Lesson 25: Speed of Light

Over hundreds of years, physicists have tried to measure the speed of light.

- This is not an easy task, since it travels so fast that it can cover large distances almost instantly.
- Many of the scientists who tried failed, but with each attempt we learned more and more about how we might be able to do it.

Did you know?
An ancient Greek named Empedocles predicted that light did travel at some speed, he just couldn't measure it. Other people before and after him thought that light traveled at an infinite speed.

Galileo

Galileo performed his own experiment to see if he could measure the speed of light.

- Galileo stood on one hilltop while another person stood on another, both holding covered lanterns.
    - Galileo opened his lantern first.
    - As soon as his assistant saw the light from Galileo, the assistant opened his to shine a light back.
- Galileo hoped that by knowing the distance between the two hilltops and the time it took for the light to travel between them he would be able to calculate the speed of light.

In the end, Galileo realized that the small time difference he measured was probably due to human reaction time and his poor methods to measure time.

- Galileo still believed that the speed of light would someday be measured, just not using his method.

Ole Rømer

About 75 years later a Danish astronomer named Ole Rømer did a pretty good job of measuring the speed of light based on the eclipse of one of Jupiter's moons.

- At certain times, Earth and Jupiter are closer to each other in their orbits… sometimes they are further apart.
- Rømer had noticed that at some times there was a delay in the time he could see Jupiter eclipse one of its moons.
    - The light had to travel the extra distance when Earth was farther away from Jupiter.
- Because Rømer had some rough figures on the distances of the planets in their orbits, he was able to make a rough calculation of the speed of light.
    - By today's standards he was quite far off, but it was the first attempt to measure the speed of light that actually came up with an answer.

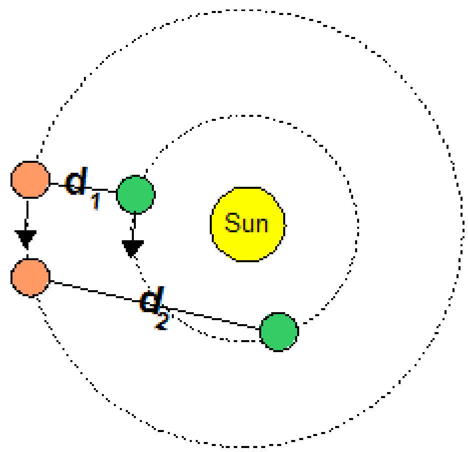

Illustration 1: Because Earth orbits the sun faster than Jupiter, the distance separating them can change quite a bit in only a few months time.

Fizeau & Foucault

By the mid 1800's a French physicist named Armand Fizeau came up with a great way to finally measure the speed of light accurately.

- He shined a narrow, strong beam of light so that it would go in between the teeth of a spinning gear.
    - The light continued on, traveling a long distance of about 8.5km, and hit a mirror and bounced back the way it came.

    - If the gear was spinning with the right period, one tooth of the gear would have had exactly the right amount of time to move in the way of the returning light, blocking it from view. An observer never saw the light this way.
- Fizeau's result was actually very accurate, with only about a 5% error.

A few years later Jean Foucault (another French physicist) refined the method a bit by using spinning mirrors and got an even more accurate measurement.
- A beam of light bounced off of a spinning mirror and headed towards a second stationary mirror about 35 km away.
- When the light bounced back to the first spinning mirror and hit it, the spinning mirror had changed it's angle a bit, so the beam of light bounced off it at an angle.
    - By figuring out how much time it would take for the mirror to have spun that far to create that angle, Foucault was able to accurately measure the speed of light.

Albert A. Michelson

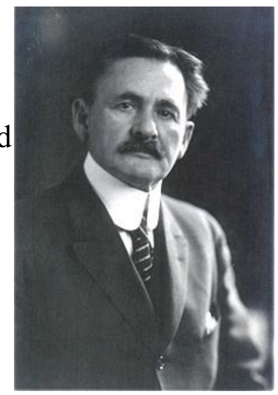

Illustration 2: Albert A. Michelson

Albert A. Michelson used a spinning mirror apparatus that was a better quality version of Foucault's apparatus.
- The reason his method was so accurate is that he used a rotating eight sided mirror.
    - A beam of light hit one of the sides and reflected to a stationary mirror 35 km away on a mountain top.
    - This beam bounced back to the rotating mirror. As long as the rotating mirror has spun exactly 1/8th of a turn, the next side is in the correct position to reflect the light to an observer looking through a telescope.

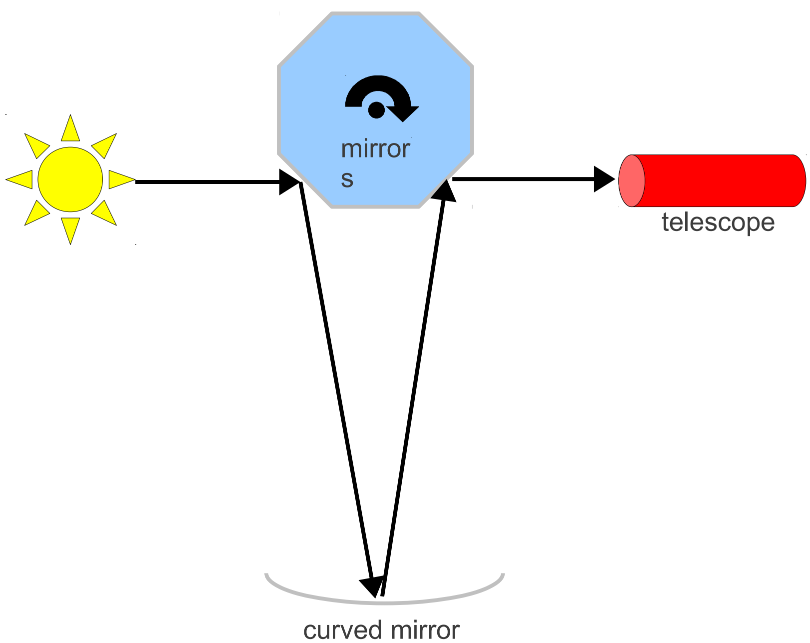

Illustration 3: Michelson's apparatus.

Example 1: When Michelson did his experiment with the curved mirror 35.0 km away, he found that the 8 sided mirror needed to spin at 32 000 rpm. Using this information, **determine** the speed of light.

We need to reduce this to the most basic information that is needed to calculate velocity using the formula...

$$v = \frac{d}{t}$$

The beam of light has to travel 35.0 km to the curved mirror and back, so it actually travels 70.0 km (70.0e3m). Note, the distance from the light source to the 8 sided mirror and from the 8 sided mirror to the observer is so small in comparison that we don't even pay attention to it.

The mirror is spinning at 32 000 rpm, which we will change into a standard measurement of frequency as we learned back in Physics 20...

f = 32 000 rpm ÷ 60 = 533.33 Hz

What we really need is the period of the rotation of the mirrors, since we need the time it takes to spin just 1/8th of the way through a complete revolution.

$$T = \frac{1}{f} = \frac{1}{533.33} = 1.875\text{e-}3\ s$$

But since the mirror only needs to spin 1/8th of the way, we only need 1/8th of this period.

t = 1.875e-3 s ÷ 8 = 2.34375e-4 s

Now we can calculate the velocity.

$$v = \frac{d}{t} = \frac{70\text{e}3}{2.3438\text{e-}4} = 2.98\bar{6}\,e8 = 2.99\text{e}8\ m/s$$

Between the 1880’s and 1920’s Michelson made more and more accurate measurements of the speed of light using this method.

- It was his ability to measure the speed of light so well that won him the Nobel prize in 1907.

Currently the most accurate measurement we have (still using Michelson's method!) is 2.99792458e8 m/s. This value was measured in 1986.

- This measurement is such an accepted standard, that we actually use it to define the metre. The distance a beam of light travels in 1 / 2.99792458e8 seconds is one metre.

Example 2: If the Sun were to blow up right now, **determine** how long it would take before we saw the explosion here on the Earth.

To see it blow up the light from the explosion has to travel from the explosion (at the Sun) to our eyes (here on Earth). On average, the Earth is 1.49e11 m from the sun, so…

$$v = \frac{d}{t}$$

$$c = \frac{d}{t}$$

$$t = \frac{d}{c} = \frac{1.49\text{e}11}{3.00\text{e}8} = 496.\bar{6}\,s = 497\,s = 8.28\,minutes$$

Homework

p650 #1-3 and p652 #1-5,8,9