Modern Physics notes – Spring 2007
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Lecture 28

- The ether (and lack thereof)

- Born, III.1, V.14-15
- Fowler, “The Speed of Light”, “The Michelson-Morley Experiment”

The ether

We’re now going to back in time to the 1890s. We’ll ignore that guy Planck and his strange explanation of black-body radiation. Thus we’re squarely in the realm of classical physics again. In particular, one thing we know is that light is a wave. The reason we know this is that a century of experiments seem to have settled an even older question: is light a wave or particle? Newton thought it was a particle, Huygens a wave. The observation of light refracting and thus bending around corners was most easily described by treating light as a wave. The result which convinced everybody it was a wave came in the early 19th century, when careful experiments showed that with diffraction by a solid circular disc had a maximum at the center.

By the end of the 19th century, people could do incredibly accurate experiments measuring light’s wavelength by an “interferometer”. Remember from our double-slit experiments that one obtains interference between two beams of light when the two travel different distances: constructive interference occurs for $d_1 - d_2 = n\lambda$, and destructive for $d_1 - d_2 = (n + 1/2)\lambda$. What they would do is vary d_1 or d_2 by moving a mirror, and observe the change from constructive to destructive. The wavelength is very small ($\sim 500nm$), so if all they did was observe one change, the result would be very inaccurate. So the clever folk, they would change $d_2 - d_1$ very slowly, and count how many peaks and valleys they went through. So you make some poor student count a few thousand wavelengths, and then measure $d_1 - d_2$, which is now order a millimeter. If the student misses a few peaks, the error is still order 1%. By being extremely careful, they could do much better than that. This was how they measured so accurately the spectral lines associated with various atoms, a crucial part of understanding quantum mechanics.

But before quantum mechanics, many people were interested in using this technology to find the existence of the “ether”. Since light clearly behaves as a wave, an important question is: what is it a wave of? A ripple in water is clearly a disturbance of the water: there is more water in some places, and less in others. Sound is a similar sort of disturbance in air. So what is light a disturbance in? They knew that light from very distant stars still manages to reach earth, and knew that if there was anything between here and the star, it hadn't been (and still hasn't been) seen. But they figured there had to be something there which carries the light, so they named it the ether. So how do you detect it?

In the 19th century people did many experiments to try to detect the ether. The reason you can hope to find the ether is that light has a finite velocity, and people always measured the same one (in a vacuum – it changes in different media, but it was understood how). Light always travels at the speed c in a vacuum, no matter the color, no matter what source, no matter what anything. Thus it was assumed that light had some fixed velocity with respect to this ether. If you were moving with respect to the ether, then you would observe a different velocity. So say that you and the light bulb are moving with respect to the ether with a speed v. Then the light emitted will travel in the ether with speed c. Say the light is traveling in exactly the same direction the ether is moving. You would then measure the light as having speed $c + v$ if the ether is traveling toward you, and $c - v$ if the ether is traveling away. This is observable. Say we put shine light in the direction of our motion with respect to the ether, it bounces off a mirror a distance L away, and comes back. Then this should take a total time

$$\frac{L}{c-v} + \frac{L}{c+v} = \frac{2Lc}{c^2 - v^2}$$

So we measure a longer time than we would have if we were at rest with respect to the ether, where we would have just measured a time $2L/c$.

Thus if we could measure this time difference, we could tell which direction the ether is moving. Since c is so large, this is very difficult, because the difference in the two times not just order v/c (already very small), but order $(v/c)^2$ (really really small). Of course we don't know a priori which direction we're moving with respect to the ether. So the experiment needs to measure how things change when we change our velocity with respect to the ether. One experiment is usually taught to students today, because it is so elegant and simple to understand. It was done with excellent accuracy by Michelson and Morley in the 1890s. This involves interfering light sent at ninety-degree angles. As the whole apparatus is rotated, the interference pattern should change, as the velocities through the ether change. But Michelson and Morley saw no change in the pattern, no matter how they rotated the apparatus (they even waited 6 months, so the earth would be going in the opposite direction).

The way people explained this was "ether drag", that the earth carried the ether along with it as it moved around. But Fizeau did this clever series of experiments of light shining through moving water, and as a result people had to then say that the dragging of the ether wasn't perfect, but there was a coefficient of ether drag. This didn't work either, and so people said that things moving through the ether must get shorter: if the distance shrank then the time elapsed would be the same, and so we would measure no change in distance. It turns out to make this all fit you need to make moving clocks run slower as well.

But all these experiments had one common thread: they never could measure a motion of the earth or anything else relative to the ether. This means they detected no evidence whatsoever for the ether: all these contorted explanations are not designed to explain the ether, but rather to explain why the ether is there but this particular experiment doesn't see it. As Born points out nicely, this means *there is no ether*. If you can't measure it, it ain't there!

Einstein was the first to realize this, and to abandon the ether. He pointed out that no matter how you set it up, everybody measures the same speed of light, no matter whether the source is moving or not. You always (in a vacuum) measure $c = 3.0 \times 10^8\, m/s$. If the source is moving at a velocity v, you do *not* measure velocity $c + v$, you just measure c. Or if you're moving, you still measure c. The consequences of this very simple but strange observation are enormous.