Activity 5  Producing and Harnessing Light

**GOALS**

In this activity you will:

- Describe the relationship between energy, frequency, and wavelength of electromagnetic radiation.
- Explain how atoms are able to produce light of different colors.
- Contrast fluorescence and phosphorescence.

**What Do You Think?**

If you have any glow-in-the-dark items, such as stars on the ceiling of your bedroom, you know that they keep giving off light after you turn off the lights in your room.

- How are an LED and a glow-in-the-dark item the same? How are they different?

Record your idea about these questions in your *Active Chemistry* log. Be prepared to share your thoughts with your small group and the class.

**Investigate**

For the *Chapter Challenge*, you have to light up an LED at the end of a sequence of steps. Different colors of LEDs have different properties that you will investigate in this activity.

**Part A: Examining Colors of Light**

1. Examine the light produced by a light-bulb (incandescent) lamp through a diffraction grating.
   
a) Use colored pencils to record what you see with the naked eye and through the diffraction grating in your *Active Chemistry* log.
2. You will now investigate the light from at least four LEDs. First, view each LED with the naked eye. Then look at it through the diffraction grating. 

a) Record the color of each LED when viewed with the naked eye and when viewed through the diffraction grating. If your diffraction grating denotes wavelengths, you should record these as well. If not, use this chart to approximate the wavelengths of the light you see.

<table>
<thead>
<tr>
<th>Color of LED</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>660 nm</td>
</tr>
<tr>
<td>Orange</td>
<td>610 nm</td>
</tr>
<tr>
<td>Yellow</td>
<td>587 nm</td>
</tr>
<tr>
<td>Green</td>
<td>555 nm</td>
</tr>
<tr>
<td>Blue</td>
<td>430 nm</td>
</tr>
<tr>
<td>Purple</td>
<td>395 nm</td>
</tr>
</tbody>
</table>

b) Compare and contrast the light from the incandescent bulb and that from the LEDs.


In this part of the activity, you will use the different-colored LEDs as tools to investigate how a glow-in-the-dark star glows.

1. Use a single-hole paper punch to make a hole in the side of a film canister. Place a piece of masking tape over the hole. You will use the canister to isolate a glow-in-the-dark star from the overhead lights. It will allow you to expose the star to only light from the LED. You can remove the masking tape from the hole in the canister to observe the star.

2. Place the star inside the film canister. Keep the lid on the container until the star stops glowing. When you check to see if the star has stopped glowing, make sure that you avoid letting any light into the canister.

3. Once the star has stopped glowing, remove the cap from the canister. Illuminate the star with the LED for one minute. Recap the canister. Remove the masking tape and look at the star.

In your Active Chemistry log, you may wish to use a data table similar to the one shown below to record your data.

<table>
<thead>
<tr>
<th>Color of LED</th>
<th>Wavelength of LED</th>
<th>Did the star glow (phosphoresce)?</th>
<th>How long did the star glow (phosphoresce)?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. As you saw in Part A, the light bulb produces a light with a variety of colors and specific wavelengths. 

a) Which of these wavelengths are responsible for making the star glow?
HOW IS LIGHT PRODUCED?

The Nature of Light

In this activity you examined the colors that make up visible light and used LEDs to investigate a glow-in-the-dark star. Light is a form of energy known as electromagnett radiation. Electromagnetic radiation includes X-rays, ultraviolet (UV) rays, microwaves, and radio waves in addition to visible light. The only thing that makes visible light special is that your eyes can detect it. The electromagnetic spectrum (a list of electromagnetic radiation in order of wavelength) is illustrated in the diagram.

Light can be characterized by its wavelength and its energy. The wavelength of light is the distance between two corresponding points of a wave, for example, from crest (high point) to crest, or from trough (low point) to trough. Wavelength is measured in nanometers (nm). A nanometer is one-billionth of a meter or $1 \times 10^{-9}$ m.

Notice that gamma rays have the shortest wavelength and radio waves have the longest wavelength. The wavelength of radio waves is close to $10^9$ nm (nanometers) or 1 m. Gamma rays have a wavelength of less than 0.1 nm, which is close to the size of an atom.

All waves of light travel at the same speed in a vacuum. This speed is called the speed of light. Technically, light travels at the speed of light only in a vacuum (a space where there is nothing, not even air). However, air slows down light waves only a little, so it’s a good approximation to say that even in air, all light waves travel at the same speed.

Since you can make the approximation that all waves of light travel at the same speed, you can relate the wavelength to another property of light, called frequency. The frequency of light is related to the wavelength of light by the following expression:

$$c = \lambda \times f$$

where $c = \text{speed of light} = 3.00 \times 10^8 \text{ m/s}$

$f = \text{frequency in waves per second}$

$\lambda = \text{wavelength in meters}$

Chem Words

- **electromagnetic radiation:** the energy that travels through space as waves.
- **wavelength:** the distance between two corresponding points on a wave. For instance, from crest to crest or trough to trough.
- **speed of light:** in a vacuum, the speed of light is $3.00 \times 10^8$ m/s (meters per second).
- **frequency:** the number of cycles of a wave that occur in a second.
Remember that you recorded the wavelengths of light using the unit of nanometers. You must be consistent and convert wavelength to meters if you are using the value of the speed of light in meters per second (m/s).

Waves with long wavelengths have relatively low frequencies. Waves with short wavelengths have relatively high frequencies. This relationship is expressed as “frequency and wavelength are inversely related.” This means that as wavelength increases, frequency decreases.

The energy of light is related to the frequency (and wavelength) of the light.

\[
E = h \times f
\]

where \(E\) = energy measured in joules
\(h\) = Planck’s constant = \(6.63 \times 10^{-34}\) J·s
\(f\) = frequency in s\(^{-1}\)

Light that has a long wavelength has less energy than light that has a short wavelength. The wavelengths of visible light range from 700 nm for red to 400 nm for violet. As the wavelength of light becomes shorter, the energy of the light increases. For example, red light has less energy than blue light. This is why the red LED had no effect on the glow-in-the-dark star. The wavelength of light determines if the light has enough energy to interact with the electrons in an atom.
How an Atom Produces Light

The atom is composed of protons, neutrons, and electrons. The protons and neutrons are located in the nucleus of the atom. The electrons exist outside the nucleus in certain allowable states that are called energy levels. The outermost electrons are called the valence electrons. These are the electrons that take part in chemical reactions.

The main idea behind spectroscopy (study of spectra) is that energy is conserved. When an electron absorbs energy it can move from a lower energy level to a higher one. However, the energy that the electron absorbs must be equal to the energy difference between the two levels. Think of the energy levels as the rungs of a ladder. If you only give your foot enough energy to make it halfway between one rung and the next, it is not going to reach the next rung. Instead, your foot will remain on the lower rung. If an electron does not receive enough energy, it will not be promoted to a higher energy level. This happened in Part B when the glow-in-the-dark star was irradiated with red light. The red light did not have enough energy to have any effect on the glow-in-the-dark star.

When an electron absorbs enough energy to be promoted to a higher state, that state is called an excited state, to distinguish it from the ground state where the electron began. The energy that an electron absorbs may come from lots of sources of energy, including heat energy, collisions between particles in the material, chemical reactions, visible light, or even other forms of electromagnetic radiation. The electron, however, cannot remain in the excited state forever. It eventually falls to a lower energy state and gives up energy in the process.

Fluorescence and Phosphorescence

A common process by which light is emitted from atoms or molecules is fluorescence. The process of fluorescence is illustrated in the diagram.

When the LEDs gave off light, they did so by a process of fluorescence. When the glow-in-the-dark star gave off light, it did so by a slightly more
complicated process called **phosphorescence**. In phosphorescence, there is another excited state in between where the electron is first promoted and the ground state. Depending on conditions such as temperature, the electron can temporarily get stuck in this intermediate state. As a result, the emission of light in some cases of phosphorescence is delayed over a period of time, ranging from seconds to hours. This delayed emission of light causes the glow-in-the-dark star to continue to glow long after the source of excitation, in this case the UV LED or the blue LED, is removed.

In the activity, a glow-in-the-dark star was irradiated with red, orange, yellow, green, blue, UV, and white light. Red, yellow, and green light did not do anything to the star because they did not have enough energy to move electrons from their ground state to an excited states. However, when blue or ultraviolet light was used, electrons were excited and the star emitted a green-yellow light. The white LED also caused the star to glow because a small portion of the light that the white LED emits is in the blue portion of the visible spectrum.

### Checking Up

1. Name four kinds of electromagnetic radiation in the electronic spectrum, and order them from shortest wavelength to longest wavelength.
2. What are the colors of visible light, in order from longest wavelength to shortest wavelength?
3. What is the speed of light (in a vacuum)?
4. Are wavelength and frequency directly or indirectly related to each other? Explain.
5. Why did the red LED have no effect on the glow-in-the-dark star, but the blue LED did have an effect?
6. What is the difference between the process of fluorescence and the process of phosphorescence?

### What Do You Think Now?

At the beginning of this activity you were asked:

- How are an LED and a glow-in-the-dark item the same? How are they different?

Now that you have investigated LEDs that produce different colors of light, review your answer. Why would more energy have to be provided to produce blue light as opposed to red light? Why must a glow-in-the-dark object be exposed to light before it will glow?
**Chem Essential Questions**

**What does it mean?**

Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your *Active Chemistry* log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compare and contrast the light given off by a typical light bulb and an LED when observed through a diffraction grating.</td>
<td>Describe the changes that the atoms undergo when they produce light. Explain what determines the color of light that an atom will produce.</td>
<td>Sketch a series of drawings that would illustrate the changes that occur when an atom produces light. Show how you would modify your changes to indicate that light of greater energy is produced.</td>
</tr>
</tbody>
</table>

**How do you know?**

The production of light from an LED is different from the production of light in the glow-in-the-dark star. How are they different? How are they similar?

**Why do you believe?**

When electricity is passed through gaseous samples of different elements, different colors of light are produced. You may have observed this phenomenon in the form of different colored “neon” signs. Use your knowledge from this activity to explain why atoms of different elements would be likely to produce light of different colors.

**Why should you care?**

In your report to the board executives, you will need to explain the chemistry behind how atoms produce light. Take some time now to write down in your *Active Chemistry* log a rough draft of the explanation you will give in your report.

**Reflecting on the Activity and the Challenge**

In this activity you learned that light is composed of different wavelengths. Each wavelength has a specific energy associated with it. If the energy of the light is equal to the difference in energy between two energy levels in an atom or a molecule, it can cause a change to take place. These changes include the emission of light in LEDs and phosphorescence in glow-in-the-dark pigments. You have several colors of LEDs to choose from for the end product of your *Chemical Dominoes* apparatus. The color of LED you choose to use may affect how much energy you must supply to the LED. In the next activity, you will learn how to manipulate the amount of energy a battery produces. You may need to take advantage of some of that information to light your LED.
1. Which color of visible light has a longer wavelength, yellow or green?
2. Which wavelength of visible light is of higher energy: 535 nm or 620 nm? Explain.
3. Calculate the frequency and the energy of light that has a wavelength of 450 nm. Show your work.
4. What evidence is there that the LEDs give off light by a fluorescent process and not a phosphorescent process? Explain.
5. When you exposed the glow-in-the-dark star to blue light, it gave off green light.
   a) Which color of light has less energy, blue or green?
   b) Why was the light given off in the phosphorescent process different in energy than the light that entered originally?
   c) Why is it impossible for an atom to absorb yellow light and give off green light in a phosphorescent process?
6. An electron in an atom moves from the ground state to an excited state when the energy of the electron
   a) decreases b) increases c) remains the same
7. **Preparing for the Chapter Challenge**
   What will you and your group write about the color of light you decide to use in your *Chemical Dominoes* apparatus? Brainstorm a list of concepts with your group members and choose which are most important to you or your presentation.

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**Inquiring Further**

**The spectroscope**

Scientists such as Niels Bohr learned much about the atom using a technique called spectroscopy. Research spectroscopy using the Internet or a college-level chemistry textbook. Ask your teacher for a diffraction grating and use the Internet to build a spectroscope. You can also build a spectroscope using an old music CD. The following reference has an excellent set of directions for making a CD spectroscope—*Journal of Chemical Education*. (Wakabayashi, F.; Hamada, K.; Sone, K.; *J. Chem. Educ.* 1998, 75, 1569). Examine different light sources in your home, in the mall, and in a parking lot. Is light being emitted by a fluorescent or phosphorescent process? Draw the spectra you see. Explain why the spectra you see are different from each other.