Physics III: Chapter 34 - Notes from the Reading

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This chapter continues from the electromagnetic waves discussed in Chapter 33. For the next few chapters on optics, we'll be focusing on light as an electromagnetic wave. This chapter will begin by discussing the nature of light and early methods for measuring the speed of light. Next, we'll be looking at the phenomena of geometric optics: reflection from a surface and refraction as light crosses the boundary between two media. After all of that, we'll take a look at what's called total internal refraction, which is the basis of operation for things like fiber optic cables. All of this will give us a decent background of knowledge going into Chapter 35, which will take a look at how light interacts with mirrors and lenses.

34.1. The Nature of Light

(Disclaimer: this is a bunch of history, so if you're looking for equations, you gotta skip ahead a little.)

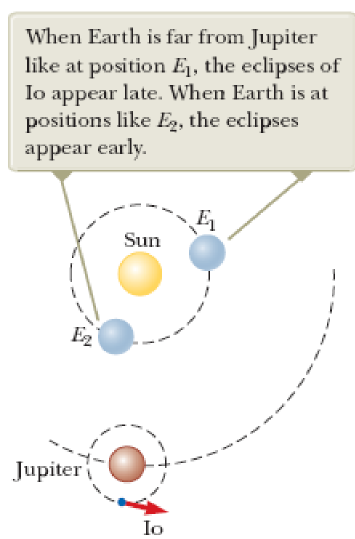
- Before the 19th century, light was just viewed as a stream of particles that was either emitted by an object (like a flashlight or a candle or THE SUN), or emanated from the eyes of the viewer. Basically, Isaac Newton held to the idea that particles emitted from a light source and that these particles simulated our sense of sight. He was mostly correct, but this idea is still incomplete.
- This idea was fine for a while, but another theory arose during his lifetime, one that argued that light might actually be some sort of wave motion. In 1678, Dutch physicist Christiaan Huygens showed that a wave model of light could also explain how light reflects of surfaces and refracts through things like glass or water.
- Fast-forwarding a bit to 1801, Thomas Young gave the first clear experimental demonstration of the wave nature of light. He showed that under the right conditions, light rays interfere with each other according to the waves in interference model, just like mechanical waves. This idea could've never been reached with the particle model of light, because the idea that two particles could come together and cancel each other out was inconceivable. Throughout the 19th century, the light-wave model became the dominant idea, and one of the most important developments in this model was from the work of Maxwell, who asserted that light was a form of high-frequency electromagnetic wave.
- However, in the 20th century, scientists found out that Newton was also right! Light also bears a particle nature under certain conditions. For this chapter, we'll just be looking at the wave nature of light.

- For a while, it was effectively impossible to examine the speed of light in any laboratory. While there were efforts, many of them, like those of Galileo, who had hypothesized that by placing two lamps approximately 10km apart from each other, one would shutter one lantern for the other to shutter their lantern when they see the change, were inconclusive. However, there were a couple that were successful, and we'll be taking a look at those.

Roemer's Method

- In 1675, Danish astronomer Ole Roemer made observations that led to the first conclusive estimate of the speed of light. His technique involved observing Io, one of Jupiter's moons. Io takes about 42.5 hours to orbit Jupiter.
- An observer using Io as a basis for a clock would expect it to consistently orbit around Jupiter in 42.5 hours. However, over the course of a year, Roemer noticed that the orbital period varied. He found that eclipses of Io were later than expected when the Earth was at position E_1 on the figure, and was earlier when at position E_2 on the figure.
- Roemer concluded that this had to be due to the speed that light travels.

Figure 34.1

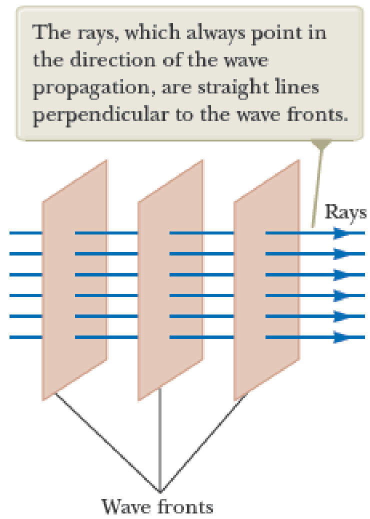


- Using Roemer's data, Huygens estimated the lower limit of the speed of light to be $2.3 \times 10^8 m/s$. This experiment showed that light has a finite speed, a historical discovery.

34.2. The Ray Approximation in Ray Optics

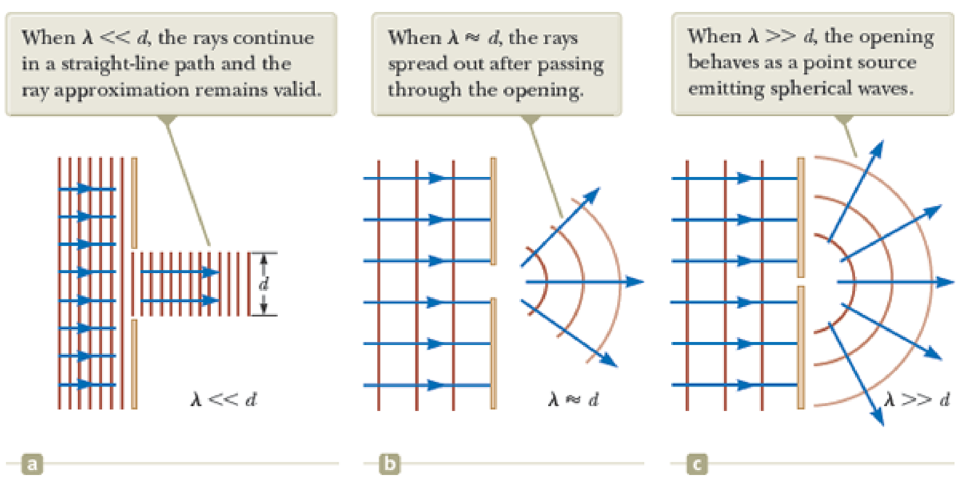
Ray optics (sometimes called geometric optics) involves studying how light propagates. Ray optics assumes that light travels in a fixed direction, in a straight line, and it **stays in the same direction** if a medium it passes through is uniform until it meets a surface. At which point, it'll change directions.

Figure 34.3



Basically, light-waves actually travel in a spherical fashion, but it'a very difficult to calculate this. For simplicity's sake, we can approximate it as a straight line (assuming that we're looking at the light from very far away). The rays represent the direction that the wave fronts are going. And the wave fronts represent the spherical wave itself.

Figure 34.4



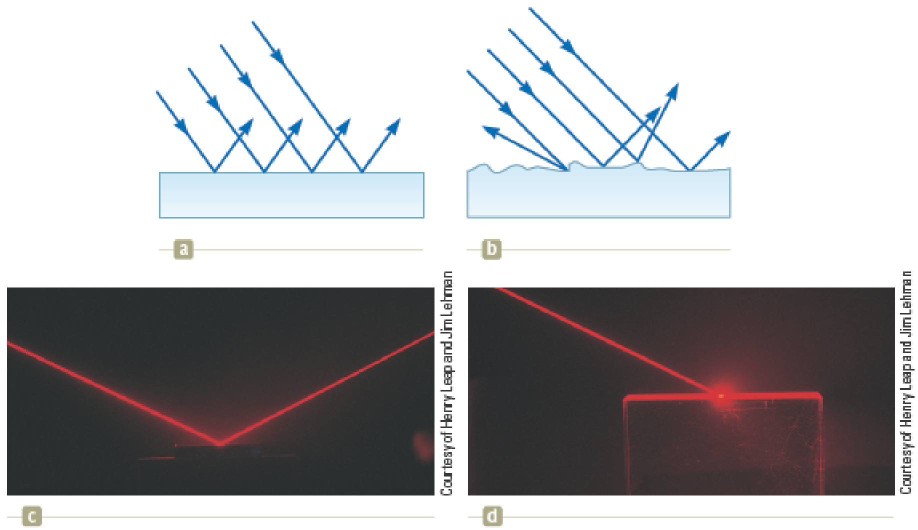
34.3. Analysis Model: Wave Under Reflection

Here are some key terms for reflection:

- **Specular reflection**: reflection of light from a smooth surface
- **Diffuse reflection**: reflection from any rough surface

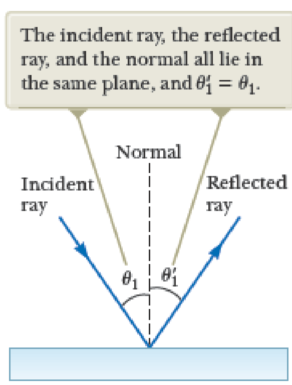
Figure 34.5

Schematic representation of (a) specular reflection, where reflected rays are parallel to one another, and (b) diffuse reflection, where light is traveling in a bunch of random directions, and then you have photographs to correspond with each.



- **The law of reflection** - the angle of reflection is equal to the angle of incidence: $\theta_1' = \theta_1$
- Because the reflection of waves is so common, there's a visual model for this.

Figure 34.6



34.4. Analysis Model: Wave Under Refraction

- **Refraction:** how light changes as it travels through different mediums. This can be changed in both angle and speed. Ever put a straw into a glass of water and you noticed it looked funky in the water? That's because of refraction.
- There are always three components to refraction: the incident ray (going through the first medium toward the second medium), the refracted ray (going through the second medium from the first medium), and the weak reflected ray (part of the ray that dissipates when refraction occurs).

- In order to observe the angles and speeds of the different rays, we use what's called a "normal line," which is always going to be perpendicular to the plane of intersection.
- The **angle of refraction** is always going to depend on the material of the second medium (what the light is moving toward), and the angle also determines the speed.

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

- To put it simply, angle going toward normal line = it slows down after refraction, angle going away from normal line = faster after refraction.

Index of Refraction

Generally speaking, light is going to travel slower in every material that is not a vacuum. However, the speed traveled in air is so close to that of a vacuum that in most cases, we can just approximate it as the same as in a vacuum. We can pull from what's called an **index of refraction**, which is abbreviated as n.

$$n \equiv \frac{c}{v}$$

where c is the speed of light in a vacuum, and v is the speed of light through the medium. There's also a very convenient table of indices of refraction for different materials.

Substance	Indices of Refraction
Solids at 20℃	
Cubic zirconia	2.20
Diamond (C)	2.419
Fluorite (CaF_2)	1.434
Fused quartz (SiO_2)	1.458
Gallium phosphide	3.50
Glass, crown	1.52
Glass, flint	1.66
Ice (H_2O)	1.309
Polystyrene	1.49
Sodium chloride ($NaCl$)	1.544
Liquids at 20℃	
Benzene	1.501
Carbon disulfide	1.628
Carbon tetrachloride	1.461
Ethyl alcohol	1.361
Glycerin	1.473

34.5. Huygens' Principle

Huygens' Principle Applied to Reflection and Refraction

- One important equation to remember is Snell's law of refraction:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2,$$

which is just a rewrite of the equation for the angle of refraction, and we can verify that real quick.

- First, we start with the angle of refraction equation:

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

- We also take note of the index of refraction equation:

$$n = \frac{c}{v}$$

- Rearranging the equation, taking n_1 and n_2, we get $v_1 = c/n_1$ and $v_2 = c/n_2$.
- Now, we can plug these into the angle of refraction equation to get

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{c/n_2}{c/n_1} = \frac{n_1}{n_2}$$

- Doing a bit of algebra magic, we're left with

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

34.6. Dispersion

34.7. Total Internal Reflection

Optical Fibers