January 2017

Dumpster Optics

WHAT IS A LASER?

HOW DO LASERS WORK AND WHAT MAKES LASER LIGHT DIFFERENT FROM THE LIGHT FROM A FLASHLIGHT? AND WHY IS LASER NEVER SPELLED WITH A "Z"?

The PowerPoint presentation for this lesson has animations that will display in slide show view. Click once to begin the animation for each slide.

MATERIALS

Activity 1 – Flashlight and Laser Beams
- Laser pointer
- Flashlight - old fashioned single bulb kind, or a single white LED
- Meter stick

Activity 2 – Flashlight and Laser Colors
- Laser pointer
- Flashlight
- Recordable CD or purchased diffraction grating

Activity 3 – Blobs and Speckle
- Laser pointer
- Flashlight
- Piece of waxed paper

Where to find materials: Inexpensive red laser pointers can be purchased online or from pet stores where they are sold as "cat teasers". Be careful of lasers purchased on the internet at sites with "awesome" or "wicked" in their names. Some of these are well above the legal output level for laser pointers.

The flashlights need to have a single bulb; multiple bulb LED flashlights won't work. Single bulb LED lights, such as keychain or finger lights, will work. If the only flashlights available have multiple bulbs you can try covering the end with aluminum foil and poking a hole with a pencil over just one of the LEDs.

The CD (or diffraction grating) is used to break light into its rainbow spectrum. There is more information in the instructions below.

VOCABULARY:
- Acronym
- Atom
- Photon
- LASER
- Diameter
- Monochromatic
- Diverge
- Speckle

TEACHER NOTES

LASER SAFETY: Review laser safety before handing out any materials. Laser pointers are generally low power and safe (when bought from a reputable source). Legal laser pointers in the U.S. have a 5 milliwatt output limit. As with any bright light there is always a danger if someone tries to stare into the beam. Remind students that it is not safe to stare at ANY bright lights because they might damage the delicate sensors in their eyes.

Either provide the students with rules or have them come up with their own such as no high sticking (waving the laser around). Make sure students understand the consequences, for example, they will lose the privilege of using a laser pointer. Other important rules are

- Leave the laser on the table.
- Put a book or other block at the far end of the table to keep the beam from entering other students' space.
- Stand when working. Do not bend down when the laser is on so that your eye is at laser level.

THE WORD "LASER" is an acronym for "*Light Amplification by Stimulated Emission of Radiation*", which refers to the way light is produced inside the laser. Acronyms are usually considered to be pronounceable words made of letters (such as NATO or RADAR), but some sources include “initialisms” as acronyms, such as LOL or FBI. Other common acronyms: NASA, NOAA, RADAR, NATO, UNICEF, POTUS, WHO, ZIP (code), OPEC, ASAP, and SCUBA. This site has some acronym worksheets: www.enchantedlearning.com/acronyms/

HOW A LASER MAKES LIGHT Slides 6 through 12 explain on an elementary level how a laser works (loosely based on a delightful laser show animation by Sean "LaserGuy" Kearney). It is assumed that students know what an atom is (and that they don't really have smiley faces!). The other "player" in this explanation is the photon, a "particle" or short burst of light waves. Light has both wave and particle properties, and often we use the particle nature of light when explaining how light interacts with matter and the wave nature when we are describing how light propagates through space. The animation on Slide 6 animation introduces atoms and photons.

There are dozens of different kind of lasers but in general each has three components: a *medium,* a source of *energy,* and a *resonator* or *amplifying cavity*. The medium is the part that has atoms (or molecules) that can be excited by the source of energy. For example, metal ions in a glass rod can be excited by shining light of the right wavelength of light on the material. Semiconductor materials are excited by electricity. Neon in a helium-neon laser is excited by high voltage. In SLIDE 7, the animation illustrates atoms becoming excited when exposed to a source of energy.

Energized atoms usually give off the extra energy quickly in the form of light (or heat). This is illustrated in the Slide 8 animation. An ordinary light source, like a light bulb, produces a range of wavelengths with each photon emitted at random times and heading off in random directions (Slide 9). In a laser, the process of giving off energy is controlled so only a very narrow range of wavelengths is produced. *Stimulated emission*, the SE in LASER, means an atom produces light only when other light of the correct wavelength is present. All light produced this way is identical in wavelength and the waves are “in step” with each other, traveling in the same direction. This is illustrated in the animation in Slide 10.

The laser medium is chosen so it has atoms that stay energized for a while, long enough for stimulated emission to occur. The first photons produced start the chain reaction of stimulated emission. To keep the process going (and amplify the light, or make it brighter) the medium is placed between two mirrors. With each round trip through the medium more and more light is created by stimulated emission. One of the mirrors is "leaky", that is, it lets some of the light escape to form the laser beam (Slide 11). In this way, light of a single color (*monochromatic)* is produced, traveling in the same direction in a tight beam. The activities will reveal more characteristics of laser light.

The activities for this lesson are shown in a video at http://bit.ly/1OmntIq

ACTIVITY 1 – FLASHLIGHT AND LASER BEAMS (Directional)
Be sure the lasers are pointed only at the wall and not at other students! The laser or flashlight should be held steady for measurement. If the output end is at the edge of the table, the table won't block any of the light and the spot will steady on the wall.

The laser spot will be bright and difficult to measure. It may be elongated rather than round. In that case, be sure to measure the same dimension (length or width) from both 1 m and 2 m. The flashlight will probably make a smudgy blob of light with some dark patches. Again, have students decide what to measure and be consistent between the two distances.

Students can decide how to determine how much a beam has spread. One method is to divide the larger diameter (more distant measurement) by the smaller diameter to see how much bigger the spot is when the light source is farther away. The laser should spread very little, the flashlight will spread quite a bit even with a focusing mirror behind the bulb. Divergence means spreading, so what is important is not how large the spot is but how much the spot size changes as the laser or flashlight is moved away from the wall. If there is space in the room, the measurement can be repeated at other distances.

The laser spot will have spread noticeably across the room but not as much as the flashlight. Because laser beams do not diverge much, they have been aimed at the moon where they strike mirrors left there by astronauts. The beams are then reflected back to Earth. Measuring the time for the laser beam to go from Earth to the moon and back allows the distance to the moon to be very accurately measured.

$$\text{Distance} = \text{Speed of light} \times \text{Time}$$

ACTIVITY 2 – FLASHLIGHT AND LASER COLORS (Wavelength)
You will need a diffraction grating to separate light into its component colors. You can make one from an old recordable CD or purchase one from a source like Rainbow

Symphony Store. http://www.rainbowsymphonystore.com

To use a CD: Cut a recordable CD into four pieces using sturdy scissors. You need the kind of CD you can record on; the labels on commercially recorded CDs are too difficult to remove. Round the sharp edges of the pieces. Use tape to remove the metal coating by placing tape on the coating and pulling sharply upward.

Hold the CD or grating about 20 cm above a piece of white paper (or in front of a white wall) and shine the flashlight beam through it. It may be necessary to darken the room so the flashlight spectrum can be seen. It should be a rainbow. Be sure the entire beam goes through the CD. If the flashlight is large, it may be necessary to cover part of the beam so the spectrum is not washed out by light that goes around the CD. The laser will produce several spots but they will be red, no other colors should be seen. Students seem to focus on the number of spots, not the color. You might point out that the flashlight also makes the same number of "spots" but that they are larger and the ones on either side of the center spot are rainbows.

Monochromatic is an "impress your friends" word. It helps to break into its component parts: mono = one, chromatic = color. The laser is monochromatic because of the way its light is made through stimulated emission.

ACTIVITY 3 – BLOBS AND SPECKLE (Coherence)

Coherence is a fairly complicated concept (even for college students) but students will be able to see the result of coherent light in this experiment. You will probably need to dim the lights and hold the laser fairly close to the wall or a white piece of paper (15-20 cm). When spread out by the waxed paper the laser spot will show small bright spots that appear to move as you move your head. The spots are called *laser speckle.* The flashlight spot will show little change except maybe to be smoother. There will be no speckle. There is a photograph of laser speckle in the video demonstration of the activities mentioned above.

The monochromatic waves that make up the laser beam are orderly, they stay "in step" with each other as they travel. This property is called "coherence". You can describe the laser as making coherent light. When coherent light reflects from the wall the waves interfere to create a mottled pattern called *laser speckle.* This will be seen on the wall as a pattern of small bright and dark spots that seem to move as the beam moves. The coherence of laser light allows lasers to be used for applications like making holograms. The flashlight beam will not show any speckle because the chaotic multicolor waves of a flashlight are not coherent.

SUMMARY

These are the three properties of laser light. They arise from the way laser light is produced (stimulated emission in a reflecting cavity):

- laser light travels in a tight beam and does not spread much (small *divergence*)
- laser light is made up of one color (*monochromatic*)
- the waves in a laser beam stay in step as they travel (*coherent*)

OPTIONAL ACTIVITY

With a class of cooperative students you can illustrate spontaneous emission of light ("regular" light source) and stimulated emission of light (laser) with a handful of ping-pong balls. (Or you can just use balled up pieces of paper that won't fly as far.) Tell students that when they are sitting they are in the "ground state" and when energized by a photon (ping pong ball) they are to stand up.

Spontaneous emission – (Start in the "ground state") Toss out a few ping-pong balls. Receiving students stand up (are energized) and immediately toss the ball in a random direction and sit down (back to the non energized state).

Stimulated emission – (Start in the "excited state") Hand out a few balls. "Excited state" students remain standing until a ball passes by, then they toss theirs in the same direction and sit down. You begin the process by tossing a "photon" toward one of the excited students. It takes some practice but students usually enjoy the activity.