Demonstrating Sources of Light and Color

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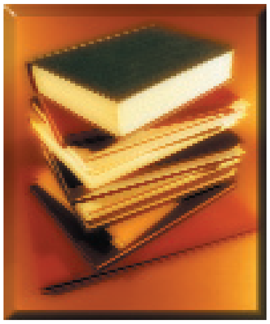

A few years ago at a family day celebration at MIT Lincoln Laboratory, I organized a series of demonstrations designed to awaken the curiosity of people with only a casual understanding of optics. I kept the materials simple, so they could be rounded up readily from home or from an optics lab. In a high tech world it is sometimes fun to present concepts in a low tech manner, and from the rapt attention in the eyes of the viewers at family day they seemed to appreciate it. The demonstrations described below were also given at a national convention of amateur telescope makers. The show was much enjoyed by serious amateurs and their families alike.

Sources of light

First, I demonstrated the obvious, that you can get light out of fire, a candle or a propane torch. I introduced the candle to the audience as one of the earliest sources of artificial light. The torch was used to demonstrate the principle that the hotter the flame, the more blue the light it produces. Fire is a chemical process that gives off heat as well as light, I explained, but some chemical reactions give off light and little or no heat. I mentioned bioluminescence as an example, but had no sample to show. Of course, a light stick is a perfect example of chemical luminescence: if your budget allows, light sticks can be handed out to the audience, a tactic which is guaranteed to stimulate their interest.

Electrical processes, as we know, are another source of light. I mentioned lightning but of course had no sample at hand. I made up for that by showing how to get yellowish light, along with some sizzling sound and steam, out of a dill pickle, which drew laughs of amazement. Two electrodes stuck into the pickle allow 115V ac to be used, with proper resistance in series.

If the room can be completely darkened, one can see light coming from a quartz rock. This result is achieved by banging two quartz rocks together rapidly: the piezoelectric quartz releases light in response to the mechanical force of the impact.

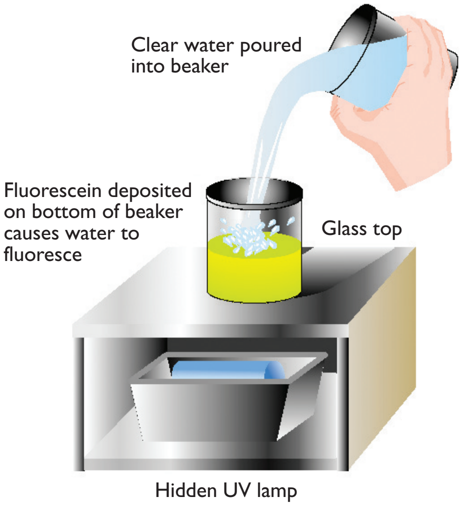

Figure 1.

With a small UV fluorescent lamp, it's an easy matter to show that many objects fluoresce and to explain that this phenomenon occurs when certain materials absorb UV energy and immediately reradiate it as visible energy, and that the process stops as soon as the UV light is turned off. The following fluorescent materials are easily assembled: copy paper, white T-shirt, survey tape, certain minerals, teeth, antifreeze, certain detergents, highlighter pen. I cut out a recognizable pattern from copy paper and stuck it onto a sheet of nonfluorescing white paper. In normal room light the pattern was not obvious but when the UV lamp was turned on, the pattern jumped out.

If fluorescein is available, before the show one could dissolve some in a small amount of water in a beaker and then gently boil all the water off, leaving the fluoroscein stuck to the bottom. Before the audience assembles, the beaker could be placed strategically on a stand under which a hidden UV lamp is turned on. Pour water into the beaker and it magically starts fluorescing (see Fig. 1).

Since a number of people inside and outside the field of optics consider lasers fun, laser light should naturally be the grand finale of the demonstration. Some imagination is required to liven up the demonstration of a low-power laser beam. A few ideas appear below.

Sources of color

Light can be spread into its component colors by making a metal slit of razor blades mounted to a 35-mm slide and using a slide projector to focus the slit on a far wall. I used a double prism in series to get enough dispersion. This is a good talking point for an introduction to the concept of wavelength. With the projected spectrum, one can show that absorption filters subtract colors, leaving a dark band in the spectrum. This is much more dramatic than simply letting the audience look through a filter at a white source. Interference filters reflect what color they do not transmit; this effect can be demonstrated by reflecting the light from the filter onto the ceiling.

It is easy to show how raindrops produce a rainbow by punching a small circular hole in a 2 x 2 in. piece of thin cardboard and projecting it to represent the sun. A large glass sphere placed in the projected light will double refract and reflect the light back toward the projector where the spectral colors can be shown on a white piece of cardboard (see Fig. 2). By placing a black circular stop in front of the

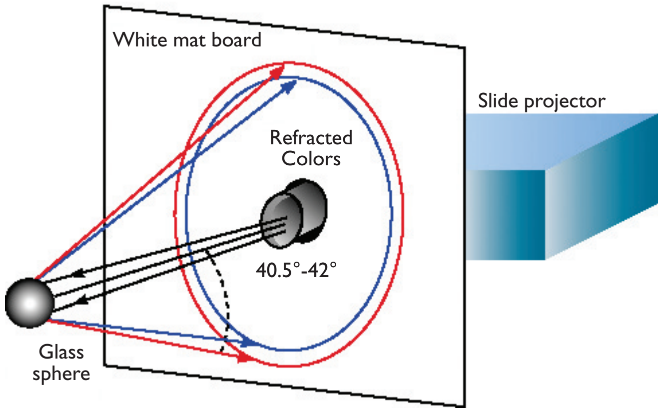

Figure 2.

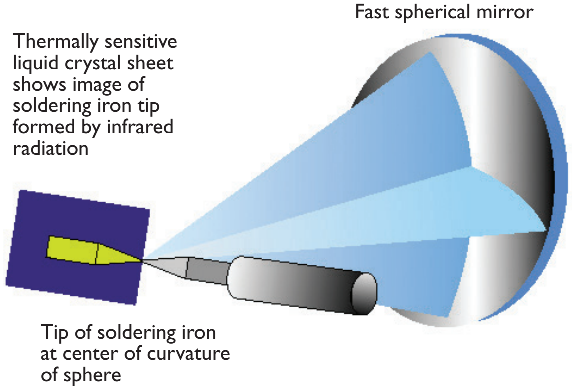

Figure 3.

glass sphere to block its central section, one can demonstrate that only the outer portions of the raindrop contribute to the rainbow.

Before showing how diffraction gratings produce color, I demonstrated the concept of diffraction by shining an unexpanded laser beam through a variable slit to show that the smaller the slit, the larger the diffraction angle. Then I had the audience look at a bright point source: the tiny quartz-halogen bulb on a mini-flashlight, with lens removed, works well. I showed the audience that by placing two fingers close to one eye and gently squeezing on them, they could produce a variable slit and notice how the diffraction images were spread out in various amounts and colors. Next, I passed the unexpanded laser beam through a course grating to show the multiple orders, and by tilting the grating it was easily seen that like the slit, the finer the grating lines, the wider the space between the diffraction orders.

Everyone received a diffraction grating, for example, the sheet sold by Edmund Scientific, the perfect tool with which to show the difference between various lamps—incandescent, sodium, and fluorescent—by pointing out that the incandescent filament lamp gives out a broad spectrum of light in what we call blackbody radiation while the other lamps give out only a small selection of wavelengths. I encouraged the audience to pay attention in the future to the difference between mercury and sodium street lights.

Next I showed them how to make a simple spectroscope to look at the sun's spectrum by placing a slit at one end of a cardboard tube and the grating at the other end. A serviceable slit can be made by taping together two razor blades. Direct sunlight falling on the slit without imaging lenses assures that the spectral lines are not too bright to examine.

At this point I introduced the concept of polarized light by placing two identical colored images on an overhead projector. Each image had a polarizing sheet underneath; these were oriented at right angles to each other so that when a large polarizing sheet was rotated above the images, they darkened out alternately. Everyone received two 2 x 2 in. Edmund polaroid samples, and I encouraged them to be on the lookout for sources of naturally polarized light, such as the blue sky in certain directions from the sun, water reflections at certain angles, LCD watch faces, and of course, rainbows. I demonstrated polarization in rainbows with the glass sphere used earlier, by rotating a polarizer in front of the projector.

Finally, I showed how the reflection of polarized light from a glass surface varies with the incident angle. By projecting a small spot with the slide projector, placing a polarizer after the projection lens, and reflecting the light off an uncoated glass, I showed that at one angle, Brewster's angle, the reflected image on the ceiling disappeared with the proper orientation of the polarizer. I pointed out that this concept was behind the use of polarizing sunglasses to reduce glare.

Even for an audience made up of optics students, explaining birefringence can be a lengthy process; but the resulting colors are a never-ending source of amazement. First, a calcite crystal placed on an overhead projector can show the double refraction which depends on polarization. Next, pieces of mica sliced as thin as possible and glued onto a sheet of glass for easy handling show birefringent colors with a fixed polarizer underneath and one on top which can be rotated. To demonstrate that ice is a birefringent material, I showed slides of ice taken using a polaroid filter with blue sky light as the source of polarized light. Other birefringent materials that work well in the overhead projector are transparent material for making view graphs, Scotch tape montages, and plastic drafting tools.

My final demonstration of birefringence required two large sapphire phase plates placed between crossed polarizers and after the slide projector with no slide in place. A strong negative lens increased the divergence through the phase plates, which increased the size of the stunning colored hyperbolic birefringent patterns produced. This demonstration is sure to "wow" the crowd (see "After Image" in this issue of OPN).

Toward the end of the talk, I threw in some miscellaneous demonstrations which have nothing to do with creating light and color, but can be fun. Transparent materials like glass slow down the speed of light and cause the light to bend at the boundary between the glass and the air at angles other than normal incidence. If the boundary disappears, the glass can be made to disappear. A quartz rod dipped into a glass jar of sugar solution mixed to the proper index easily demonstrates this effect.

Bending at a glass boundary can be shown by sending a laser beam up through a right-angle prism by entering one of the faces and exiting the hypotenuse side, placed horizontally, so the transmitted beam ends up safely on the ceiling. Rotating the prism, it suddenly becomes apparent that the light no longer comes out of the hypotenuse side of the prism but is reflected one hundred percent: total internal reflection (TIR), as we know it.

An application of TIR (upon which, I told the audience, the revolution in optical communication is based) is suggested by filling a vertical 1-in. quartz tube with high-index sugar solution and sending an unexpanded laser beam up through the sealed-off bottom at an angle so it reflects off the internal sides numerous times. Of course, one has to explain that scattering allows the audience to see the beam traveling up through the tube after claiming that TIR keeps it inside.

Next, I placed on a stand a 2-liter soda bottle filled with water and with a small hole drilled on the side and near the bottom but covered over with tape. The unexpanded laser beam was directed diametrically and horizontally through the bottle to hit the tape over the hole. When the tape was removed, the water poured out in a parabolic arc into a transparent catch bucket. The procedure is sure to produce chuckles when the laser light follows the arc and scatters about in the catch bucket. The mineral ulexite has a natural coherent fiber bundle arrangement which can be shown in the overhead projector by placing it on top of text and showing one has to refocus the projector between the text next to the mineral and the image of the text formed at the top of the mineral.

Finally the concept of IR radiation can be explored briefly with two simple demonstrations. First, the radiometer can be made to rotate with the light from the slide projector, a flashlight, and a match. Then, with the slide projector, the radiometer vanes can be made to rotate at different speeds with red, green, and blue filters. The red filter permits the fastest rotation and the blue no rotation at all, demonstrating that there is more energy coming from the lamp in the red than in the blue.

IR imaging can also be demonstrated with a fast spherical mirror and a liquid crystal sheet. Place the tip of a soldering iron near the center of curvature of the sphere so it is imaged tip to tip at 1:1 magnification. Place the most sensitive liquid crystal sheet available over the image. Proper illumination of the liquid crystal sheet will show the image of the soldering iron formed completely by IR radiation (see Fig. 3). Hold a piece of glass between the soldering iron and the mirror and the image dies out. Hold a germanium window in the same place and the image continues to show, even though the audience can see the germanium is opaque.

As you can see, even on a limited budget, a little ingenuity goes a long way. Choosing basic principles of optics and rounding up the simple materials to demonstrate them can be as fun as the presentation is rewarding.

Note: Be sure to take proper eye safety precautions when using UV lamps and lasers.

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