Lesson 23: Models of Electromagnetic Radiation

Scientists spend a lot of time coming up with, refining, and sometimes disproving models of natural phenomena.

- Light is a great example of just how much competing models can divide the scientific community, but also allow us to eventually understand the universe much better.
- The models that are discussed here, and the people that came up with them, will be coming up in later lessons when we need to look at the details of their work.

Historically, there were two competing models of light:

- **Particle** (or **corpuscular**) model: light is made up of small particles of actual stuff.
- **Wave** model: light is made up of some kind of wave.

Particle Model of Light

The particle model of light was the one that Sir Isaac Newton believed in.

- Because Newton believed in it, his influence in the scientific community forced many people to follow a particle model of light even when other evidence seemed to show it could be wrong.

Newton did have good reasons to believe that light was a particle...

1. **Light travels in straight lines.**
   If light is a particle then it will not be able to ***diffract*** after going through an opening or around an obstacle. Particles always move in straight lines, and light seems to move in straight lines. When you shine a bright light on a person you expect to see a shadow on the ground, not light bending around the person to fill in all the ground behind them with light.
2. **Light can be reflected.**
   Light can reflect off of surfaces, just like a ball bouncing off. Kind of a lame reason, since waves can reflect also.
3. **Light can travel through a vacuum.**
   In Newton's time, the only waves that anybody knew about were **mechanical waves**, which need a substance (a medium) to move through (e.g. sound travels through air). Since they had a pretty good idea in Newton's time that the space between the Earth and the Sun was a vacuum, how could light ***waves*** reach Earth? Light ***particles*** would have no trouble moving through a vacuum.

Diffraction is the property of waves that allows them to go around an obstacle or through a small opening, and then go back to looking like normal. For example, if a water wave hits a pole sticking out of the water, the waves might leave a small gap directly behind the pole, but eventually fill in the gap like it was never there.

Wave Model of Light

Eventually the work of some scientists seemed to point out that there were aspects of light that could be explained more clearly using a wave model.

- Each of these scientists did great work, but until Newton died it was difficult to get anyone to even listen to evidence of light that disagreed with the particle model.

Christiaan Huygens

> **Did You Know?**
> Huygens was a strong believer in the existence of life on other planets. Towards the end of his life he wrote a book called Cosmostheoros in which he described animal and plant life on other planets in detail.

Christiaan Huygens was a Dutch physicist who believed that a wave model was better at explaining the properties of light. He focused most of his attack on Newton's particle model concerning the idea of light traveling in straight lines.

- If he could show that light would diffract when it passed through openings or around obstacles, it would prove that light was behaving like a wave.
- He looked at the work of Francesco Grimaldi, who had shown the edges of shadows are ***not*** perfectly sharp.
  - If light was a **particle** they should be sharp. It would be like shooting spray paint at an object in front of a sheet of paper; you get a sharp image from particles that get past.
  - We can explain the fuzziness that that ***does*** happen around the edges of shadows as the diffraction of the **waves** partly around the object.
- Huygens also used the observation of the Poisson Spot as evidence that light was able to diffract around obstacles.
  - Siméon Poisson had predicted that if the wave model was true, light should sometimes be able to diffract around a disc and make a bright spot in the centre of the shadow. He thought this was impossible to see, and used it as a way to fight ***against*** the wave model.
  - When Dominique Arago actually produced this effect, Poisson looked like an idiot and they named the spot they saw after him as a joke.

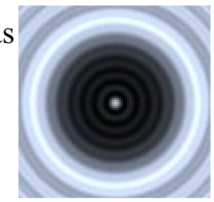

Illustration 1: The Poisson Spot.

Huygens developed these idea further in order to explain the diffraction of light waves around obstacles or through openings.

- He said we should imagine the crest of a wave as being made up of an infinite number of tiny waves, which he called **wavelets**.
- As these wavelets pass through an opening or an obstacle they will begin to spread out again… this is what leads to diffraction of waves.

There was still resistance to Huygen's theories, but he came up with a separate argument that would seem to indicate that the particle model was simply wrong.

- When **incident** light hits the boundary between two media (like air and water) part of the light is **transmitted**, while part of it is **reflected** (*Illustration 2*).
- Using a wave model of light Huygens was able to show that waves could do this. If you measure the amount of light reflected and the amount that was transmitted, it adds up to the incident wave.
- When Newton was asked to explain this using his **particle** model of light, he came up with an… ahem... *odd* answer.
  - He said that when light particles reach the surface, they have "fits" (just like when you had a fit when you were 3 years old and you didn't get what you wanted). Some of the particles "decide" to go into the water, while the rest "decide" to bounce off.
  - Given that this is such a pathetic response, Newton basically lost any remaining support that he had for his particle model of light.

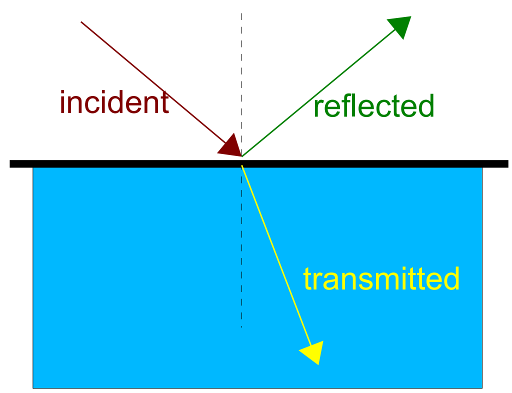

Illustration 2: Light at the boundary between air and water.

Thomas Young

In 1801 the British scientist Thomas Young set up an experiment to show that when light passes through two slits in a screen, the light will interfere on the other side just as waves should.

- We will examine this "Double Slit" experiment in detail in Lesson 30.
- At the time, this seemed to be a final undeniable piece of evidence to show that light was a wave.
- The wave model of light became the standard way of explaining light for about the next 100 years.

Wave-Particle Duality

It might seem that with all this evidence we are at the end of studying light and have everything tied up neatly.

- Instead, physicists found a problem when they tried to describe something called Blackbody Radiation (covered in detail in Lesson 32).
  - Max Planck was able to come up with a solution as long as he assumed that energy came in little pieces, called **quanta**.
- This led Albert Einstein (yup, the big guns are coming out now) to come up with a theory that joined the idea of quanta to an explanation of light.
  - This meant the light came in little pieces (yikes, particles!) that were named **photons**.

Quanta is the plural form of quantum, an individual piece of energy. This became the basis of the branch of physics called Quantum Mechanics, the subject of the next chapter in Physics 30.

So, we have a big problem.

- Guys like Huygens and Young had shown definite proof that light was a wave.
- Planck and Einstein showed that light must be a particle.

It seems as though one must be right, and the other wrong.

- This is in fact a bias of Western thought.
  - We always try to divide things into opposites; left-right, up-down, right-wrong, black-white.
  - Is there a reason to think that this is the way nature must work? Nope.
- Many Eastern philosophies are based on the idea of mixing seemingly opposite ideas together, like Ying and Yang.
  - In this way of thinking, light can be a wave and a particle.
  - How we choose to measure it will reveal one or the other.
  - Both aspects (wave and particle) make up light at the same time.

Illustration 3: The concept of Ying and Yang is a classic Chinese idea that nothing is entirely one thing... there is always a bit of the opposite included.

This leads us to the current way of describing light, the model known as **Wave-Particle Duality**.

- In the following lessons, we will sometimes use the wave model to explain what we are seeing, and sometimes the particle model.

Still having a hard time with this? Think of this example. At school everyone thinks of me as "Mr.Clintberg the physics teacher." But when I go home my kids see me as "daddy." I am not one of these, I am both of them. It just depends on who the observer is (a student or my kids) that determines how I am "measured."