General Physics - E&M (PHY 1308) Lecture Notes

Lecture 022: The Nature of Light

SteveSekula, 12 April 2011 (created 14 November 2010)

no tags

Goals of this lecture

- Explain how four equations describing electricity and magnetism came together to explain the nature of light

What is light?

What is light? This is a question that had troubled thinkers and scientists for a long time before the late 1800s. It is capable of carrying information across great distances - witness the light from our sun, which begins its journey 150 million kilometers away and arrives here on earth, delivering energy. It delights our eyes, which are optical systems sensitivity to a rainbow (literally) of colors. But just what is light?

A thing with a definite speed

Light, whatever its nature, was already observed to travel at a great but finite speed. Galileo Galilei, who lived in Italy in the 1500s and was the first *modern scientist*, wondered whether light, like sound, traveled at a finite speed. He devised an experiment to measure this, in fact, but it failed because he did not appreciate just how fast light moves.

You can measure the speed of sound quite easily, by comparison. Get some air horns, a stopwatch, and a few friends. Put one friend on the steps of Dallas Hall with an air horn, another friend 100m away (just south of the "Dedman College" sign on the Boulevard). Have a third friend stand on a bench by the fountain between the Dedman College sign and Dallas Hall. Friend 3 will signal Friend 1 and 2 by waving their arms wildly. Friend 1 will fire their air horn and you'll start the stopwatch when that horn goes off.

When Friend 2 hears the first air horn, they will fire their horn. By doing this, you make sound do a round trip from Dallas Hall, to a distance 100m away, and back again. You stop timing when you hear the second horn.

Repeat the experiment, moving Friend 2 a distance 200m away from Dallas Hall. By doing this, you correct for reaction time (the time between hearing the first horn and firing the second horn). Knowing the distance the sound must travel, and the time it takes to make the trip, you can easily calculate the speed of sound.

Profs. Olness and Tunks run a "Physics of Musical Instruments" class with a required lab, and in that lab you do this experiment. You may also have the pleasure of watching your TA swarmed by campus cops while conducting the experiment, because apparently noise on a college campus is a serious law enforcement problem these days.

Sound travels at about 300m/s in air. To make the first round trip, it requires 7/10 of a second. Human reaction time is about 2/10 of a second, so it's a big factor in this first trial. In the second trial, sound has to travel 400m and that takes just over a second (1.3 seconds). Assuming that reaction time is the same in both, and that the speed of sound is the same in both, you can actually obtain a speed of sound that is accurate and has a precision of about 5%. Not bad!

Can we do this with light? Galileo tried. In fact, the above experiment with sound is a modern variation on the one he proposed for light. He put people on distant hills and have them lamps. The first person would open their lamp, sending light to the second person. When the second person sees the light from the first, they open their lamp. The first person stops timing the experiment when the light from the second person arrives. Galileo himself has designed very good clocks, something in high demand in his day. However, human reaction time is 2 tenths of a second, while light actually travels at a speed so great that it crosses the distances in Galileo's experiment much too fast. But at the time, he didn't know that. He learned this by failing to succeed in his experiment.

How fast does light travel, and why can't Galileo's experiment work as designed? Light, we now know, travels at a speed of about $3.0 \times 10^{8} \mathrm{m/s}$. The furthest you can see on the earth is about 60 miles, or 100km. Light makes a round trip of 200km in $\sim 0.7 \times 10^{-7}\mathrm{s}$ - far too fast for a human to react with such a simple experiment.

Ole Roemer and Christian Huygens are two scientists credited with determining that light truly travels as a finite speed. A modern interpretation of their work suggests they came within 20% of the correct value. Roemer's work preceded Huygens, and corresponds to a measurement of $2.2 \times 10^8 \mathrm{m/s}$.

The Nature of Sound

Sound is a wave. It occurs when air is compressed by a force, and that compression travels through air. When it strikes the eardrum in the human ear, a series of small bones that can respond to vibration, they cause the bones to shake and that becomes electrical impulses that our brain interprets as "sound". But, regardless of what we hear, sound is just a compression of a medium (air) that travels with a definite speed determined by the mechanical properties of the medium. Sound cannot travel in the absence of air, just as water waves cannot exist without water. All the waves that any scientist had ever encountered up to the late 1800s REQUIRED a medium to travel. The language of waves demanded a medium.

Let's refresh a little on that language. A simple wave is just a variation in amplitude (e.g. air density) that repeats at regular intervals. Such a wave can be described using terms like *period* - the time that passes between similar parts of a wave traveling by you - and *wavelength*, λ - the physical distance between similar parts of a wave.

Using a sine wave as an example, we can easily see the wavelength. The period, T, is just the time it takes for a wave to travel one wavelength - that is, the time for similar parts of the wave to pass you. The *frequency* (f) is just $1/T$, and is the rate at which similar parts of the wave pass you.

The *speed* of a wave is given by distance traveled by the wave in a unit of time. For instance, in one period, T, the wave will travel one *wavelength*. λ. Thus the speed of the wave is given by:

$$v = \lambda/T = \lambda f$$

the product of the wavelength and the frequency.

Sound is fast, but it's not fast enough. For instance, musicians in an orchestra pit have to use two important tools in order to remain synchronized - that is, all be playing at the appropriate times. The first tool is the conductor and the second tool is called "leading the beat". Why do