Experimenting with Phosphorescence

Materials that glow in the dark for an extended period after all sources of excitation are removed are said to be ***phosphorescent.*** For years, phosphorescent paint has been used to make the numerals and hands of mechanical alarm clocks visible in the dark. Phosphorescent tapes and paints are often used so that signs and markers may be seen in dimly illuminated locations. Nowadays, it is not unusual to see the cozy glow of phosphorescent stars and planets on the ceilings and walls of children's bedrooms. Phosphorescent film will allow you to explore the many aspects of phosphorescence.

The Physics of Phosphorescence

Visible light is produced by either of two processes: incandescence or luminescence. Incandescent light sources are hot; luminescent light sources are cool.
The most familiar incandescent source is the standard light bulb. With this common device, light is produced when an electric current heats a metal filament.

Examples of luminescent sources include fluorescent lamps, the fluorescent screens of TV tubes and computer monitors, and phosphorescent materials. Luminescent light sources are often preferred because they are more efficient, producing much less heat than incandescent sources. Luminescence may also result from bioluminescence (fireflies), chemiluminescence (chemical light sticks), and electroluminescence (television screens).

To understand the mechanism responsible for the production of light by luminescent sources one must examine the atom. When an atom absorbs light, an electron moves to a higher energy state. Conversely, when an electron transitions to a lower energy state, light may be emitted. Because atoms have discrete energy levels, the energy absorbed, or emitted, must equal the energy difference between some pair of energy levels. Thus light of only certain wavelengths can be absorbed by or emitted from a given atom.

Fluorescence occurs when the emitted light has a longer wavelength, and therefore less energy, than the light that caused the excitation. This happens when the atom returns to its lowest energy state in stages. Instead of returning to its ground state in one fell swoop, the atom drops via intermediate excited states. This multiple-step decay process may result in a number of photons, or bundles of light, each with a fraction of the energy of the photon that was absorbed.

The fluorescent lamp uses this principle to produce white light. An electric current passes through a tube containing mercury atoms in the form of a vapor. After being excited by the electric current, the mercury atoms decay to their ground state and in the process emit strong ultraviolet light along with some visible light. The ultraviolet light, whose wavelength is too short to seen by human eyes, is absorbed by phosphors that line the walls of the tube. These phosphors then “fluoresce,” re-radiating the absorbed energy as visible light.

When the time required for an atom to decay to a lower energy state is quite long, the emission of light is called phosphorescence. So when asked about the difference between fluorescence and phosphorescence, you can say that it’s just a matter of time.

What is meant by quite long? Well some definitions of phosphorescence require that the emission delay be only 10 nanoseconds (10^{-8} s)! However, when most people think of phosphorescence they think of an object glowing for minutes or even hours.

Inorganic compounds known as phosphors exhibit phosphorescence and are used to produce the variety of colors emitted by devices such as fluorescent lights, television screens and computer monitors. Phosphorescence is quite prevalent in nature. Compounds of calcium, such as calcium chloride, calcium sulfide, and calcium nitrate, phosphoresce. Some plants and animals glow in the dark. This bioluminescent effect is seen in certain types of fungi, insects, and marine organisms.

In the experiments that follow, a sheet of phosphorescent film will enable you to become acquainted with the properties of one of the “coolest lights around!”

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I. Shadow Formation

Materials: sheet of phosphorescent film, camera flash or other bright light source

1. In a darkened room, place your hand on the photosensitive side of a sheet of phosphorescent film.

2. Illuminate your hand and film with a camera flash or other bright light. Notice the beautiful green glow after the light source ceases to shine on the film. This is phosphorescence!

3. With the room lights still off, remove your hand and observe the shadow on the phosphorescent film. Explain why a shadow is produced. Is the shadow sharp? That is, are the edges of the shadow clean or fuzzy? Explain your observation.

4. Keeping the distance between the light source and the phosphorescent film constant, raise your hand to a position above the surface of the film and once again actuate the flash or other light source. Is a shadow of your hand formed this time? Describe the shadow. Is it as sharp as before or are there regions that are only partially darkened? A totally dark region is called the *umbra*. An area only partially shaded by your hand is referred to as the *penumbra*.

5. Find the relative positions of your hand, light source, and phosphorescent film that produce sharpest shadows and those that produce blurriest shadows.

II. Stop Action Shadow Formation

Materials: sheet of phosphorescent film, camera flash and small fan

1. In a darkened room, place a small fan between a sheet of phosphorescent film and the flash unit.

2. With the fan blades spinning, actuate the flash. Examine the resulting shadow on the film. Did the flash "freeze" the motion of the rotating blades?

3 Closely examine the shadow of a single fan blade. Does the blade's shadow have an umbra? a penumbra? Why do you think a region of partial shadow exists?

III. Disappearing Shadows

Materials: a black light or bright white light source, sheet of phosphorescent film

1. In a darkened room, place your hand or other object on the phosphorescent film.

2. Illuminate the phosphorescent film with the light source.

3. Remove your hand but do not turn off the light source. Watch the shadow closely. What do you observe? Explain your observation.

IV. "Chillin' Out:" Temperature and Phosphorescence

Materials: a black light or bright white light source, sheet of phosphorescent film, an ice cube, Ziplock bag or plastic wrap.

1. Enclose an ice cube in plastic. This will prevent damage to the phosphorescent film.

2. In an otherwise darkened room, "charge" up a sheet of phosphorescent film by exposing it to a source of bright light.

3. Place the ice cube on the phosphorescent film and turn off the light source.

4. After four or five minutes, remove the ice cube and compare the relative brightness of the region that was beneath the ice to its surroundings. What do you observe? What does this indicate about the rate at which light is given off by the phosphorescent material in the two regions?

5. Keep your eyes on the phosphorescent film and be ready for a surprise! What changes in brightness do you observe as time passes? Can you explain what is going on?

V. Glow and Afterglow

Materials: a television or computer monitor

The myriad colors produced by a television picture tube are due to the mixing of light from red, blue and green phosphors that coat the inside of the picture screen. A beam of high-speed electrons sweeps across the screen, exciting the phosphors. Most of the phosphors fluoresce, quickly giving up their energy in the form of visible light. However, some atoms phosphoresce, giving up their energy more slowly.

1. Turn on the television in a completely dark room. The bright light you see while the set is on is due to fluorescence.

2. When the television is turned off, you may notice a dim afterglow emanating from the screen. This glow is produced by phosphorescence.
3. As with the phosphorescent film, you can form a shadow of your hand, or other object, on the television screen. In a completely dark room, with the television turned off, place your hand on the glass covering the screen. Now illuminate the screen with a camera flash or black light. When the energizing light source is removed, you will observe a faint shadow on the screen. In this case, light, rather than electrons, are used to excite the phosphors in the screen.

V. Absorbing Science

Materials: sheet of phosphorescent film, bright light source, small colored filters (red, blue, green, cyan, magenta, yellow)

The phosphorescent film produces a greenish light when it is phosphorescing. This means that if the light used to excite the phosphors is less energetic than green light, there will be insufficient energy to produce phosphorescence. That is, red light will not be able to "charge" the phosphorescent film, but green and blue light will.

1. In a darkened room, place the six filters on the surface of the phosphorescent film. It is not necessary that the filters completely cover the phosphorescent film. On the other hand, the filters should not overlap.

Illuminate the filter-covered phosphorescent film with bright light.

2   After the light is off, remove the six filters and examine the film. Can you explain the regions of relative light and dark you see on the film? It may help to remember that a yellow filter passes both red and green light, a cyan filter passes green and blue light, and a magenta filter passes both red and blue light.