ACTIVITY 8

Using Light Sticks to Predict the Effects of Changing Temperature on the Light Emitted by Fireflies

Goal
We will investigate the relationship between temperature and emission of light by light sticks. Then, we will apply the energy band model to explain this relationship

If you live east of the Rocky Mountains, you may enjoy chasing, catching, and putting fireflies in a glass jar during a warm summer evening. Fireflies emit an eerie yellow-green light. Despite the name, "fireflies" do not use fire or heat to emit light. Instead, fireflies convert energy from a chemical reaction into light. Thus, they produce light by chemiluminescence. Because this chemiluminescence occurs in a living organism, the production of light by a firefly is also classified as bioluminescence.

Fireflies, also known as "lightning bugs", emit light from their bellies by using two chemicals called luciferin and luciferase. These chemicals take the chemical energy stored in the firefly's cells and convert it into a yellow-green light.

Near the ocean, we can find bioluminescent sea creatures. The oceans are filled with tiny plants and animals called plankton, which are too small to see with the naked eye. Some plankton also contain luciferin and luciferase. Late at night, the water along parts of the coast will glow with an eerie blue light. If you drag a stick through dark, ocean water, sometimes the plankton will leave a blue glow along the path of the stick.

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In addition to fireflies and plankton, certain types of bacteria[1,2], algae, plants, shrimp, jellyfish[3], shallow sea creatures (for example, flashlight fish and luminous brittle stars), and some deep-sea creatures (such as squid and lantern fish) emit light due to bioluminescence. The great majority of luminescent organisms inhabit the seas, mainly in the deepest parts. Scientists estimate more than 70% of all organisms below 400 meters are luminescent. Some fish become luminescent when they are alarmed and swim away from danger, but do not emit light when they are motionless. Unlike fireflies, some squid emit visible light to become invisible. To fool predators, these squid use light to camouflage themselves by controlling the intensity of emitted light to match the intensity of sun light at their depth.

Underwater researchers have found that hydrothermal vents at the bottom of the sea, like deep sea organisms, emit faint light. Physicists maintain that although some of the light may be created by intense heat, much of it must be attributed to some as-yet-unknown process. Biologists believe that these vents produce enough light for photosynthesis to take place.

Fireflies are not actually flies, but male beetles that produce light in body segments near the end of the abdomen. Fireflies use their flash to attract their female counterparts who cannot fly. For at least one species of firefly, the faster the male flashes, the more likely he is to lure a female.

An organ called a lantern that is found on the underside of the firefly's abdomen produces the flashing light emitted by these male beetles. To produce the light, a chemical reaction takes place in the lantern in which two compounds — luciferin and the enzyme luciferase — react with oxygen.[4] Thus, the firefly's light becomes dimmer when it is trapped in a closed glass jar because the supply of oxygen has been decreased.

Nearly 100% of the energy given off by this chemical reaction appears as light. The firefly controls the intensity of the flashing by controlling the amount of air that is supplied to the lantern organ. A distinct flashing pattern is characteristic of each species of firefly, and is used to attract a mate of its own species.

[1] In March of 1996 after the death of a British Columbia man, a Canadian food inspector cautioned the public not to eat seafood that "glows-in-the-dark" because of some harmful luminescent bacteria that may be found in raw seafood (Kansas City Star, 9/4/96).

[2] Bacterial luminescence provides an inexpensive, direct method of detecting potentially biohazardous materials in water (Thomulka, Peck, & McGee, 1993).

[3] Plant biochemists are experimenting with a protein that causes certain marine creatures, such as the jellyfish, to emit light in the hopes that it can be used to develop luminescent blue plants which may someday provide an early-warning system that will alert farmers to infection and herbivore attack in time for defensive measures. For more info, check out the following web site: http://www.sigmaxi.org/amsci/issues/Sciobs96/Sciobs96-01DavidB.html

[4] The biological mechanism that causes fireflies and other luminescent organisms to "glow" is being used by inspectors to help detect the presence of deadly bacteria in meat and other foods. For more information, see the following web site: http://www.uoguelph.ca/atguelph/95-11-29/orlux.html

Normally we see fireflies on warm summer evenings. In the space provided below, predict what would happen to a firefly's light if the surrounding temperature suddenly becomes very hot. Because you have not yet studied the effects of temperature on chemiluminescence, your prediction will be based on other experiences. Describe those experiences in your explanation.

In the space below, predict what will happen to a firefly's light if the surrounding temperature were suddenly to become very cold. Explain based on any appropriate experience.

Unfortunately, using real fireflies to test your predictions would be difficult. For example, the current season could be in the middle of winter. In scientific investigations, experimenting with biological organisms is not always feasible, practical, or ethical. Instead, scientists often use some similar, non-living system to represent the subject under investigation and then apply the results to the real subject. In this activity, we will use the light stick, which utilizes chemiluminescence to emit light, to act as a model of the firefly. To investigate the effects of changing temperature on the light stick, we will then apply the results to the firefly.

A light stick is made of a sealed plastic tube that contains a solution of fluorescent dye and phenyl oxalate ester. Floating in this solution is a thin glass vial filled with a solution of dilute hydrogen peroxide. (See Figure 8-1.) When the plastic tube is bent enough to break the glass vial, the two solutions mix, react, and give off energy in the form of visible light.

In a previous activity, we observed that a light stick would glow when exposed to UV light even if the light stick were previously activated. This observation provides evidence that the dye found in the light stick is indeed fluorescent and is not "used up" during the chemical reaction that produces the emitted light.

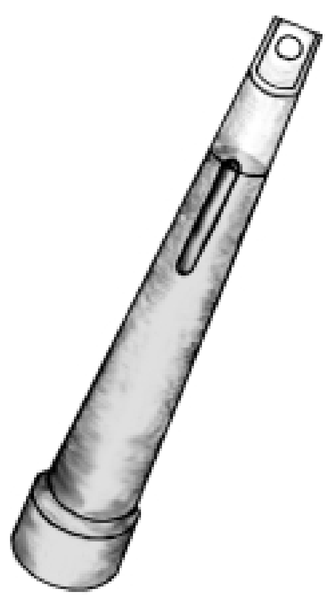

Figure 8-1: Light Stick

To investigate the effects of temperature on the light emitted by light sticks, we will compare light from light sticks at room temperature, placed in warm water, and placed in ice water.

Obtain the following materials: 3 small identical light sticks, 2 beakers, warm water (65°C), ice water (4°C), 3 thermometers, and a watch.

Examine the light sticks and wrappers to be sure that they are identical. They should have identical colors, time for light emission and intensity. (Some will be labeled high intensity; others do not have intensity listed.)

Fill one beaker with warm water (approximately 65°C) and another with ice water til each is about 75% full.

In the space provided below, record room temperature and the temperature of each beaker.

- Take the filled beakers and the other equipment into a darkened room.
- Activate each light stick and note if they are at the same intensity.
- Then place each light stick in the appropriate beaker location and start timing.

Observe the brightness of the light emitted by each light stick for 10 minutes. In the table provided below, record the following during your investigation:

- Any changes in the intensity of light emitted by each light stick.
- The time it takes each light stick to lose its characteristic glow.

Light Stick	**Intensity of Light**	**Duration of Light Emission**
in ice-water (° C)		
at room temperature (° C)		
in warm water (° C)		

After everyone has completed his/her investigations, each group should share its results with the entire class. The resulting discussion should focus on completing the following:

List the 3 light sticks identified by their respective temperatures, in order of brightness. List the dimmest first.

List the 3 light sticks identified by their respective temperatures, in order of duration. List first the light stick which loses its “glow” the fastest.

? With respect to temperature, what is the most effective way to make a light stick glow for the longest period of time?

? With respect to temperature, what is the most effective way to make a light stick glow the brightest?

? Apply the results of this investigation to fireflies. What effect, if any, would changing temperature have on the light emitted by fireflies? Explain.

? What problems, if any, would result in applying these results to fireflies? Explain.

? How could we conduct this investigation with real fireflies? Explain.

In this activity, we found that the temperature affects, not only the intensity of light emitted, but also the duration of light that is emitted by the light stick. The light stick utilizes a chemical reaction to emit light and temperature must have an effect on the rate of this chemical reaction. Recall that a light stick contains two solutions — a dilute hydrogen peroxide solution that is found in the glass vial and a solution that consists of fluorescent dye and phenyl oxalate ester. The ester and hydrogen peroxide react first, producing a reaction that transfers energy to the dye. As a result, the electrons in the dye gain energy. Recall from the previous activity that electrons like to have the lowest possible allowed and available energy. If the electrons gain energy by heat, chemical reactions, mechanical manipulations or any other means they will naturally return to the lowest energy level and lose the gained energy in the form of light. The glow is visible as the electrons in the dye lose energy and return to their lowest possible allowed energy.

The chemical reaction between the dye and the ester cause the dye molecules to gain energy. That energy is then released in the form of visible light. We can apply the energy bands and gaps model to this process.