Properties of Light

Reference Guide

Equipment Setup

Investigation Guides

C-1 Light and Color

Key Question: What are the properties of light

Light is both a wave and a particle. The wave properties of light include frequency and wavelength. On an atomic level light also shows particle-like properties. A photon is a ‘particle’ of light. Within the visible spectrum, we see different wavelengths of light as different colors. The primary colors are red, green, and blue. Other colors can be made by mixing red, green, and blue. Blue light is more energetic than red light. The Investigation will use photo luminescence to demonstrate the different energy content of red and blue light. A diffraction grating splits light up into its spectrum.

Preparation

Students should be familiar with the Bohr model and the concept of electron energy levels. The idea that light is a photon and a wave is reviewed in the Investigation. The primary color model of light (RGB) is explored. The concept of a spectrum is also developed as students use the diffraction grating glasses to look at the spectra of different light sources.

Setup and Materials

Students work in groups of four to five at tables.

Each group should have:

- light and optics kit: including the three colored LED lamps, the laser, and the diffraction grating glasses.
- Some colored pencils to sketch a spectrum

The Investigation

Time

One class period

Leading Questions

- What creates light?
- How does glow in the dark material work?
- What creates the different colors of light?
- How do we make different colors of light?
- How can we tell what colors of light we are seeing?

Learning Goals

In this Investigation, students will:

- Explore photo luminescence with glow in the dark material,
- Demonstrate that different colors of light carry different amounts of energy,
- Mix red, green, and blue to get different colors of light,
- Use a diffraction grating to break light up into its component colors.

Key Vocabulary

photo luminescence, photon, primary colors, spectrum, color filter, diffraction, diffraction grating, wavelength

Teaching Tip: Introducing the Investigation

Many students are quite fascinated by the glow in the dark material on the back side of the optics table. Try and get a discussion started by asking the students how they think the material works (before you hand out the labs). If the material gives off light there is clearly some energy involved. Where does the energy come from? The energy comes from 'charging up' the material with another light source that contains blue (or shorter wavelength) light. A red lamp will not charge up the material because red light does not have enough energy.

The glow in the dark material gives off green light. You can use the diffraction grating glasses to see that the material gives off only colors with lower energy than green. Green has more energy than red, which is why red light will not charge up the material. Blue light has more energy than green so blue light works. A black light has some UV in its spectrum. Black lights charge up the glow in the dark material even faster than white light because UV light has more energy than blue or violet.

1

Student responses are not required for Part 1.

2

Sample observations

The material glows where the light reached it. The material does not glow where my hand covered it up. It is like the material records the shadow of whatever shape covered it up when the lights were on.

When my hand was left on the glowing material the parts my hand touched glowed brighter that areas my hand did not touch.

C-1 Light and Color

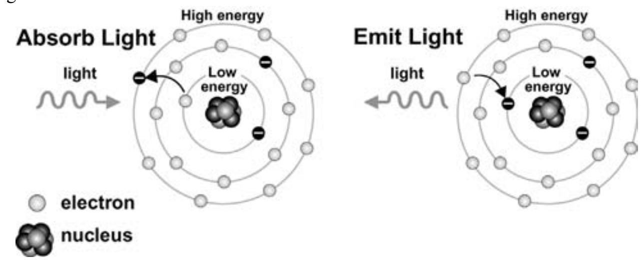
Question: What are the properties of light

In this Investigation, you will:

1. Show that white light can be made from red, green, and blue
2. Observe evidence that light of different colors has different energy content

1 How is light produced

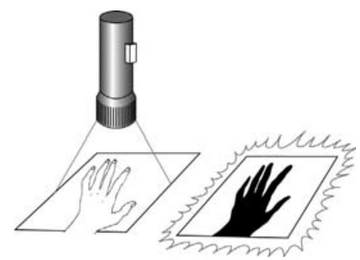
Almost all the light you see is produced by atoms. When atoms absorb energy, electrons rise to higher energy levels. When the electrons fall back to their lower energy state, they may release energy in the form of light.



In some elements it takes time for the energized electrons to fall back and give up their energy. These elements store energy and give off light slowly over a period of time. This is how glow-in-the-dark material works. Embedded in the material are atoms of the element phosphorus. When light energy hits the phosphorus atoms, some of the electrons absorb energy. When the electrons fall back, they release the stored energy and the material glows. The glow stops when all the electrons have returned to the lowest energy level. The process is called **photoluminescence**. The word "photo" means light and the word "luminescence" means glowing.

2 Examine the effects of light on glow-in-the-dark material

1. Uncover the glow- in-the-dark material (on the underside of the optics board) in a darkened room.
2. Cover part of the material and turn the lights back on, or shine a flashlight onto the material.
3. Turn off the light source, remove the covering, and record your observations.
4. Expose the material to light completely uncovered.
5. Turn off the light and wait a minute, then place your hand over part of the material.
6. Remove your hand, and then record your observations.



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3 Recording and analyzing your results

C-1

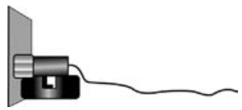
In answering these questions, think in terms of light and energy. Explain what happens to the energy in each of these situations.

a. What happened when the light was not allowed to strike the glow-in-the-dark material? Explain.

b. What happened when your hand was allowed to rest on the glow-in-the-dark material? Explain.

4 Examining the effect of different colors of light

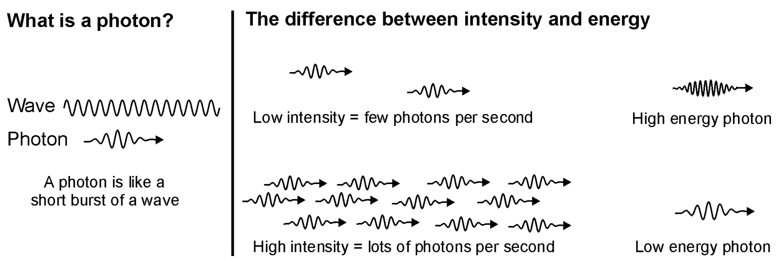
In part 2, you used a source of white light to add energy to the phosphorus atoms in the glow-in-the-dark material. White light is a mixture of all colors of the rainbow. In this section, you will determine what happens when just one color of light is used to add energy to the phosphorus atoms.



1. In a darkened room, allow the glow-in-the-dark material to stop glowing.
2. Switch on the red LED and shine it on the glow-in-the-dark material from a distance of about 10 centimeters. Wait 15 seconds, then take the LED away and record your observations.
3. Try the same experiment again with the red LED 5 centimeters away, then again with the LED held right up against the surface. Decreasing the distance increases the intensity of the light without changing its color.
4. Repeat the procedure with the green LED. Record your observations.
5. Repeat the procedure with the blue LED. Record your observations.

5 The quantum theory of light

A **photon** is a small quantity (like a particle) of light. You can think of a photon like a short packet of a wave. The *intensity* of light describes how many photons per second are produced (or absorbed). The *color* of each photon depends on its energy. Different colors of light are produced by photons with different energies. High energy photons have shorter wavelengths than low energy photons.



In order to glow, an electron in a phosphorus atom must first absorb energy from a photon of light. One of the predictions of the quantum theory is that electrons cannot have any energy, but can have only the specific energies corresponding to the energy levels in a particular atom. That means a photon must have enough energy to boost the electron up one whole level to be absorbed. If the photon does not have enough energy, the electron cannot absorb it and the phosphorus atom cannot glow.

2

3

3a. No light energy could be absorbed by the atoms of phosphorus in places where light was not able to reach the glow in the dark material. Since no light energy was absorbed in these areas, no glow was produced because there was no source of energy to make the light.

3b. Resting my hand on the material made it warmer. The extra energy from the warmth makes the phosphorus glow a little brighter.

4

Sample observations

4.2 The red light does not make the material glow.

4.3 The red light produces no glow no matter how far away it is from the surface.

4.4 The green light produces a very faint glow if you hold it right up to the surface.

4.5 The blue light produces a strong glowing spot. Blue light makes a glow even if it is far from the surface.

5

Student responses are not required for Part 5.

6

6a. Blue light has the highest energy. Red light has the lowest energy. Blue had enough energy to make the phosphorus glow. Red did not have enough energy to make a glow.

6b. The intensity only mattered for the blue light, and a little for the green light. The more intense the blue light, the brighter the glow.

6c. Intensity did not matter for the red light because red photons do not have enough energy to excite electrons in phosphorus atoms to a high enough energy to make a glow. Blue light makes a glow because blue photons have more than enough energy to excite electrons in phosphorus atoms. This supports the quantum theory. If atoms could absorb any energy, the red light would have made a glow too.

6d. Einstein won the Nobel prize for explaining the photoelectric effect.

7

Student responses are not required for Part 7.

8

8a. Mixing red and green makes yellow.

8b. Mixing red and blue makes magenta.

8c. Mixing blue and green makes cyan.

8d. Mixing red, blue, and green equally makes white.

8e. White light makes the phosphorus glow because it contains blue light, which has enough energy.

6 Thinking about what you learned

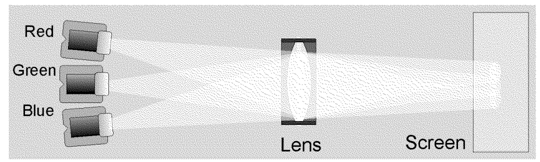
a. Based on the observations you made in part 4, what color light has the highest energy? What color light has the lowest energy? Your answer should state how your observations support your conclusion.

b. Intuitively you might think the more intense you shine the light, the more brightly the phosphorus should glow. Explain how your observations either support or refute this hypothesis.

c. How does what you observed support the quantum theory of light and atoms? HINT: What would have happened if electrons were free to absorb any energy rather than just certain energies?

d. Einstein received the Nobel prize for correctly explaining the results of an experiment much like the one you just did. Find out what Einstein's brilliant insight was and identify the experiment that Einstein correctly explained.

7 Mixing primary colors of light



1. For this Investigation, you will use red, blue, and green LEDs (light emitting diodes). Attach each LED to the power supply and plug in the whole assembly.
2. Place the three LEDs next to each other side by side on one edge of the optics table. Set one of the lenses in the middle. Set the screen at the opposite edge from the LEDs. You should see three spots of color in the screen corresponding to the red, green, and blue LEDs.
3. Move the lens and screen to make the three spots overlap and observe the colors on the screen.

8 Explaining what you see

a. What color do you see when you mix red and green light?

b. What color do you see when you mix red and blue light?

c. What color do you see when you mix blue and green light?

d. What color is produced when all three colors of light are equally mixed?

e. Explain why white light was able to make the phosphorus glow in the dark?

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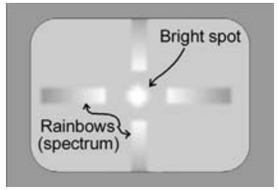
9 **Breaking apart light**



Most of the light we see is made of a mixture of many different colors. The diffraction grating glasses can separate out the different colors. If you look at a bright light through a diffraction grating you see rainbows on all sides. The rainbows spread out all the colors that are present in the light coming through the bright spot in the center. Technically, the rainbows are called a **spectrum**. A spectrum shows what different colors of light make up a particular sample of light.

You have three different sources of colored light. The green light looks green; but just how "pure" is the green? In this part of the Investigation you will examine the light produced by each colored LED, and learn how a **color filter** works. You will use the diffraction glasses to make your observations. The diffraction glasses allow you to see the different colors of the spectrum that a light source produces.

For each observation, look at the spectrum on the sides of the bright LED to observe the mixture of colors.

1. Look at the red LED through the diffraction glasses.
2. Look at the blue LED through the diffraction glasses.
3. Look at the green LED through the diffraction glasses.
4. Unscrew the color filter from one of the color LEDs. Look through the diffraction glasses at the light produced by the white LED.
5. Shine the red laser onto the screen. Look at the spot on the screen through the diffraction glasses. DO NOT LOOK DIRECTLY AT THE LASER BEAM.

10 **Explaining what you see**

a. Describe the similarities and differences you observed in the spectra from the red, blue, and green LEDs. You may want to use colored pencils to sketch the colors in the spectrum.

b. Describe what you saw looking at the white LED. Compare the spectrum from the white LED with the spectra from red, green and blue. You may want to use colored pencils to sketch the colors in the spectrum.

c. Describe what you saw looking at the laser spot. How is the spectrum of the laser different from the red LED?

d. Based on your observations, explain how the colored filters transform the white light of the LEDs inside the lamps into red, green, and blue.

4

9

Sample observations

All three colored lamps will show spectra that have a rainbow of color. The red lamp will show mostly red with almost no blue, but some green and yellow. The green lamp will show a bit of blue and mostly green and yellow. The blue lamp will show blue and green with a bit of red and yellow.

The white lamp will show an even spectrum with blue, red, yellow, and green.

The laser spot will show only a pure red spectrum.

10a. All lamps showed some mixture of colors with the color of the lamp being the widest part of the spectrum. For example, the red lamp had a wide band of red light in its spectrum while the blue lamp had a wider blue band in its spectrum.

10b. The white lamp showed all colors more or less evenly.

10c. The red laser spot showed only red light. This is different from the red LED which had other colors mixed in with red.

10d. The colored filters remove parts of the spectrum from white light to make the color. For example, the blue filter of the blue lamp removes almost all the red and some of the green, allowing mostly blue to pass through.

1. a
2. Not without adding energy some other way. Red light has lower energy than blue light. Phosphorus atoms absorbing one photon of red light would not have enough energy to emit one photon of blue light. In the very unlikely scenario where a phosphorus atom absorbed two red photons, two electrons would gain energy. Neither electron could fall back with enough energy to emit a blue photon.
3. d
4. Red and green in equal amounts make yellow. If there is more red than green you get orange.
5. The blue light source emits photons with higher energy than the red source. The red light source makes more photons per second than the blue light source.
6. The spectrum has almost no blue, only green, yellow, and red. After a 10-15 seconds, the spectrum is almost all green. After a minute the spectrum shows only one pure green color.

   The interpretation is that the phosphorus atoms absorb the blue light and therefore can emit only light with energy lower than blue.

Curriculum Resource Guide: Light and Optics

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