

## Science-1A Lab: Week-7, Wednesday, February 24, 2021

This lab is about optics, the study of how light behaves. We have eyes, use mirrors and lenses, and see rainbows, colors in soap bubbles and in very thin oil on water. Optics is all around us, and Monday's Crash Course videos explained much of that.

### Pig Illusion

I like to start the lab by having a demonstration that the students need to walk past as they enter. It is described at <https://yosemitefoothills.com/Science-1A/Handouts/Week-07/VirtualPig.png>

Two parabolic mirrors are used face-to-face, one with a hole in it, and the other with a small rubber pig at its bottom center. A viewer is convinced that the pig is just above the hole because the mirrors reflect the light from the pig to come out from the hole. This demonstration is simply an optical illusion. The ones the school has are larger than those commonly found on the web. They were marketed as "Hologram" and "Mirage", but are neither.

To understand how it works, you just need to know that a parabolic mirror takes light from infinitely far away and focuses it to a point called its **focal point**. Alternatively, it takes light from its focal point and projects it to infinity. The focal point for the upper mirror is at the center of the bottom mirror, and the focal point for the bottom mirror is at the (missing) center of the upper mirror.

The pig is at the center of the lower mirror so light coming from the illuminated pig image is focused by the upper mirror toward a point infinitely far below the demonstration. That light gets intercepted by the lower mirror and is refocused to the center of the upper mirror's hole. It passes right on through the hole to the person's eye making the person think that the pig is just above the hole in the upper mirror.

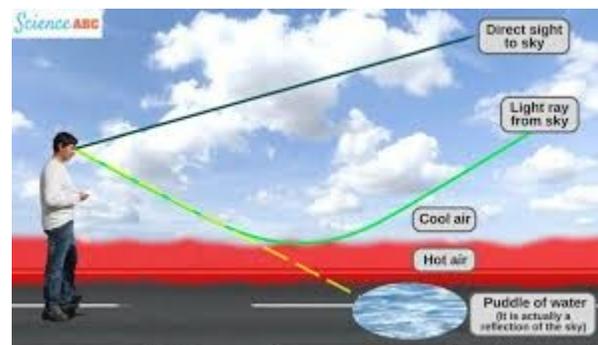
The illusion is so convincing that the observer is tempted to reach out and try to touch the pig only to find nothing is there. Even shining a laser at the image makes it appear to be lit up as if it were actually there.

This demonstration ought to be on every teacher's desk to amaze students get them interested in learning more about optics. If you buy one of these, be aware that the reflective coating is extremely thin and easily damaged by any rubbing when cleaning. It is best to keep fingers from touching the surfaces, and if cleaning is necessary, look if there are cleaning instructions provided with it. If not, try liquid dish soap and water followed by an air dry. Do not rub!

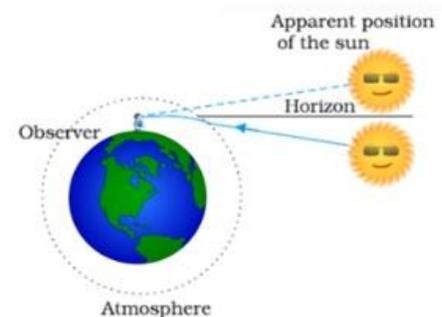
### Mirages and Sunsets

The illustration at the right shows how a mirage works. You have probably driven along a long road on a hot day and looked ahead to see what appears to be blue water on the road (yellow dashed line). What you are seeing is light from the sky that has been bent by the hot air on the road toward your eyes (light green curve). Hot air allows light to travel faster, so we can use Fermat's Principle, discussed on Monday, to understand this.

The light from the sky can get to our eyes by taking a detour down close to the road where the air is hotter and it can travel faster. Going straight to your eye from the sky (dark green line) takes more time than using the detour.



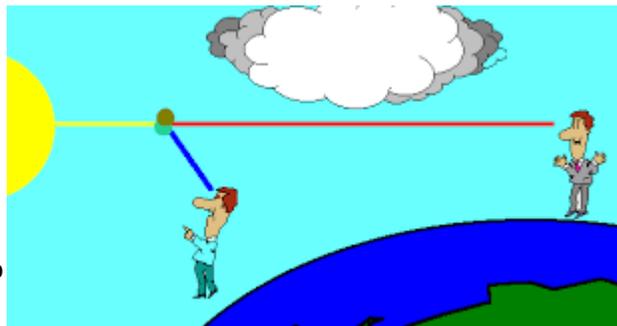
Light travels fastest in the vacuum of space so the sunset shows a similar effect as shown in the illustration at the right. As the sun sets, light from the sun is entering the atmosphere at a glancing angle to get to your eyes. It can get there faster if it spends more of its trip above the atmosphere and then cuts down into the atmosphere to your eye. The result is that even when the sun has actually passed below the horizon, it actually can still appear as if it has not yet set. Variations in the temperature and density of the air also can make the sun appear to split into pieces as it sets.



### Light scattering by the atmosphere

Remember that the sun has a wide range of colors from red to blue which we see together as yellow. Keep this in mind when studying the diagram at the right.

The molecules of the air are far smaller than the wavelength of light, but they can still scatter light because each tiny molecule is a bit like a dipole antenna. Their short size makes them much less effective at intercepting the light waves, but they can still do so.



It turns out that they intercept the shorter-wavelength blue light much better than the longer-wavelength red light. That is basically why the sky is blue. When you look away from the noon sun on a clear day, you see blue light that has been preferentially scattered by the air molecules to your eyes. The red light passes on to be part of a sunrise or sunset somewhere far away.

### Coherent and Incoherent Waves

A large gathering of kids on a playground yelling excitedly as they play produces hundreds of **incoherent** sound waves with frequencies covering audio range. A choir singing a pure note produces a single **coherent** sound wave at a specific frequency.

The sun and hot light bulb filaments produce incoherent electromagnetic waves with a wide range of frequencies centered on that of yellow light, and with random polarizations. Lasers and radio transmitters produce coherent electromagnetic waves at specific frequencies and specific polarizations.

### Circular rings of interference from a laser

A simple demonstration of interference is made by shining a laser beam at a distant white target. In the classroom, I use the whiteboard which is about 8 m distant. Unless I take the time to darken the room by closing the blinds, the spot on the white board is difficult for all to discern. I ask a student to come up close and describe what the spot looks like. They report seeing a spot in the center surrounded by concentric rings that get progressively dimmer as they become larger. The rings have gaps of about 0.5 mm between them, with the largest visible ring being about 1 cm in diameter.

Those rings come about because the laser light passed through a 3 mm diameter hole at the end of the laser. As explained in the Monday video entitled "Light is Waves" (CC 39) light taking slightly different paths can interfere. In this case, light from the center of the laser opening interferes with light from the perimeter of the opening. Over the 8-m length to the white board this slight distance difference is enough to produce alternating constructive and destructive regions surrounding the central spot.

Those rings were quite small, but I then put a copper sheet with an 0.3 mm diameter hole, the smallest size I could drill. That produced rings about 10 times greater in size, but significantly dimmer because most of the laser light was blocked. **A smaller hole produced larger rings!** That is because with a smaller hole, a larger angle is necessary to produce the constructive and destructive path differences.

### Vertical bands of interference from a laser

I next pass the laser light through a narrow slit made using a pair of **horizontal** razor blades. That produced a series of progressively dimmer **vertically-oriented** light regions above and below a central bright spot. The light from the lower part of the razor blade slit was interfering with light from the upper part at multiple wavelength differences to produce the successive bright regions.

### Sending a laser beam through a diffraction grating

A diffraction grating is mentioned 1 min 23 s into the video entitled "Spectral Interference" (CC40). It is a glass plate full of closely-spaced scratches – really closely spaced. Ours in the lab have 600 scratch lines per millimeter. That is a distance between lines of only 1.67  $\mu\text{m}$ , or about 3 wavelengths of green light.

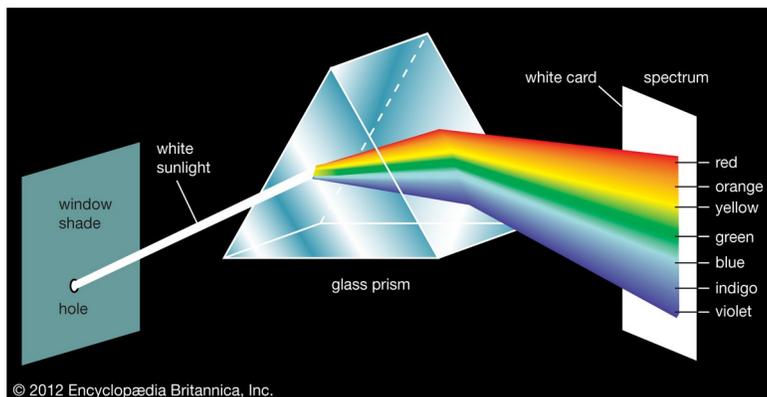
A slit that small produces spots of light at angles of about  $\pm 23$  degree and  $\pm 53$  degrees from the central spot. These are bright spots, because all of the grating lines hit by the laser beam (about 1800) contribute constructively to produce them.

I also pass out diffraction gratings and ask the students to use them to look at a long slit of white light coming from fluorescent lights lighting the long benches at the sides of the lab. When they do so, they see different colored lines offset at angles of between 10 and 30 degrees. These are lines coming from specific changes in the mercury atoms inside the fluorescent lights. The students can also hold the gratings in front of their eyes and look around the room and outside the window to see colors along the edges of various objects.

### Light passing through a glass prism

When I taught a class on the south side of the building, I could place a triangular glass prism in front of the window and cause a beautiful spectrum from the sun to appear on the ceiling. The glass bends different colors (frequencies) of light differently, blue more than red, to produce a spectrum on a screen as shown at the right.

I have done that at home for grand kids who admire the colors, and then hold the prism up to their eyes and parade around the house and outside looking through it.



### Magnifying Glass and Concave "makeup" mirror

I pass around a magnifying glass and a concave makeup mirror. We are all familiar with magnifying glasses, but when you use them with young children, make sure to watch the kids to be sure that don't blind themselves by looking at the sun with it. Just telling them to not do it is likely to not be sufficient; they must be followed. They can also start fires with a magnifying glass because it can concentrate all the sunlight hitting its entire diameter to its small focal point.

From a distance, the makeup mirror shows an upside down image of your face, but when close up, you are right-side up and magnified. The transition point is when your eye is at the focal point of the concave mirror. Those effects can be understood using ray diagrams.

### Clear glass spheres are interesting magnifiers

A glass sphere, like a clear marble, is not a good lens except when looking through its center like when it is placed above letters on a page. Lift it up slightly and you can see the letters magnified, but the image becomes highly distorted as you look near the edge of the marble. I use two sizes of marbles to show that smaller marbles magnify more than larger ones.

The first person to see microscopic animals in pond water was a curious Dutch seller of cloth named Antonie van Leeuwenhoek ( [https://en.wikipedia.org/wiki/Antonie\\_van\\_Leeuwenhoek](https://en.wikipedia.org/wiki/Antonie_van_Leeuwenhoek) ) who inspected his cloth with a microscope he made with a tiny glass sphere. His story, along with many others, are in a great entertaining book on the people that discovered the connection between disease and microbes. It is entitled "Microbe Hunters" by Paul de Kruif. Even though it was written in 1926, it is a classic full of engaging stories of scientific discovery and medical history.

### Interference between two very flat thick plates of glass

I bring out a pair of very thick and extremely flat plates of glass rubber banded together with a hair separating them at one end. The gap between the plates provides a chance for interference between waves hitting the top of the bottom plate and the bottom of the top plate. That produces colored bands of light like are also seen in thin oil slicks on water and in soap bubbles. Even though the plates were very sturdy (about 6 mm thick), a rather gentle pressing on the top one would cause the interference bands to move around indicating that the top plate had been bent and the gap changed by a fraction of a micron of distance.

### Light polarization demonstrations

The lab has sets of polarizers made of stretched plastic where long polymer molecules are aligned so that light passage through them depends on the light polarization. My sunglasses are polarized, so I place them in front of the laser beam. As I rotate them, the laser beam disappears at a particular angle showing that the laser puts out polarized light.

If I set that up so the light is blocked by one polarizer, I can put another polarizer rotated at a 45° angle between the laser and the blocking polarizer. Lo and behold! The laser light reappears. The added polarizer has shifted the polarization of the laser light to a 45° angle so that some of it can then pass through the original polarizer.

### Binocular Camera

When I was in high school, an uncle gave me a binocular camera build in the 1930's. A picture of one is shown on the right. It uses film as all cameras did in those days, but it had two lenses and recorded its pairs of pictures on the film in half-frames. They could then be developed and mounted in cardboard frames that fit into a three dimensional (3D) viewer that has two lenses, one for each eye. I bring that camera and the viewer to the lab along with some slides I took with that camera in the high country of Yosemite and on a 10-week youth hostel trip to Japan in 1967. The pictures are strikingly more satisfying than normal normal pictures.



Long ago, Nature decided that two eyes were more useful than one. Predators can accurately judge the distance to prey with binocular vision, and prey can get a wider view with eyes on opposite sides of their heads.

Our brain amazingly synthesizes the slightly different images from our two eyes into a 3D sensation.

On a side note, experimenters have put goggles on that turn the world upside down. At first, of course they have a great deal of difficulty navigating their world, but after a few days their brains have adjusted and things start seeming almost normal. After a few weeks when the goggles are removed, there is a recovery process where their brains must re-adapt. Fascinating books have been written about the "plasticity" of our brains.

The 3D pictures are a stunning reminder of how much more our eyes enjoy than can be saved in a simple photograph.

25-years ago, I was talking to Gary Demos who had won an Oscar for his technical contributions to the movie industry. I asked why 3D movies never really caught on. He explained that our 3D vision involves our brain blending the visual information from our two eyes, but also subtle information from the muscles that adjust the focal length of the lens in our eyes. Our brain gets confused by the information from our binocular vision that suggests some things are closer or farther away, and contradictory information from our lens muscles that indicate that everything we are looking at is on a flat screen a fixed distance from our eyes. This can lead to headaches and a less than satisfactory 3D sensation.

Many of you now take sequences of pictures that your camera software stitches together into a panorama. The panorama can provide a much more satisfying reminder of why you were so impressed by a particular vista.

What do our eyes miss? We cannot see ultraviolet colors that flowers use to impress insects, or infrared colors that help rattlesnakes see the heat from mice in the dark. We also cannot see polarization. I wonder what our brain would do with such additional information?

### The Raspberry Pi Computer (This will not be tested. It is just me going on about something I love.)

I am deeply in love with a small, inexpensive computer called the Raspberry Pi created for the purpose of low-cost computer science education. When originally produced in 2012, it was intended to improve the quality of entering students to the Cambridge University Computer Science program. It has now sold over 40 million units. Newer versions are powerful enough to run a website like *yosemitefoothills.com* while still allowing web browsing, word processing and image processing. It is being used in classrooms through the world where the cost of other computers is prohibitive.

Long ago when home computers were just making it into the homes of geeks, people had free access to the innards of their computers. Consequently, they did many wonderful and creative things, but during the 1980's a dark shadow crept over the computer world. It became hard to access and do things with computers that were not intended by the manufacturers. It became illegal to figure out how commercial software worked, and information about computer hardware was also restricted.

Normally, a computer manufacturer hides its processor connections from curious owners because it is easy to damage that expensive processor with incorrect usage of its dozens of input/output pins. A specially attractive feature of the Raspberry Pi is that it is so inexpensive, that the risk of damaging it is tolerable to the curious geek. Those pins are therefore available to use for controlling robots and other interesting things. Knowledge about how to avoid damaging them is widely available for the Raspberry Pi.

There are inexpensive cameras sold for use with the Raspberry Pi. I use one as a critter cam to take continuous HD videos of a remote gully to see what various wild animals are doing there. I have taken the lens out of another camera exposing its bare CCD sensor. I then placed that CCD at the focal point of a telescope to make it into a digital telescope that can send images to a projector or even over the web. I bring that one into the Lab and feed its image to a projector aimed at the whiteboard. The class can then see an impressive image of a distant light on a street lamp pole above Willow Avenue.

I use another Pi to monitor the battery voltage and temperature on a solar-panel system. I once blew out the circuit on a digital microscope by accidentally using a power brick providing 9 V instead of the needed 5 V. I then tore out its guts and used a Raspberry Pi and another CCD sensor to fix it. In 2013 when we got a Geiger counter for the lab, I made a Raspberry talk to a microprocessor, and had that microprocessor monitor each click of the Geiger counter. That let me monitor cosmic rays day and night for weeks. The time of each cosmic ray was recorded to within 1 ms, the data then sent from the microprocessor to the Raspberry Pi every few minutes, and eventually put in my main computer for use in classes.

If you are curious about the Raspberry Pi, check out the following:  
<https://www.raspberrypi.org/> and [https://en.wikipedia.org/wiki/Raspberry\\_Pi](https://en.wikipedia.org/wiki/Raspberry_Pi) .

The Linux operating system was created in the 1990's to make available software that could be free and freely modified. I have used Linux ( <https://en.wikipedia.org/wiki/Linux> ) since 1997 in my home computers, and it is also the operating system in my 10 Raspberry Pi's. It costs nothing since it was created by people that felt that software should be freely available. All my lessons are created with free software.

### **Making a Raspberry Computer transmit music to an FM radio receiver**

Computer geeks admire a good "hack" where something is done that elicits admiration among fellow geeks. One of the best hacks (that turns out to actually be illegal) is to make the Raspberry Pi into an FM transmitter. A very clever hacker figured out how to make one of its processor output pins raise and lower its voltage at a frequency in the FM radio band (I use something near 88.5 MHz). A clip of the Star Wars theme music was then used to wiggle that frequency to make it transmit the music to a FM radio receiver. With a little wire antenna on that pin, the music could go 10's or even 100's of meters (That's the part the Federal Communications Commission would be unhappy with.)

### **To earn credit for this lab, report that you have done the following:**

1. Report that you read this note and imagined the demonstrations that are described here. (Too bad I have been unable to show them to you.)
2. Studied the Pig Illusion diagram.