Science-1A Lecture: Week-7, Monday, September 20, 2021

We saw in last Friday's lecture that Maxwell's equations produced a wave of changing electric and magnetic fields that carry energy through the vacuum of space at the speed given by $1/\sqrt{\mu_0 \epsilon_0}$, a speed which matched the measured speed of light. The ether idea had to be discarded, but the true nature of light remained puzzling.

Geometric Optics (CC 38) 9 min 39 s

https://www.youtube.com/watch?v=Oh4m8Ees-3Q&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV

This is way too much information to absorb in 10 minutes. Ignore the math. Just pay attention to the general discussion of how rays reflect off mirrors and pass through water or glass.

I like to stress an idea called Fermat's Principle (*https://en.wikipedia.org/wiki/Fermat%27s_principle*) that light takes the path between two points that requires the least amount of time, although in certain rare circumstances it can travel the path of greatest time. The rule that the angle of incidence equals the angle of reflection actually can be seen to be equivalent to light obeying Fermat's Principle. Any path other than the one with those angles equal will take light longer. Similarly, since light travels more slowly in glass and water, it will take a path that travels more in the quicker air and less in the slower glass or water.

Imagine a lifeguard at her tower on a beach that sees a swimmer in distress in the ocean off to her side. Even though she is an expert swimmer, she can still run faster on the shore than than swim in the water. So she will run most of the way along the shore until close enough to the distressed swimmer, and then go into the water. She is interested in getting to the swimmer in the quickest amount of time rather than take the shorter, straight-line path from her tower to the swimmer. This principle directly leads to Snell's law, but leaves us wondering how light knows which path is the quickest. The answer is subtle and requires an understanding of quantum mechanics. Simply put, light tries all paths at once and cancels itself on all but the quickest path.

Light is Waves (CC 39) 9 min 44 s

https://www.youtube.com/watch?v=IRBfpBPELmE&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV

A flashlight and a coin are too crude to show the spot behind the coin, but a laser can show such effects. I will talk about demonstrations of interference using a laser on Wednesday.

I do not talk about Huygen's Principle, but listen here to get an idea of one way to think about waves.

In lab, I use a laser bought at a hardware store to pass a light beam through small holes and narrow slits to produce circles and bands on the whiteboard 8 m away. That is nicely explained in this video.

Spectral Interference (CC 40) 8 min 24 s

https://www.youtube.com/watch?v=-ob7foUzXaY&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV

This video talks of lots of things we observe in the lab, and some we see in everyday life.

The colored handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-07/PolarizationEffectOnPhotos.png
shows pictures illustrating light from the sky behind trees and light reflected off the surface of a pond.

The images at the left were taken with the filter rotated to allow only horizontally-polarized light to pass to the camera sensor, while the images at the right were taken with the filter rotated 90° so that it blocked horizontally-polarized light. The sky had predominately horizontally polarized light so it is darker in the right image. The sunlight reflected off the pond is also predominately horizontally polarized so in the left image the sun's glare overwhelms the light coming from under the pond surface. In the right image, the vertically-polarized filter blocks that glare allowing the bottom of the pond to be seen.

Polarizing sun glasses are vertically polarized to block glaring reflections off a road and other objects.

Optical Instruments (CC 41) 10 min 35 s

https://www.youtube.com/watch?v=SddBPTcmqOk&list=PL8dPuuaLjXtN0ge7yDk_UA0ldZJdhwkoV

You don't need to worry about the formulas shown for calculating lens magnification.

The discussion of how diffraction affects the resolution of microscopes and telescopes, however, is important.

I like to explain microscopes and telescopes without discussing the eyepieces that usually are used with them. Those are there to help our eyes see the image in those devices, but modern devices use an electronic device called a charge-couple device (CCD) to convert the image to electrical signals. It is the electronic version of the retina at the back of our eyeballs. Enjoy these explanations, but they are more complicated than necessary to understand modern imaging devices.

Pinhole Camera (Camera Obscura)

The illustration at
https://yosemitefoothills.com/Science-1A/Handouts/Week-07/PinholeAndLensOpticalSystems.png
shows a simple camera. Science museums, like at the Griffith Park Observatory 2-miles from where I grew up, often have a dark room with a small opening to let light in from the outside. That light can pass onto a white wall at the back of the room and people there will see the outside action upside down. How that works is shown in this diagram.

Ignoring diffraction effects mentioned at the end of the last video, light from the top of the tree can only go to one point at the bottom of the back wall. Similarly, light from the bottom of the tree is constrained to only go to a place at the top of the wall. Light from each part of the tree will land on a part of the wall the ends up producing an upside down image on the wall.

If the hole is too big, the image will be blurred because the light has greater opportunity to hit nearby places. If the hole is too small, the image is sharp, but very dim. The resolution of the image is the same no matter what the distance is between the pinhole and the back wall. A longer room simply results in a larger image, not a sharper one. Only the size of the hole determines the sharpness of the image.

During an eclipse of the Sun where the Moon blocks out part of the sun, we can damage our eyes by looking at the eclipse. If instead we look at the spots of light under a tree, we will see crescent shapes as the Moon blocks part of the Sun. Those are pinhole images of the sun formed by the small openings between the leaves of the tree.

When I go into our barn on a sunny day, I see little round spots on the floor. They are round even though they might be passing through small, irregularly-shaped holes in the metal roof. Such round spots are also observable when the sun passes through a lace window curtain that blocks most of the sun, but lets some sunbeams pass through. The lighted spots on the floor are usually round, because they are a pictures of the round sun after passing through small odd-shaped openings that act like pinholes.

Adding a lens to a pinhole camera

In the lower image of the pinhole camera page mentioned above, is an improved version that has a glass lens with just the right shape to bend light rays striking off center toward the same spot on the back wall that the light rays going through the center strike. That lets more light illuminate the image since light hitting any part of the lens ends up at the same spot on the wall.

This trick only works for a specific distance from the lens. If the wall is too close or too far away, the image is "out of focus". The pinhole camera had no such restriction. Nature discovered this lens trick as evolution was figuring out how to make better eyes. The result was the eyeball with a lens. If, however, our eyeballs develop to a larger or smaller size than the focal length of our lens, we need to wear corrective lenses. I was in the 6th grade when I first got glasses, and was astounded that we were actually expected to see what the teacher was writing on the board. I really loved my glasses.

Side note: My glasses have helped protect my eyes. In junior high school, I liked to melt lead. My mother was nervous about that and asked me to not used the stove so I used the fireplace with its methane flame. She knew how to raise a scientist and just told me to do that when she was **not** home. Raising curious kids takes a certain amount of faith that no disasters will happen.

One day, I had washed a cast iron ladle and then poured molten lead into it. I instantly learned that even a small amount of residual water will explode when meeting molten lead. That sprayed lead around the fireplace, on a rug and on to my glasses. I got it all cleaned up before my mom got home, but I had become even more pleased that I wore glasses. You might have put something hot like oil into a wet pan on the stove and had a similar exciting experience.

People with impaired vision that don't have their glasses handy, might squint to better see something. That works, because squinting is making the light opening smaller and more like a pinhole camera. When a smaller part of a lens is used, the depth of focus becomes greater. This is an effect well-known to serious photographers that use cameras with adjustable f-numbers (iris openings).

Digital Microscopes and Telescopes

A digital telescope has a **thin lens with a long focal length** passing light from the distant object through the lens to a charge-couple device (CCD) located at its focal point at the far end of a tube. It is just an elongated version of the camera shown at the bottom of the figure mentioned above, but with a long focal length lens, a CCD at the back wall, and the tree or stars very far away.

A digital microscope has a **thick lens with a short focal length**. The tiny subject is placed close to the focal point of the lens and its image is focused to a CCD at the far end of a tube. This is like the telescope, but with a short focal length lens, and the object and CCD reversed.

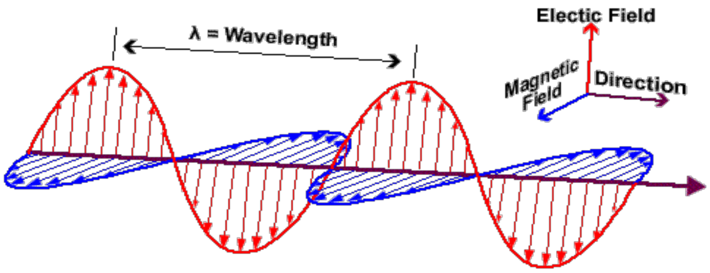
The telescope has a long focal length lens with the CCD near its focal point, while a microscope has a short focal length lens with the object to be viewed very near its focal point.

You cannot look through a telescope backwards and expect it to be a microscope (or vise versa) because they require lenses with a very different focal lengths.

Launching of Electromagnetic Waves

How do radio transmitters launch electromagnetic waves? The process starts with a circuit called an oscillator that produces periodic voltage and current variations using a resonant inductor-capacitor circuit. This is analogous to how a wind instrument produces a periodic pressure wave using a resonant pipe. That wave is then amplified by other circuits and fed to an antenna.

With just the right antenna shape and feed circuits, the antenna can launch electromagnetic waves as shown in the following two animated gif's:
https://yosemitefoothills.com/Science-1A/Chapter_07-Light/DipoleAntenna10.gif
https://yosemitefoothills.com/Science-1A/Chapter_07-Light/DipoleAntenna200.gif
The first runs quickly to give the feeling of how the waves are launched into the surrounding space, and the second is 20 times slower to allow inspection of how the voltage polarities on the two halves of the "split dipole" antenna connect to the electric field. The electric field in the antenna pieces launch the electric field of the wave and the electric currents flowing in those pieces launch the magnetic field of the wave which is not shown in those animations.



The image at the right shows how the electric and magnetic fields look together. The magnetic fields extend toward and away from the observer and loop through the electric field loops.

The direction of the light energy is determined by the relative orientations of the electric and magnetic fields. Notice how the electromagnetic wave is transverse with its electric and magnetic fields pointing perpendicular to the direction of energy flow.

In an electromagnetic wave, the electric and magnetic fields support each other as they claw their way through the vacuum of space. No medium like water or air is needed. The polarization of an electromagnetic wave is defined as the direction of its electric field. The drawing here show a vertically-polarized wave.

Atoms also launch electromagnetic waves, but at frequencies of light, 10^5 times higher than the very high frequencies used by cell phones. Atoms also have electric dipoles that can rapidly reverse under the right conditions, but the way they do that is often hidden within obscure explanations using quantum mechanics. We will discuss that when we discuss the quantum nature of light.