10.3 Optics

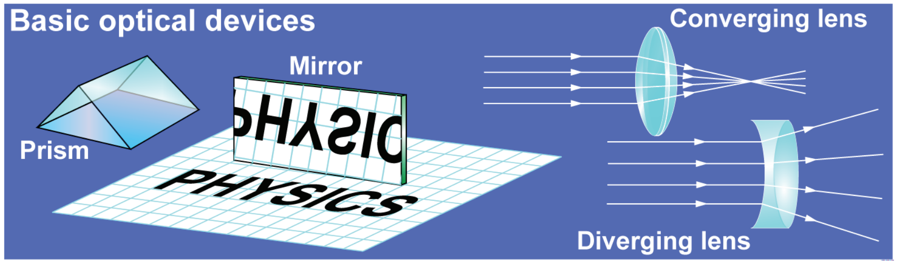
Optics is the science and technology of light. Almost everyone has experience with optics. For example, trying on new glasses, checking your appearance in a mirror, or admiring the sparkle from a diamond ring all involve optics.

Basic optical devices

Lenses A **lens** bends light in a specific way. A *converging lens* bends light so that the light rays come together in a point. This is why a magnifying glass makes a hot spot of concentrated light (Figure 10.17). A *diverging lens* bends light so it spreads light apart instead of bringing it together. An object viewed through a diverging lens appears smaller than it would look without the lens.

Mirrors A **mirror** reflects light and allows you to see yourself. Flat mirrors show a true-size image. Curved mirrors distort images. The curved surface of a fun house mirror can make you look appear thinner, wider, or even upside down!

Prisms A **prism** is usually made of a solid piece of glass with flat polished surfaces. A common triangular prism is shown in the picture below. Prisms can both bend and/or reflect light. Telescopes, cameras, and supermarket laser scanners use prisms of different shapes to bend and reflect light in precise ways. A diamond is a prism with many flat, polished surfaces. The "sparkle" that makes diamonds so attractive comes from light being reflected many times as it bounces around the inside of a cut and polished diamond.



VOCABULARY

lens - an optical device for bending light rays.

mirror - a surface that reflects light rays.

prism - a glass shape with flat, polished surfaces that can both bend and reflect light.

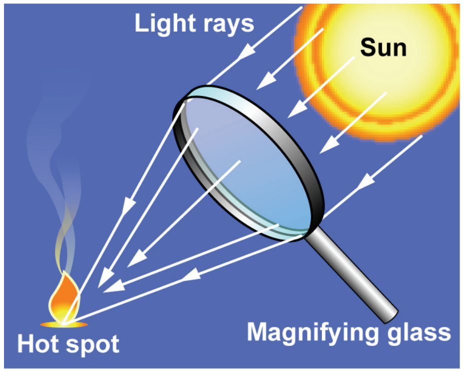


Figure 10.17: *A magnifying glass is a converging lens. This is why a magnifying glass can be used to make a hot spot of concentrated light. You should NOT try this yourself - the science is interesting, but can be unsafe.*

Four ways that light is affected by matter

The four interactions

When light interacts with matter, like glass, wood, or anything else, here are four of the things that can happen.

- The light can go through almost unchanged (transparency).
- The light can go through but be scattered (translucency).
- The light can bounce off (reflection).
- The light can transfer its energy to the material (absorption).

Transparency

Materials that allow light to pass through are called **transparent**. Polished glass is transparent, as are some kinds of plastic. Air is also transparent. You can see an image though a transparent material if the surfaces are smooth, like a glass window.

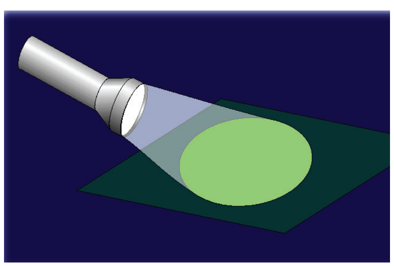
Translucency

An object is **translucent** if some light can pass through but the light is scattered in many directions (Figure 10.18). Tissue paper is translucent, and so is frosted glass. Try holding a sheet of tissue paper up to a window. You can't see an image through it.

Reflection and absorption

Almost all surfaces reflect some light. A mirror is a very good reflector but a sheet of white paper is also a good reflector. The difference is in *how* they reflect. When light is *absorbed*, its energy is transferred. That is why a black road surface gets hot on a sunny day. A perfect absorber looks black because it reflects no light at all.

All interactions at once



All four interactions almost always happen together. A glass window is mostly transparent but also absorbs about 10% of light. The glass scatters some light (translucency) and reflects some light. The same material also behaves differently depending on how well the surface is polished. Frosted glass has a rough surface and is translucent. Look at the illustration at the left. Green colored paper absorbs some light, reflects some light, and is partly translucent. Can you tell which colors are absorbed and which are reflected?

VOCABULARY

transparent - allows light rays to pass through without scattering.

translucent - allows light rays through but scatters them in all directions.

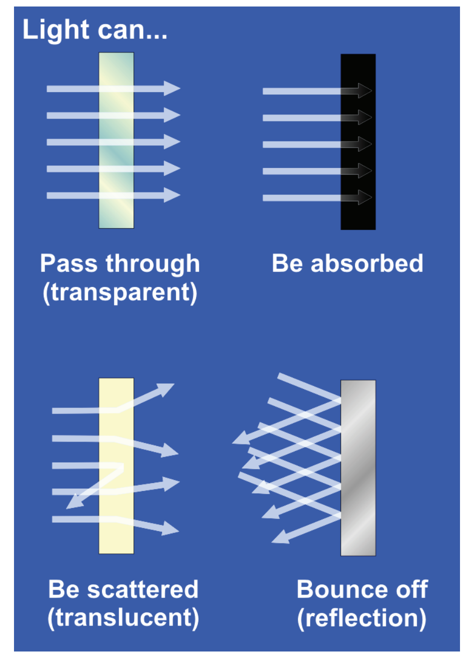


Figure 10.18: *The four interactions of light with matter.*

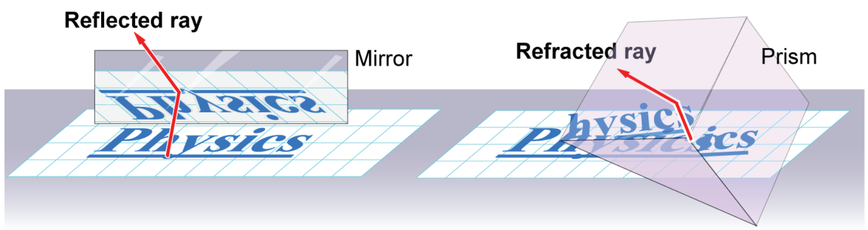
Light rays

What are light rays?

When light moves through a material, it travels in straight lines. Diagrams that show how light travels use straight lines and arrows to represent **light rays**. Think of a light ray as a thin beam of light, like a laser beam. The arrow shows the direction the light is moving.

Reflection and refraction

When light rays move from one material to another, the rays may bounce or bend. **Reflection** occurs when light bounces off of a surface. **Refraction** occurs when light bends while crossing a surface or moving through a material. Reflection and refraction cause many interesting changes in the images we see.



Light rays are reflected in a mirror, causing an inverted image.

Light rays are refracted (or bent) by a prism, causing the image to be distorted.

Reflection creates images in mirrors

When you look in a mirror, objects that are in front of the mirror appear as if they are behind the mirror. Light from the object strikes the mirror and reflects to your eyes. The image reaching your eyes appears to your brain as if the object really *was* behind the mirror. This illusion happens because your brain "sees" the image where it would be if the light reaching your eyes had traveled in a straight line.

Refraction changes how objects look

When light rays travel from air to water, they refract. This is why a straw in a glass of water looks broken or bent at the water's surface (Figure 10.19). Look at some objects through a glass of water; move the glass closer and farther away from the objects. What strange illusions do you see?

VOCABULARY

light ray - an imaginary line that represents a beam of light.

reflection - the process of bouncing off a surface. Light reflects from a mirror.

refraction - the process of bending while crossing a surface. Light refracts passing from air into water or back

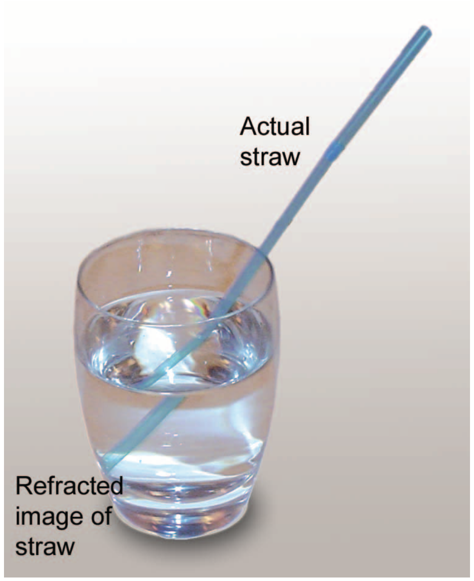


Figure 10.19: *Refraction bends light rays so the straw appears to be in a different place!*

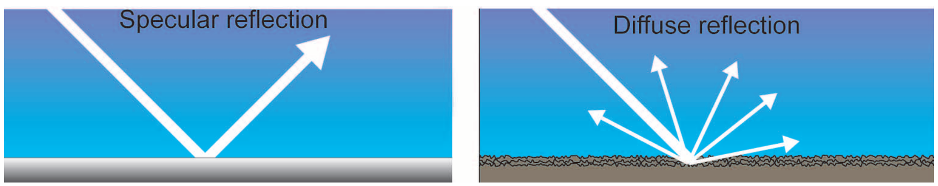
Reflection

The image in a mirror

When you look at yourself in a mirror, you see your own image as if your exact twin were standing in front of you. The image appears to be the same distance from the other side of the mirror as you are on your side of the mirror (Figure 10.20). If you step back, so does your image. Images form in mirrors because of how light is reflected.

Specular reflection

Light is reflected from all surfaces, not just mirrors. But not all surfaces form images. The reason for this is that there are two types of reflections. A ray of light that strikes a shiny surface (like a mirror) creates a single reflected ray. This type of reflection is called **specular reflection**. Specular reflection is why you see an image in a polished surface, like a mirror. In fact, a surface which has perfect specular reflection is *invisible*. If you look at that surface, you see reflections of other things, *but you don't see the surface itself*.



Diffuse reflection

A surface that is dull, (not shiny) creates **diffuse reflection**. In diffuse reflection, each reflected ray of light scatters in many directions creating multiple reflected rays. Diffuse reflection is caused by the roughness of a surface. Even if a surface feels smooth to the touch, on a microscopic level it may be rough. For example, the surface of a wooden board creates a diffuse reflection. When you look at a diffuse reflecting surface *you see the surface itself*.

One surface can create both types of reflection

Many surfaces are in between rough and smooth. These kinds of surfaces create both kinds of reflection. For example, a polished wood tabletop can reflect some light in specular reflection, and the rest of the light in diffuse reflection. The specular reflection creates a faint reflected image on the table surface. You also see the table surface itself by light from diffuse reflection.

VOCABULARY

specular reflection - "shiny" surface reflection, where each incident ray produces only one reflected ray.

diffuse reflection - "dull" surface reflection, where each incident ray produces many scattered rays.

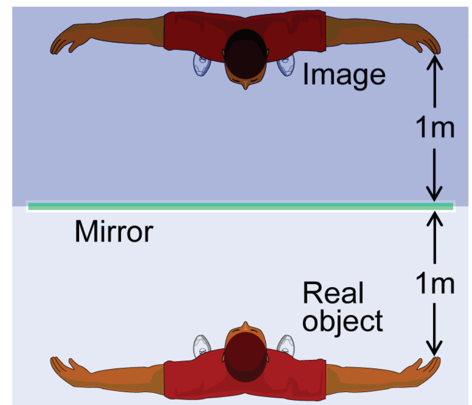


Figure 10.20: *The image you see in a flat mirror appears to be the same distance behind the mirror as you are in front of it.*

Refraction

The index of refraction

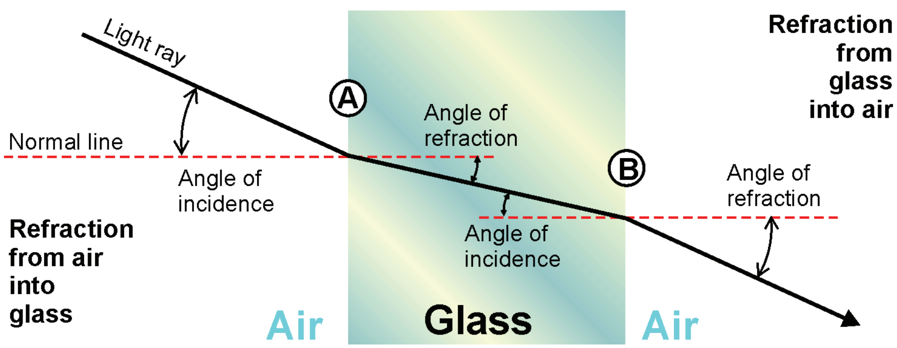
Eyeglasses, telescopes, binoculars, and fiber optics are a few inventions that use refraction to change the direction of light rays. Different materials have different abilities to bend light. Materials with a higher **index of refraction** bend light by a greater angle. The index of refraction for air is approximately 1.00. Water has an index of refraction of 1.33. A diamond has an index of refraction of 2.42. Diamonds sparkle because of their high index of refraction. Table 10.1 lists the index of refraction for some common materials.

Table 10.1: The index of refraction for some common materials

Material	Index of refraction
Air	1.00
Water	1.33
Ice	1.31
Glass	1.45–1.65
Diamond	2.42

The direction a light ray bends

When light goes from air into glass (A), it bends toward the normal line because glass has a higher index of refraction than air. When the light goes from glass into air again (B), it bends away from the normal line. Coming out of the glass, the light ray is going into air with a lower index of refraction than glass.



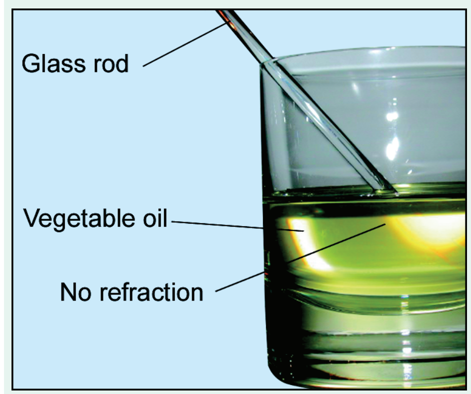
VOCABULARY

index of refraction - a number that measure how much a material is able to bend light.

A trick of refraction

If two materials have the same index of refraction, light doesn't bend at all. Here's a neat trick you can do with a glass rod. You see the edges of a glass rod because of refraction. The edge appears dark because light is refracted away from your eyes.

Vegetable oil and glass have almost the same index of refraction. If you put a glass rod into a glass cup containing vegetable oil, the rod disappears because light is NOT refracted around its edges!



Lenses

A lens and its optical axis

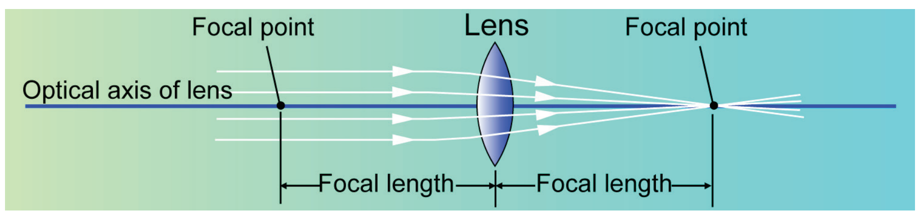
An ordinary lens is a polished, transparent disc, usually made of glass. The surfaces are curved to refract light in a specific way. The exact shape of a lens's surface depends on how strongly and in what way the lens needs to bend light.

How light travels through a converging lens

The most common lenses have surfaces shaped like part of a sphere. Any radius of a sphere is also a normal line to the surface. When light rays fall on a spherical surface from air, they bend *toward* the normal line (Figure 10.21). For a converging lens, the first surface (air to glass) bends light rays toward the normal line. At the second surface (glass to air), the rays bend *away* from the normal line. Because the second surface "tilts" the other way, it also bends rays toward the focal point.

Focal point and focal length

Light rays that enter a converging lens parallel to its axis bend to meet at a point called the *focal point* (see illustration below). Light can go through a lens in either direction so there are always two focal points, one on either side of the lens. The distance from the center of the lens to the focal point is the *focal length*. The focal length is usually (but not always) the same for both focal points of a lens.



Converging and diverging lenses

Figure 10.22 shows how light rays enter and exit two types of lenses. The entering rays are parallel to the optical axis. A *converging lens* bends exiting rays toward the focal point. A *diverging lens* bends the rays outward, away from the focal point.

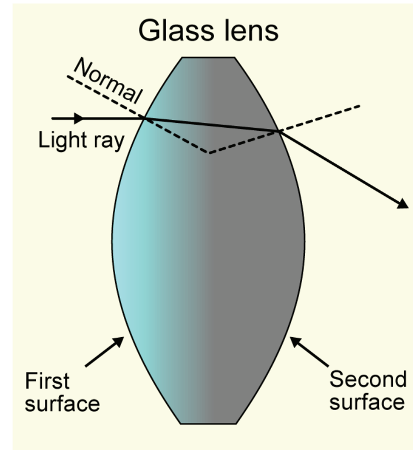


Figure 10.21: *Most lenses have spherically shaped surfaces.*

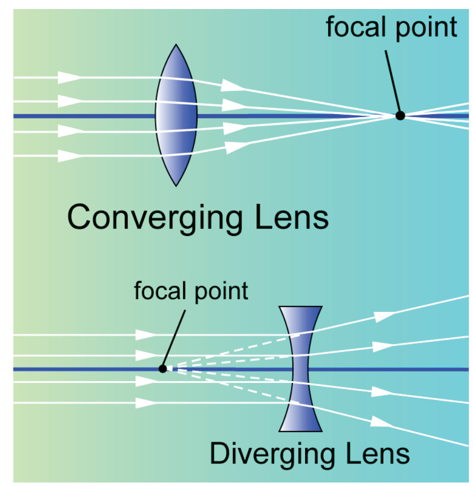


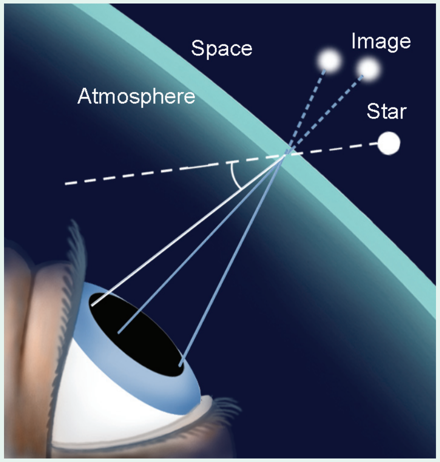
Figure 10.22: *Converging and diverging lenses.*

10.3 Section Review

1. A lens uses what process to deflect light rays passing through it?
   a. reflection
   b. refraction
   c. absorption
   d. transparency
2. Can light be reflected and refracted at the same time? If so, give an example.
3. Make a list of all the optical devices you use on an average day.
4. Name an object that is mostly transparent, one that is translucent, one that is mostly absorbent, and one that is mostly reflective.
5. Windows that look into bathrooms are often translucent instead of transparent. Why?
6. Why can you see your own reflected image in a mirror but not on a dry, painted wall?
7. Why is the true surface of a perfect mirror invisible?
8. The index of refraction determines (pick the best fit)
   a. the color of glass
   b. the ratio of thickness to focal length for a lens
   c. the amount a material bends light rays
   d. whether a material is transparent or translucent
9. A clear plastic rod seems to disappear when it is placed in water. Based on this observation and Table 10.1, predict the index of refraction for the plastic.
10. Fill in the blank. When light travels from water into the air, the refracted light ray bends __________ (away from or toward) the normal line.
11. What is the difference between a converging lens and a diverging lens?

Twinkling of stars

Another example of the refraction of light is the twinkling of a star in the night sky. To reach your eyes, starlight must travel from space through Earth's atmosphere which varies in temperature and density. Cold pockets of air are more dense than warm pockets. Starlight is refracted as it travels through the various air pockets. Since the atmosphere is constantly changing, the amount of refraction also changes. The image of a star appears to "twinkle" or move because the light coming to your eye follows a zig-zag path due to refraction.



Bioluminescence

BIOLOGY CONNECTION

Imagine you could make your hands glow like living flashlights. No more fumbling around for candles when the power goes out! You could read in bed all night, or get a job directing airplanes to their runways.

Although a glowing hand might sound like something from a science fiction movie, many living things can make their own light. On warm summer evenings, fireflies flash signals to attract a mate. A fungus known as "foxfire" glows in decaying wood. While there are only a few kinds of glowing creatures that live on land, about *90 percent* of the animals that live in the deep parts of the ocean make their own light!

Photos by Garth Fletcher

How do they do that?

Almost everything that creates light is made of atoms. If an atom absorbs energy, an electron can move to a higher energy level. When the electron moves back down to its original energy level, the atom could give off visible light.

Atoms can absorb energy from a number of sources. Electrical energy is used in ordinary light bulbs. Mechanical energy can be used, too. Hit two quartz rocks together in a dark room, and you'll see flashes of light as the energized electrons fall back down to lower energy levels and give off light. You can also use the energy from a chemical reaction. When you bend a glow stick, you break a vial inside so that two chemicals can combine. When they react, energy is released and used to make light.

Bioluminescence

Like a glow stick, living things produce their own light using a chemical reaction. We call this process *bioluminescence* (*bio-* means "living" and *luminesce* means "to glow"). Bioluminescence is "cold light" because it doesn't produce a lot of heat. While it takes a lot of energy for a living thing to produce light, almost 100% of the energy becomes visible light. In contrast, only 10 percent of the used by an "incandescent" electric light bulb is converted to visible light. 90 percent of the energy is wasted as heat.

The chemical reaction

Three ingredients are usually needed for a bioluminescent reaction to occur: An organic chemical known as *luciferin*, a source of oxygen, and an enzyme called *luciferase*.

Luciferin and luciferase are categories of chemicals with certain characteristics. Luciferin in a firefly is not exactly the same as the luciferin in "foxfire" fungus. However, both luciferin chemicals are carbon-based and have the ability to give off light under certain conditions.

Firefly light

In a firefly, luciferin and luciferase are stored in special cells in the abdomen called "photocytes." To create light, fireflies push oxygen into the photocytes. When the luciferin and luciferase are exposed to oxygen, they combine with ATP (a chemical source of energy) and magnesium. This chemical reaction drives some of the luciferin electrons into a higher energy state. As they fall back down to their "ground state," energy is given off in the form of visible light.

Why make light?

Living creatures don't have an endless supply of energy. Since it takes a lot of energy to make light, there must be good reasons for doing it.

Fireflies flash their lights in patterns to attract a mate. The lights also warn predators to stay away, because the light-producing chemicals taste bitter. They can also be used as a distress signal, warning others of their species that there is danger nearby. The female of one firefly species has learned to mimic the signal of other types of fireflies. She uses her light to attract males of other species and then she eats them!

It's a little harder to figure out why foxfire fungus glows. Some scientists think that the glow attracts insects that help spread around the fungus spores.

Photo by E. Widder

Bioluminescent ocean creatures use their lights in amazing ways. The deep-sea angler fish has a glowing lure attached to its head. When a smaller fish comes to munch on the lure, it instead is gobbled up by the angler fish.

Comb jellies (shown below) are some of the ocean's most beautiful glowing creatures. When threatened, they release a cloud of bioluminescent particles into the water, temporarily blinding the attacker.

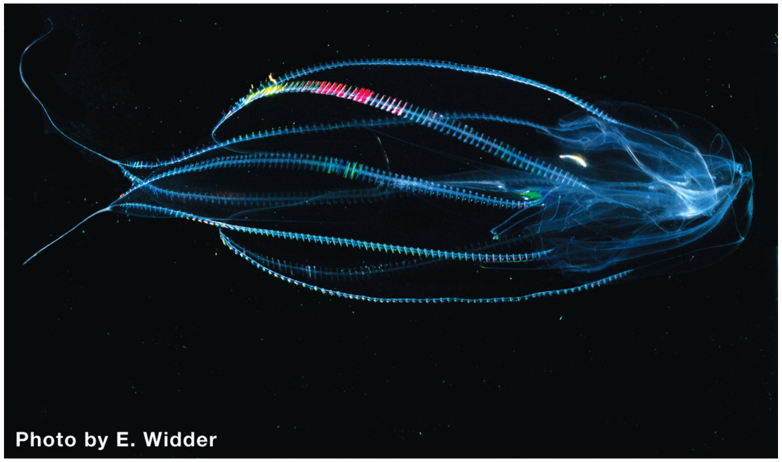


Photo by E. Widder

So far we know that living creatures use bioluminescence to attract mates, to communicate, to find food, and to ward off attackers. Perhaps someday you will be part of a research team that discovers even more uses for bioluminescence.

Questions:

1. Find out more about what is inside a glow stick. Make a poster to explain how glow sticks work, or prepare a demonstration for your classmates
2. Bioluminescence is found in a wide range of living organisms, including bacteria, fungi, insects, crustaceans, and fish. However, no examples have been found among flowering plants, birds, reptiles, amphibians, or mammals. Why do you think this is so?
3. Use the Internet or a library to find out more about bioluminescent sea creatures. Here are some questions to pursue: What is the most common color of light produced? What other colors of bioluminescence have been found?