’re working in as much as possible - the darker the room, the clearer the images!

- 1. Place the printed picture on a flat surface. The surface should either be at eye level, or you should be able to crouch down so that it is.
- 2. Hold the Reflect View over the picture at a slant. Rest the top end of the Reflect View on the table just below the picture. Make sure the bevelled (stepped) edge of the Reflect View is facing towards you.
- 3. Shine the Lazr finger onto the picture. Hold it about 10-20 cm from the picture, and be careful not to shine the light through the Reflect View. You want to get as little glare as possible on the picture.
- 4. Look directly into the Reflect View. You should be low enough that you don’t see the picture on the table.

What do you see? Think about how far the virtual image of the picture appears behind the Reflect View, and how it compares to the original picture.

You should notice that the virtual image appears to be the same distance from the Reflect View as the original picture. The virtual image is also inverted, or swapped around.

- 5. Replace the picture and Lazr finger with a video played on the smartphone. Something like a candle with a black background works best.

What do you see now? Is it different to when you used the printed picture?

This proves what we know about virtual images - the candle floats the same distance behind the Reflect View as the smartphone, and it’s swapped around!

What could you do to make the candle appear further away than it does now? Use what you know about virtual images!

To move a virtual image further away from the reflective surface, you need to move the object being reflected. We could do that by moving the Reflect View further from the smartphone, or making the Reflect View bigger and using a bigger screen!

PEPPERGRAM™ VS HOLOGRAM

Holograms have been hugely popular in movies and video games for the last 40 years. What do you think a hologram is? How is it different to a normal projection, like in a movie theater?

Pepper’s Ghost

Pepper’s Ghost is an illusion that uses the law of reflection to create a scarily realistic ghostly image. It is often mistaken for a hologram, but it is, in fact, not a hologram at all!

The Law of Reflection

Simply put, the law of reflection states *angle of incidence = angle of reflection*. To find these angles, take a look at Figure 1. You measure these angles from an imaginary line called the **normal**, which is basically any line at 90° to your reflective surface. The angle of incidence is the angle between the ray moving from your source of light to the mirror (the **incident ray**) and the normal. The angle of reflection, then, is the angle between the **reflected ray** and the normal.

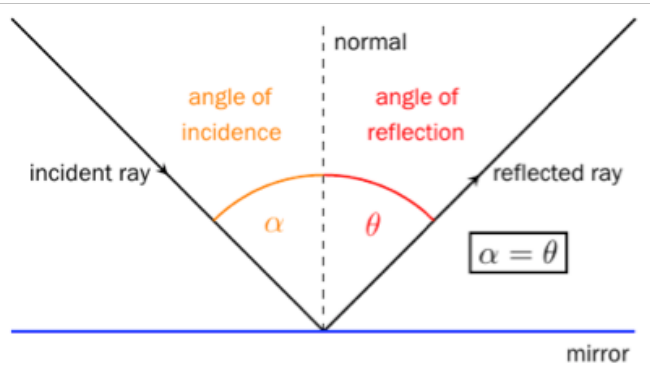


Figure 1: The Law of Reflection

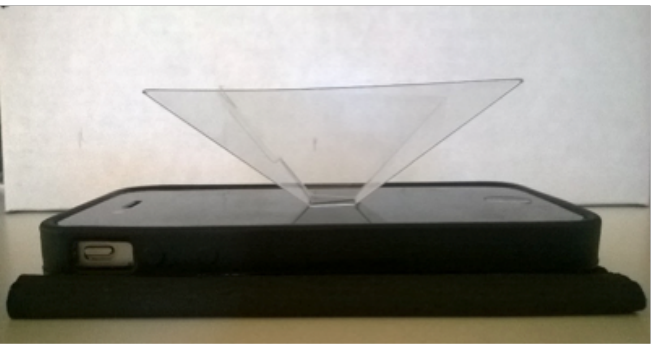


Figure 2: The PepperGram™ Setup

Figure 3 shows one of the four sides - they all work the same way, independently. While it may look like all four sides are working together to create a floating 3D image, the PepperGram™ would work just as well with only one side.

Big Idea
Demonstrate the law of reflection by creating a Pepper’s Ghost with the PepperGram™.

- What You’ll Need**
- A smartphone
 - A PepperGram™
 - A mounting square

How the PepperGram™ Works

We’re going to create a Pepper’s Ghost using a PepperGram™; a device which makes a video played on your smartphone appear to float in mid-air. The PepperGram™ is made of stiff, reflective plastic. When bent into shape and placed on a smartphone, each of the four sides are at a 45° angle to the screen, as shown in Figure 2.

The video played on the smartphone is reflected against the side of the PepperGram™ and directly outwards.

To the viewer, the image in the video appears to float inside the PepperGram™. This is the Pepper’s Ghost, and it is a **virtual image**. Your eye expects light to always travel in straight lines, so it is tricked into thinking that the video is actually straight ahead, inside the PepperGram™. This is why the virtual image appears the same distance from the reflective surface as the real object actually is.

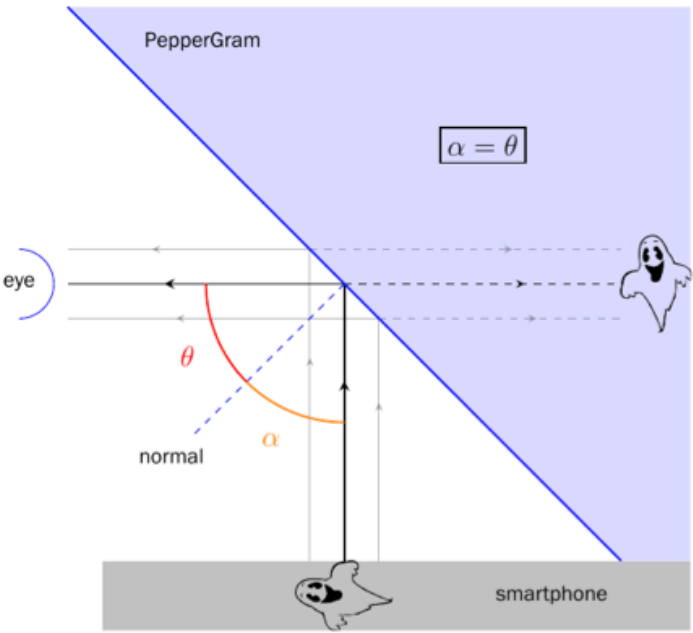


Figure 3: One side of the PepperGram™

But it isn't a Hologram!

The images created by the PepperGram™ may look just like holograms, but they aren't! Holograms are actually three-dimensional "photographs" of objects. Shining lasers at the object from different angles, the size and shape of the object is recorded on holographic film, which produces a holographic print.

When you look into the holographic print, you see the 3-D object from a head-on perspective. The object appears to float behind the print, as if you were looking at it through a window. You can turn the print (or your head), and the perspective of the picture will change - you'll see the object from a different angle! One can also shine a laser through the holographic print and project the image onto a screen, which can then be viewed from different angles as well.

Holograms in Real Life: Security

The next time you hold a bank note up to the sun, see if you can spot its security hologram. This is usually a strip of words or pictures, depending on the currency, that changes color and shape as you move the bank note around.

Security holograms are also used in passports and on credit cards. Their purpose is to make forgery more difficult - the holograms are copies of a master hologram that's very expensive and difficult to make yourself. This way, they discourage people from making fake money!

ACTIVITY SHEET

PepperGram™ vs Hologram

Let's create a Pepper's Ghost with the PepperGram™. Try to make the room as dark as possible. This will make for clearer images.

- 1. Remove the protective film from each side of the PepperGram™.
- 2. Fold along the three lines on the PepperGram™ - you might have to press quite hard to get the plastic to snap into place. Your PepperGram™ should now look like an upside-down pyramid.
- 3. Wipe down the PepperGram™ with a clean cloth. You'll want it free of fingerprints and dust for the best result.
- 4. Search YouTube for any "4 Faces Hologram Videos". For a jellyfish, try this one: <https://www.youtube.com/watch?v=WFvlnYxEJGU>. Make sure your smartphone screen is set at its brightest.
- 5. Place the PepperGram™ in the middle of the screen. You can use one of the mounting squares to stick it down so that it doesn't move. Crouch down so that the PepperGram™ is at eye-level and play the video!

Move the PepperGram™ slightly slower than eye-level. What do you see now? Using your knowledge of the law of reflection, why do you think it's important that you look directly into the side of the PepperGram™?

The reflected light rays are moving in only one direction - horizontally from the side of the PepperGram™. They can't move upwards to meet your eye above the PepperGram™, because then the angle of reflection would be bigger than the angle of incidence, and the law of reflection would be broken!

We're now going to confirm that the PepperGram™ does not create holograms!

Pause the video. Take a good look at the jellyfish, then move around the PepperGram™ and compare. What do you notice? Does the jellyfish "turn around"?

The jelly-fish looks the same, no matter which side of the PepperGram™ you view it from. If the jellyfish were a hologram, you should see the back of the jellyfish when you go to the other side of the PepperGram™.

Now switch off the screen of the smartphone. Is the jellyfish still swimming? What does this tell us about the image?

Remember that a hologram is a photograph taken of an image. This means that you can't "switch off" a hologram, like you switched off your jellyfish. This proves that what we created was a Pepper's Ghost, and not a hologram!

MONOCHROMATIC LASER LIGHT

Working with LASERs, it's immediately obvious that they don't behave like the light we encounter every day. What makes LASER light different to the light emitted by a normal light bulb?

What is color?

Color is a property tied directly to the wavelength of light. Different colors of light have different wavelengths. When you look at a red object, it looks red, because the object is reflecting red light.

When light consists of only one wavelength of light, we say it is **monochromatic**.

White Light

So what color is the light emitted from the sun, or the overhead lights? Yellow? White? Does it even have a color?

Yes, it does! This light is called **white light**, and despite its name, it's actually made up of a combination of the primary colors of light. When red, green and blue light mix it creates the "clear" light we know as white light.

This is why we can see all the colors imaginable under sunlight, or the light from a flashlight, for example. Every wavelength of light is available to be reflected or absorbed, so every color has the potential to be visible.

Diffraction Gratings

A diffraction grating is a transparent piece of plastic mounted in a frame, as you can see in Figure 1. What you can't see, is that the plastic is covered in thousands of tiny scratches. The scratches run from the top of the plastic to the bottom, and are parallel to one another. They're so thin that you can fit hundreds of scratches on one mm of plastic!

When you shine a beam of light through a diffraction grating, it splits the light up into its component wavelengths. All of the different colors of light that make up the beam of light can be seen side by side, as in Figure 2 - this is called its spectrum.

Big Idea

Demonstrate the monochromatic nature of LASER light by comparing the spectra of white light and colored LEDs to that of LASER light.

What You'll Need

- 1 Diffraction Grating
- 3 Lazr fingers/Light BLOX: Red, Green, Blue
- 1 White Lazr finger
- 1 Flashlight (optional)
- 1 Red Laser Pointer
- A blank wall/screen

Monochromatic Light in Real Life: Spectrometry

Gases absorb light as it passes through. They only absorb specific wavelengths, however, and every gas absorbs a different combination of wavelengths. If scientists know that a specific gas, and only that gas, absorbs a certain wavelength of light, they can test for that gas using LASERs.

Scientists can tune a LASER to the specific wavelength and shine it through the area where they suspect the gas exists. If the LASER returns weaker, the gas must be present, since it absorbed some of the LASER light. This technique is used in exploring other planets' atmospheres.



Figure 1: Diffraction Grating

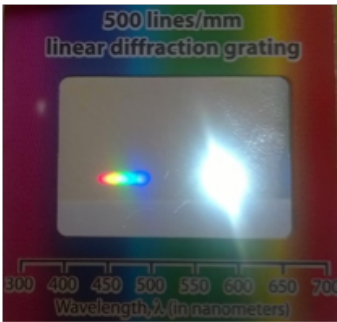


Figure 2: Spectrum of white light

ACTIVITY SHEET
Monochromatic LASER Light

- Let's investigate one of the aspects of LASER light that makes it different from "normal" light.
1. Hold the diffraction grating up to one eye.
 2. Hold the white Lazr finger at arm's length, pointing towards your eye, and turn the Lazr finger on. Don't look directly at the light; rather slightly to the left or right of the source.

What do you see? Record the order of the colors, starting from closest to the light source.

White light is made up of a rainbow, all mixed together. The order of colours are blue, green, yellow, orange and red.

3. Now hold the diffraction grating up to a flashlight, the overhead lights, or the sun.
- Was the rainbow the same for all sources of white light? What do you expect to see for the colored Lazr fingers?
- This spectrum is the same for all white light; always in the same order.
4. Repeat the process with the red, blue and green Lazr fingers.

What do the spectrums consist of? Was this what you expected? Why/why not? What is colored light really made of?

You might've expected to see only red light for the red Lazr finger, blue for the blue Lazr finger, etc. Actually, colored lights are not one colour at all. They consist of a spectrum of colours as well, although the spectrum is smaller than that of white light. Red, for example, is mostly red with a little yellow and green.

5. Point the red LASER pointer towards a blank wall or screen, approximately 15-20 cm away from the surface. IMPORTANT: Never look directly into the LASER!
6. Hold the diffraction grating about 5-10 cm from the front of the LASER, and switch on the LASER pointer.

How is this different to the colored Lazr fingers? What does this tell us about what makes LASER light special?

Even though the LASER was split up into its components, they were all red. Hence, the LASER pointer consists of only one color light, i.e. only one wavelength. This is called monochromatic light.

COLLIMATED LASER LIGHT

LASERs are often used during presentations, to highlight important points. One could not do this with a normal light, though! Why can LASERs shine so much further than LED lights, without getting dimmer?

How Light Moves

We can represent a beam of light as a collection of light rays, as shown in Figures 1 and 2. These light rays follow a very specific set of rules. The most important of these is that these rays always travel in straight lines. They cannot curve, and unless they are refracted, they cannot bend.

Why is Light Bright?

The light rays making up a beam of light can be arranged in a lot of different ways. This affects how bright the light is.

Take a look at the ray diagram in Figure 1. The rays making up this beam of light are very close together, so the beam will be bright. The closer together the rays of light, the brighter, or more intense, the beam.

Conversely, Figure 2 shows a dim beam of light. The light rays are far apart, so the beam is less intense, or less bright, than the first one.

Often, when the rays of a beam of light leave its source, like an LED, the light rays start to spread out. This is shown in Figure 3. This means the beam starts out brightly, but loses intensity as the rays move further away from each other.

When the rays don't spread out, but instead remain parallel to each other, we say the beam of light is collimated.

Big Idea

Demonstrate that LASER light is collimated by comparing the area of light produced by LED lights to that of LASER light at various distances.

- What You'll Need
- 1 Lazr finger/Light BLOX: Red, Green or Blue
 - 1 Light BLOX with/without slit cap (optional)
 - 1 Red Laser Pointer
 - 2 blank sheets of paper
 - A ruler



Figure 1: Bright Beam of Light



Figure 2: Dim Beam of Light

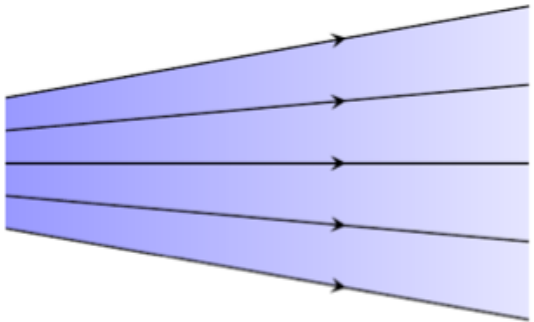


Figure 3: Light Rays Spreading Out

Calculating Area

In order to complete the activity sheet, you'll need to know how to calculate the area of a circle and a rectangle.

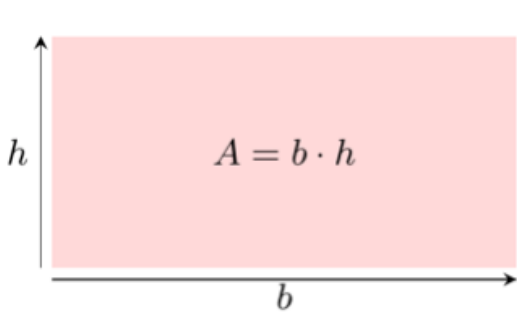


Figure 4: Area of a Rectangle

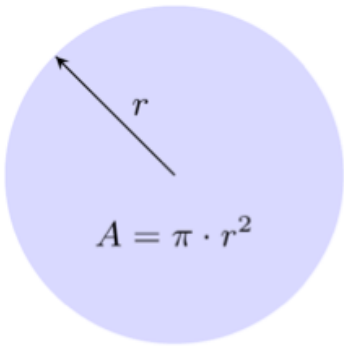


Figure 5: Area of a Circle

Figure 4: Area of a RectangleFigure 4 shows the measurements required of a rectangle, which need to be substituted into the equation

$$A=b\cdot h$$

Figure 5 shows how to measure the radius of a circle, in order to calculate the area using

$$A=\pi\cdot r^2$$

Collimated Light in Real Life: Microscopy

While parallel light rays are a well-known property of LASERs, you can collimate any light source with the right equipment. One of the uses of collimated light is in microscopes.

In order to ensure clear, accurate images in high-powered microscopes, a collimated beam of light must travel from the light source below the specimen being viewed, to the eyepiece. This light can originate from either a LASER or an LED.

ACTIVITY SHEET

Collimated LASER Light

This activity will showcase one of the properties of LASER light that makes it so unique.

- 1. Stick one of the blank sheets of paper against the wall, in line with the table top.
- 2. Stick the other sheet to the table, short end flush with the wall.
- 3. Mark off 1", 3" and 6" lines on the paper on the table.
- 4. Place the Lazr finger at the 1" mark, and switch it on. Use a pencil to mark off the area of the circle of light created. Repeat at 3" and 6".
- 5. Remove the paper from the wall and calculate the area of each of the circles. Record your data in the table below.
- 6. Repeat steps 4 and 5 with the red LASER pointer and the Light BLOX, if you have one.

	1"	3"	6"
Lazr Finger			
Light BLOX			
LASER			

What do you notice about the size of the circle of light from the Lazr finger, and that of the rectangle from the Light BLOX? What could this mean, considering the nature of the light produced?

The circle of light becomes bigger the further away the source of light is from the wall. The rectangle behaves the same way. This is because the light rays spread out as they leave the light source.

What do you notice about the size of the circle/ellipse of LASER light? What could this mean?

The light from the LASER, however, stays the same size. This is because LASER light is collimated, i.e. the light rays are parallel to one another. They do not spread out as they leave the light source. This is why the light doesn't lose brightness, like the Lazr finger and Light BLOX.

COHERENT LASER LIGHT

LASER light has three main properties that distinguishes it from normal, everyday light we come in contact with.

Light Waves

A beam of light consists of a number of rays of light. Each ray of light can be represented as a transverse wave. When all the rays of light in a beam are in phase, we say the light is coherent.

If two rays of light are in phase, it means their crests (and troughs) sync up. Figures 1 and 2 show the difference between coherent and incoherent light. In Figure 1, you can see the peaks of the waves are all aligned, forming a coherent beam of light. In Figure 2, the peaks are randomly aligned - this is an incoherent beam of light.

Diffuse Reflection

The law of reflection states that angle of incidence = angle of reflection. When a beam of light is reflected off a smooth surface, such as in Figure 3, all the rays have the same angle of incidence, and hence all move off at the same angle of reflection as well.

If a beam of light is shone on a coarse or uneven surface, however, the rays are all reflected at different angles, as shown in Figure 4. This is known as diffuse reflection.

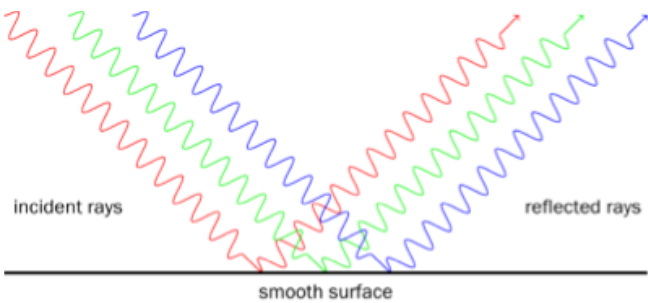


Figure 3: Diffuse Reflection

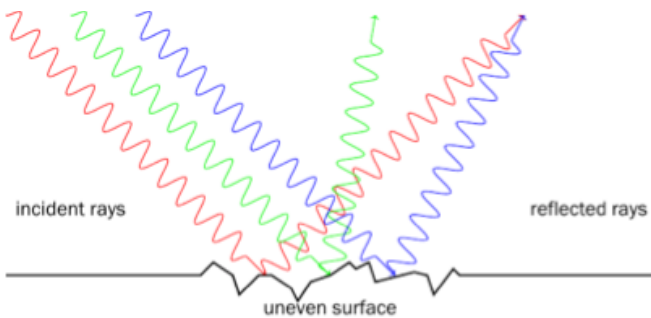


Figure 4: Regular Reflection

Big Idea

Demonstrate that LASER light is coherent by comparing the interference pattern of a red LASER pointer to that of LED light.

What You'll Need

- 1 Lazr finger/Light BLOX: • Red, Green or Blue
- 1 Red Laser Pointer
- A blank sheet of paper

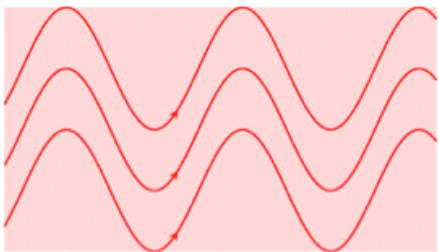


Figure 1: Coherent Light

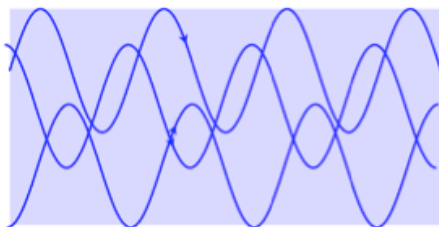


Figure 2: Incoherent Light

Interference and Speckle Patterns

When two rays of light meet, they interfere, and form one resulting ray. If two crests meet, the rays undergo constructive interference, and the resulting ray is amplified. If a crest and a trough meet, the rays experience destructive interference, and the resulting ray is diminished.

Consider the phenomenon of diffuse reflection mentioned earlier. When an incoherent beam of light is diffusely reflected, the rays of light cross and interfere, but the results are completely random. Hence, the brightness of the beam of light remains fairly constant - at least to the naked eye.

When coherent light is diffusely reflected, however, the interference is more regular. This is because the incident light rays are in phase - their crests and troughs meet up in a more noticeable pattern when the rays are reflected. This results in a speckle pattern. The reflected light beam appears to be covered in dark spots - these are areas of destructive interference - while the bright patches are areas of constructive interference.

Coherent Light in Real Life: Monitoring Blood Flow

The speckle pattern produced by a coherent source of light is dependent on the rough surface on which it reflects. If the surface changes, so does the speckle pattern produced - this is called dynamic speckle.

Dynamic speckle is used in medicine to monitor blood flow in patches of skin. As blood flows just under the skin, it cause the skin to move. Hence, by shining a coherent light source on the patch of skin and watching the speckle pattern change, doctors can judge how quickly blood is flowing in that area.

ACTIVITY SHEET

Coherent LASER Light

This activity will explore an aspect of LASER light that contributes to its amazing quality.

1. Switch on the Lazr finger and hold it close to the paper, at a small angle. The light should stretch out in front of the Lazr finger in an ellipse.

Take a close look at the light. What do you observe? Is there anything unusual about the light?

2. Now, hold the LASER pointer the same way, and switch it on. The LASER light should form a long ellipse.

What do you observe about the LASER light? Is there anything unusual happening? How is it different to the light from the Lazr finger?

You'll notice that the LASER light isn't consistent in brightness, like the light from the Lazr finger. The LASER light is covered in dark spots. This is the speckle pattern of the LASER light.

You might have to move between the Lazr finger and the LASER pointer a couple of times before you see the difference in the light - keep going until you see it!

Now that you know what the speckle pattern looks like, move the LASER slowly while shining it on the paper. What do you observe about the speckle pattern? Why do you think this happens?

As you move the laser, the surface of the paper changes, even if you can't see it. This changes the speckle pattern!

3. See how many other coarse surfaces you can find to observe the speckle pattern on. The skin on the inside of your elbow is a good one.

Does the speckle pattern change? How so?

The speckle pattern will be different for every surface you shine the LASER on! In the crook of your elbow, you might observe more very bright spots than on the paper.

MEASURING THE WAVELENGTH OF A LASER

Imagine water waves moving along the shore. What do you think would happen is they suddenly met an obstacle, like a harbour wall, which contained only a narrow entrance for them to move through? How would the waves behave once they passed through the hole in the wall?

Diffraction

Diffraction refers to how waves bend when they move through a small opening, or around a narrow obstacle. Consider Figure 1. This shows a wave moving through a small slit in a barrier. You might expect the waves to continue onwards in a uniform fashion, just slightly shorter. Instead, the edges of the waves bend towards the barrier as they pass through.

In the same way, waves diffract as they move past a narrow obstacle. This is shown in Figure 2 - the waves bend towards the obstacle, again, as they pass.

Light is a wave, and hence it will diffract when faced with one of the two abovementioned obstacles.

Diffraction Grating

A diffraction grating is a piece of plastic containing thousands of thin, vertical scratches, running from the top of the plastic to the bottom. These scratches act as narrow obstacles, and the light diffracts as it passes through the diffraction grating.

As the waves diffract and bend, however, they interfere with each other. When two crests meet, there is constructive interference, and the wave is amplified, or made brighter. When two troughs meet, destructive interference occurs, and the wave is dampened, or made dimmer. This causes the interference pattern you see emerging from the diffraction grating.

Big Idea
Demonstrate the concept of diffraction by calculating the wavelength of red LASER light.

- What You'll Need**
- 1 Red LASER pointer
 - 1 Diffraction Grating
 - Sheet of blank paper
 - A ruler
 - Diffraction grating holder (optional)

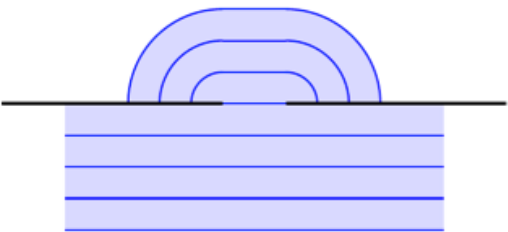


Figure 1: Diffraction through a narrow slit

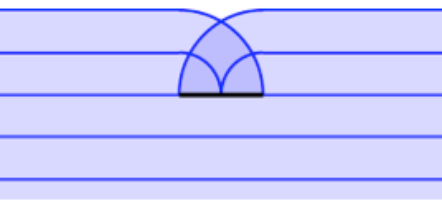


Figure 2: Diffraction around a narrow obstacle

Interference Pattern of LASER Light

Different wavelengths of light diffract at different angles. If you were to pass white light through the diffraction grating, you would observe its spectrum, or all the colors of light which it consists of, side by side. As a test, hold the diffraction grating up to one eye and take a look at a source of white light, like the overhead lights. You should observe its spectrum!

LASER light is monochromatic, however - it consists of only one wavelength of light. Hence, all the light waves diffract at the same angle, and we don't observe a spectrum - rather, its interference pattern consists only of one color light, shown in Figure 3. We can use this pattern to calculate the wavelength of the light!

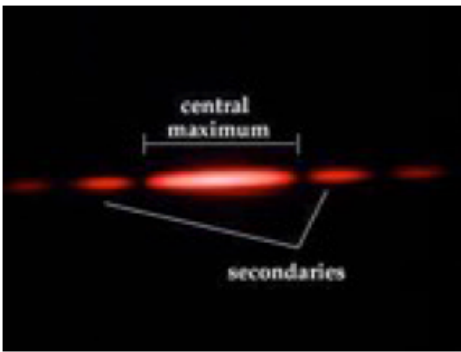


Figure 3: Interference Pattern of LASER Light

Calculating the Wavelength of Light

In order to calculate the wavelength of the LASER light, you need to be able to identify certain aspects of its interference pattern. Take a look at Figure 3 again. The brightest spot of light, right in the middle, is called the **central maximum**. The smaller dots on either side are referred to as **secondary maxima**. In white light, the secondary maxima are entire spectra.

The formula for calculating the wavelength λ of light is as follows:
 $\lambda=(X)(d)L$

where X is the distance between the central maximum and one of the secondary maxima,
 d is the width of the slits of the diffraction grating, and
 L is the distance from the diffraction grating to the screen showing the interference pattern.

Diffraction in Real Life: Holograms

Holograms are 3D “photographs” of objects that capture perspective. This means that a hologram has depth, and if you turn the hologram, the picture changes, as if you were holding the real object.

To view a hologram, you would usually shine a LASER through a hologram plate. This hologram plate is actually a glass square with opaque and transparent lines, which acts as a diffraction grating. When you shine a LASER through the hologram plate, the LASER light diffracts and an interference pattern is formed. This interference pattern is the image, or the hologram!

ACTIVITY SHEET

Measuring Wavelength of a LASER

We’re now going to use what we know about diffraction patterns to measure the wavelength of a red LASER.

- 1. Stick the blank paper to a wall above a flat surface on which you can rest the red LASER pointer.
- 2. Place the diffraction grating upright in front of the paper. Measure the distance between the grating and the wall, L , and record it in the table below.
- 3. Shine the laser pointer through the diffraction grating. If possible, place it on a small box or similar to hold it steady.
- 4. Mark off the central maximum and one of the first-order maxima on the sheet of paper with a pencil.
- 5. Remove the sheet and measure the distance between maxima. Record the distance X .
- 6. Repeat twice more with different distances L .

	Diffraction Grating lines/mm	Slit Width (d) cm/line	Distance from grating to screen (L) in cm	Distance from maximum to maximum (X)
1				
2				
3				

- 7. Substitute the values for measurements 1 to 3 into the equations below to calculate the wavelength of the LASER.

	$\lambda 1=(X)(d)L$	$\lambda 2=(X)(d)L$	$\lambda 3=(X)(d)L$	Average Wavelength $\lambda=\lambda 1+\lambda 2+\lambda 3$
Substitutions of data in formula				
Final Value (cm)				
Final Value (nm)				

TIP: You need to convert your final value for from cm to nm in the table above. To do this, note that
 $1\text{ cm}=1\times 10^7\text{ nm}=10\,000\,000\text{ nm}$

TIP: Red light usually has a wavelength of 650nm - 750nm. Check that your average wavelength falls in this range!

CHALLENGE: TESTING THE LAW OF REFLECTION

Law of Reflection

When a ray of light is reflected on a surface, the incoming ray is called the incident ray, and the outgoing ray is called the reflected ray. We can draw an imaginary line at 90° to the surface called the normal. The angle between the incident ray and the normal is the angle of incidence. The angle between the reflected ray and the normal is called the angle of reflection. The law of reflection states that the angle of incidence is always equal to the angle of reflection, as shown in Figure 1.

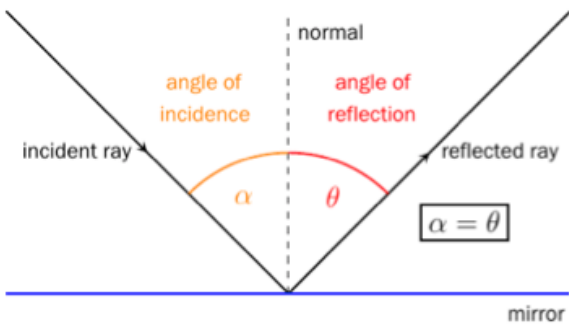


Figure 1: Law of Reflection

We’re going to test the law of reflection by drawing ray diagrams with the Reflect View.

- 1. Place the Reflect View on the dotted line. Make sure the stand of the Reflect View is facing upwards and that the bevelled edge is towards you. The reflection of the star on the left should match up with the one on the right.
- 2. Reach over to the right hand side and trace the reflected rays as you see them on the Reflect View. Use green for the reflected green ray, etc.
- 3. Use the protractor to measure the angle of incidence for each of the rays, as well as the angle of reflection. Record the angles in the table on the worksheet. NB: When measuring the angles, the dashed line acts as the normal, and the dark black line on top as the mirror.

OPTIONAL: Place the small mirror upright on the line marked “mirror” on the activity sheet. Leave the slit caps on the Light BLOX. Place the green Light BLOX in line with the green incident ray, on the left hand side. Do the real reflected rays and the traced reflected rays match up? You should find that they do!

Big Idea

Demonstrate the law of reflection quantitatively by drawing ray diagrams.

Related Activities

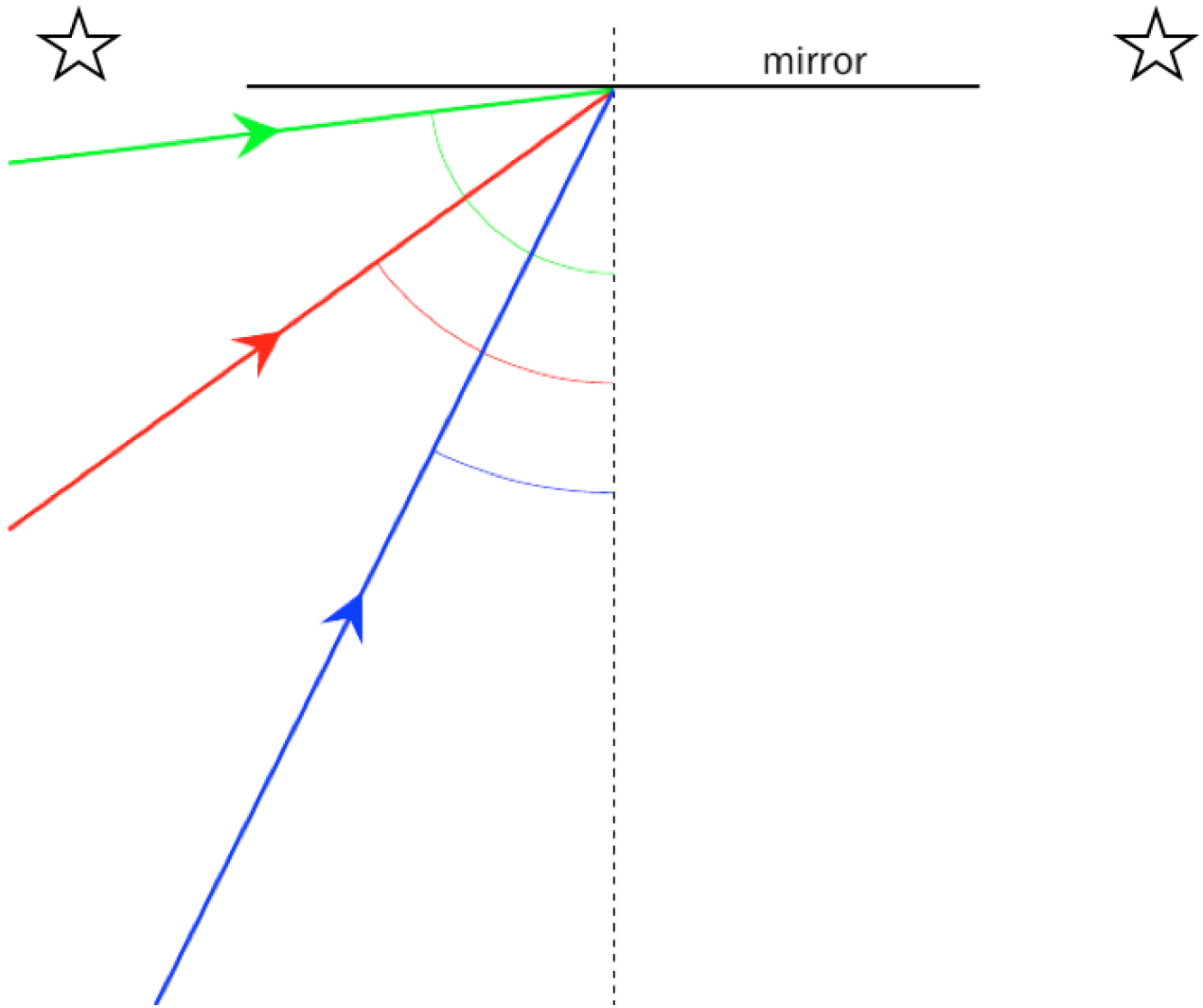
Activity 1:
Reflection with Reflect View

What You’ll Need

- Reflect View
- Green, red and blue pencils or pens
- A protractor
- A small mirror (optional)
- 3 Light BLOX: Red, Green and Blue (optional)

ACTIVITY SHEET

Testing the Law of Reflection



	Angle of Incidence	Angle of Reflection
Green Light		
Red Light		
Blue Light		

Does the law of reflection hold? You can allow a couple of degrees difference between the angles.



This activity guide and the Explore Optics Kit were developed by Laser Classroom for The Optical Society of America's Centennial Celebration. Thank you for sharing your commitment to light, lasers and optics! For more OSA Centennial Celebration information, visit WWW.OSA.ORG/EXPLOREOPTICS. For more kits and activities related to light, lasers and optics visit <http://www.laserclassroom.com>

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