Particle Theory vs. Wave Theory

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What is light? Is it a particle or a wave? What were the different experiments that helped derive the conclusion of the 150-year debate between Newton and Hooke, and how exactly did they prove it? Your questions are about to be answered. Let's dive into some of the more complicated subjects of Optics.

Prism dispersion

Is white light the purest light? By using a transparent triangular prism, you can break down white light into different colors.

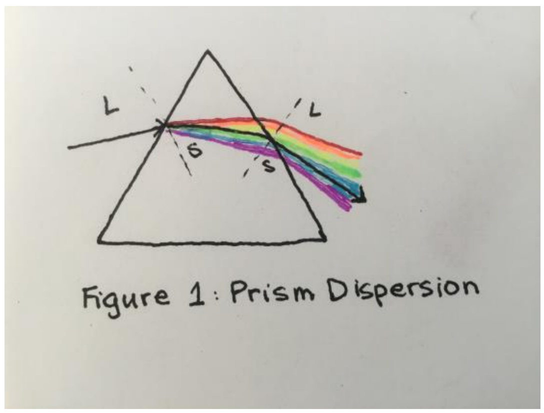


Figure 1: Prism Dispersion

As shown in the figures, violet light bends more than red light. This is because the index of refraction for violet light in glass (n = 1.53) is bigger than the index of refraction for red light (n = 1.51), so violet light travels slower and bends more severely.

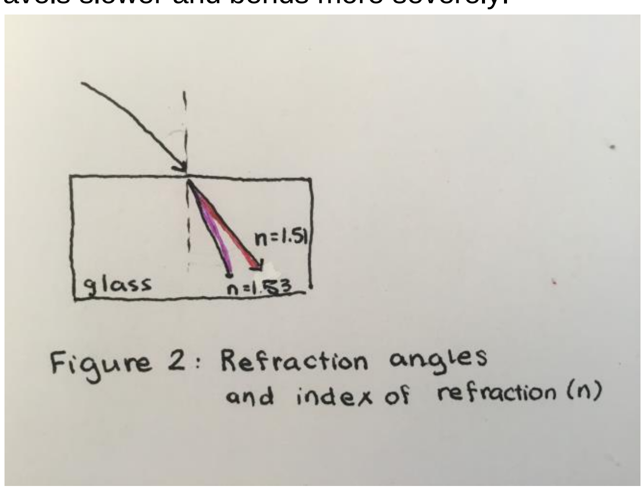


Figure 2: Refraction angles and index of refraction

Newton's findings of light dispersion include that if you place two prisms at opposite orientations, the first prism can decompose white light into different colors, then the second prism can recombine them into white light again.

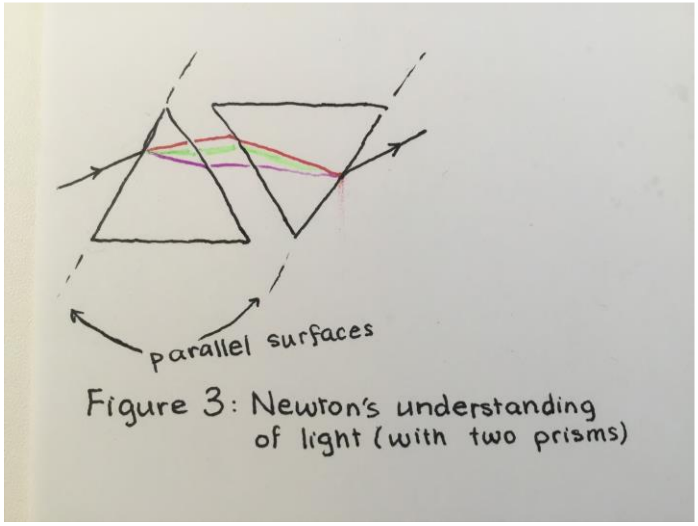


Figure 3: Newton's findings of light dispersion

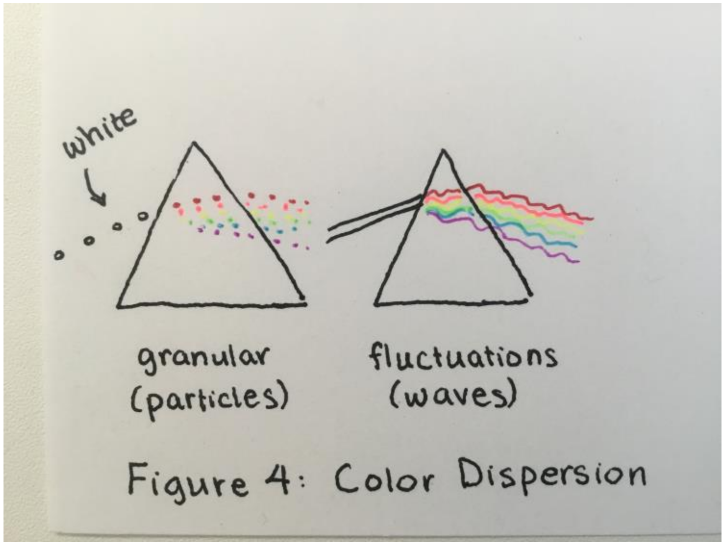
By this experiment, he discovered that white light is composed of many different colors of light. He also found out that colored light keeps the same color during any sort of propagation. This is known as Newton's color theory. Different objects absorb different colors and reflect different colors. If something reflects all colors, it appears to be white (like white paper). So yes, white is the purest light. If something absorbs all colors and reflects no colors, it appears black.

Particle Theory vs. Wave Theory

Now let's move on into the most important discussion: what is light exactly? There was a great debate that lasted for 150 years between Isaac Newton and Sir Robert Hooke and their suporters. You may already know Newton as one of the greatest scientists and mathematicians of all time and for his famous story of the falling apples. He took the stance of particle theory in this argument: "Light sources emit a large number of corpuscles that are perfectly elastic, rigid, and weightless". The other side, Robert Hooke, is also a great British scientist who accomplished many feats. He is known for Hooke's Law (the Law of Elasticity), giving the name "cell", planetary orbit, and of course, his wave theory of light. He said that "light is a rapid vibration of any medium through which it propagates." Which side is right, Newton or Hooke?

We can't feel the light being "grainy" like particles or the fluctuations like waves, but not being able to be distinguished doesn't necessarily mean it doesn't exist. Let's do some experiments and derive the conclusion with evidence.

Both particle and wave theory can explain **color dispersion** (Figure 4). Different colors of light can be particles of different colors or waves of different wavelengths. To explain Newton's color theory, particles will keep their color when they travel and waves will keep their wavelength. Both theories can also explain **straight-line propagation and reflection law** (Figure 5). Newton argued that particles made more sense because they travel in straight lines and would have perfectly equal reflection angles when they travel due to the laws of motion. However, another mathematician supporting the wave theory named Huygens proposed that the secondary wavelets from each point on the traveling wavefronts would “mutually interfere to form the actual wavefront” (“every point on a wavefront is itself the source of spherical wavelets”) so that the wave is traveling perpendicular to its wavefronts (see Figure 5). This can also explain the reflection law. So again, this one is a tie.



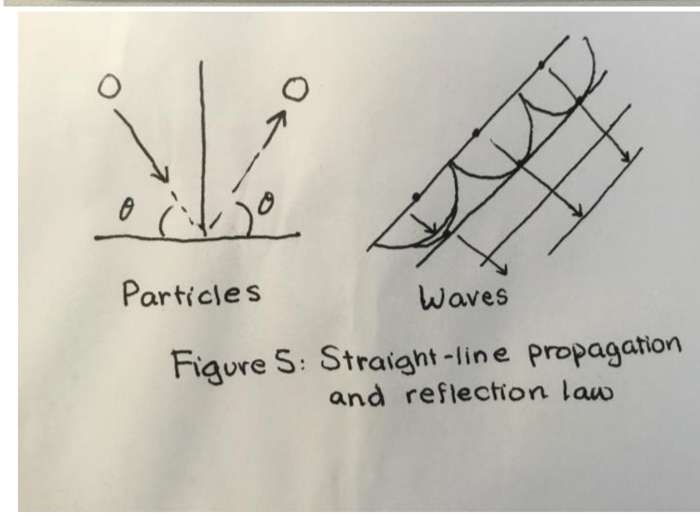


Figure 4: Granular vs. Fluctuations Color Dispersion
Figure 5: Straight-line propagation and reflection law

Then we have the **polarization phenomenon**. You may have polarized sunglasses that block out the horizontal light reflecting off surfaces and only allow vertical light rays to pass through to your eye. I didn’t know what these sunglasses were before they were mentioned in this phenomenon and I thought that they were very useful once I found out how they worked.

If you have two pieces of polarization sunglasses and you tilt one sideways by 90 degrees, you wouldn’t be able to see any light at all. This is because the horizontally-polarized one is blocking off the actual vertically polarized light rays, and the vertical one is blocking the “horizontal” rays. So both the horizontally and vertically polarized rays are blocked using two polarized sunglasses perpendiculars to each other (Figure 7), and no light will come through. If the two sunglassed are in the same orientation, the light of that polarization can pass through.

Figure 6: Polarized sunglasses normally overlapping (still some light)

Figure 7: Polarized sunglasses flipped 90 degrees (no light coming through)

So do the two theories work for this phenomenon? If the light particles were ellipsoids, this may work for particle theory. For the first piece of sunglasses, the different ellipsoids are sorted out so that only the vertical ones can pass through. But the second piece is turned 90 degrees and the vertical ellipsoids can’t pass through the horizontal bars, so no light comes through. Particle theory may be validated this way. But we have to consider: *are* the light particles ellipsoids? If they were all the same round spherical shapes, this would not work. Light would still pass through. Hmm…

As for waves, this is also validated differently depending on the direction of oscillations (Figure8 right). The different waves are sorted out so that only the wave that has vertical oscillations can pass through, but it’s blocked by the horizontal bars. So, this one could be another tie.

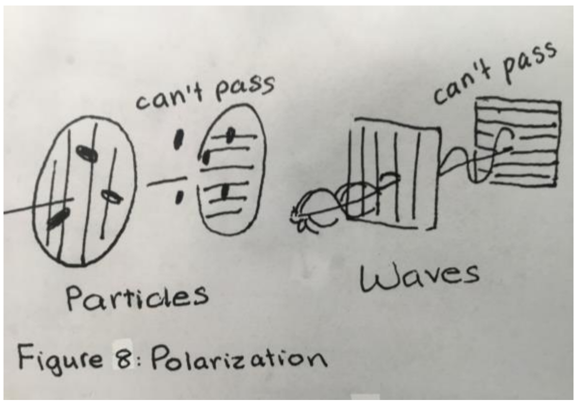


Figure 8: Polarization

What was interesting to me is that we don't know whether the particles are actually ellipsoids or not. I think that it was suspicious to create a "special case" and make the particles ellipsoids just for the particle theory to work for this phenomenon. I think that wave technically won this round, because the oscillations in various directions are natural for waves.

Next, we have the **diffraction phenomenon**. When light is shining straight at a thin slit, what would be the results? Particles would travel in a straight line, but waves can diffract. For example, if you have a tub of water with a piece of cardboard that has a slit in the middle and use your fingers to create waves, the result that comes out on the other side would be like this:

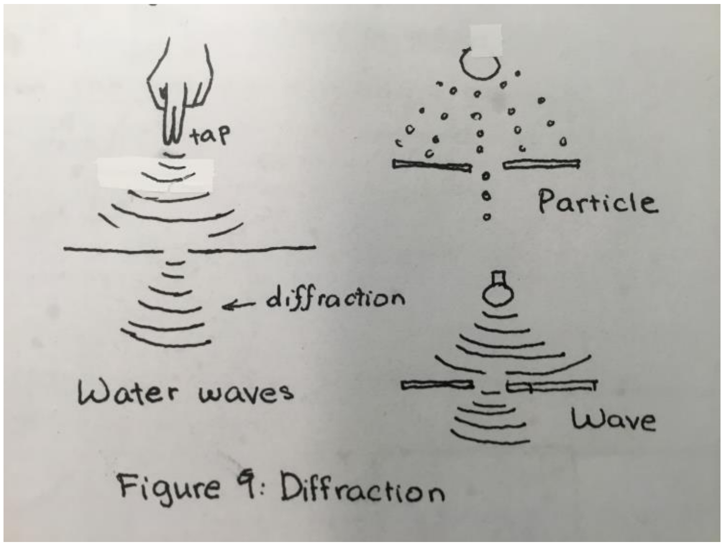


Figure 9: Diffraction

When I conducted this experiment, my fingers were not very effective, still, there were only a little bit of diffracted waves coming out of the slit. Also, when I first did the experiment to see if light would diffract through the slit of two pencils, I was very confused because I could only see the "blurred" edges of the pencils like I would normally see. But later I did the experiment again and realized that the "blurred" edges were actually the diffraction of the lamplight because it has these alternating dark-light stripes! Only it was so thin I didn't realize the first time I did it; I thought I was probably conducting the experiment wrong and went along with the solution video. Wow, I understand the conclusion much better now that I've actually gotten the correct solution! So, the wave therory wins in this one: light diffracts through a thin slit as waves and will not be a straight line as particles.

Another experiment is the interference phenomenon. If there were two slits this time instead of one, what would happen? Particles will act independently and there would be two bright strips on the other side. Waves, however, will interfere with one another and create a dark-bright-dark-bright result, like the water when you tap it with two separate fingers. The tapping-water experiment didn't work very well for me again; I then realized for creating stable interference, the two "sources" have to have the same frequency so that the waves have the same wavelength. The two fingers need to maintain the same phase shift as well. I guess I need a larger container or an open area of water like what was shown in the lecture so that the water waves reflected from the wall won't join the interference. My fingers may also be too weak to create strong enough waves that keep enough intensities throughout the way.

Then there was the experiment to cut one slit in a paper, hold it over a paper with two slits in it, and shine a light on the top. I got two bright strips when I did that experiment, but I realized my mistake was that I cut my slits too big. The size of the slits matters a lot, becase the wavelength of light is less than 1% of the hair diameter. That's also why you need to use two pencils instead of your fingers (with wide gaps) for the diffraction experiment before. If I did this experiment more "professionally" like Young's double-slit experiment, it would have shown the screen as an alternating dark-light-dark-light. Waves win again! Later with the help of a single frequency laser source, the interference experiment becomes so easy to do.

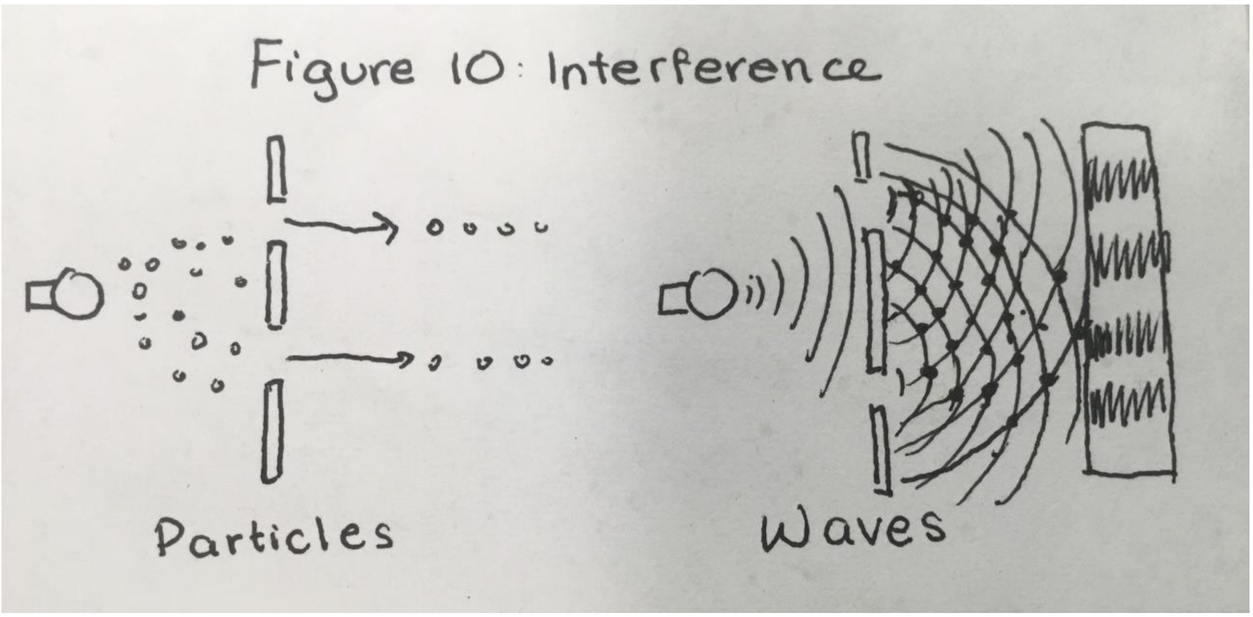


Figure 10: Interference

The decisive argument was the **refraction phenomenon**. Newton's particle theory said that light travels faster in media other than air to explain why light bends closer to the normal direction entering from air to water or glass. That is not true. The speed of light was finally measured in space using Jupiter's moon Io and was found to be slower in water in 1850. This proved that light travels the fastest in air (to be more accurate, vacuum). Waves win again for this one.

So, to summarize:

	PARTICLE	WAVE
Dispersion	✓	✓
Straight Line	✓	✓
Reflection	✓	✓
Polarization	✓	✓
Interference	X	✓
Diffraction	X	✓
Refraction	X	✓

Figure 10: Wave vs. Particle Table

Now, with an abundance of evidence collected from these experiments, we know that light is a wave! Hooke's theory was proven to be right many years after his death.

This was not the end of the story. After the debate between Newton and Hooke's debate was concluded, some questions remained, for example: If light is a wave, what is the media for it to travel in the empty space? Many years later light was found to be a special kind of wave: the electromagnetic wave which can self-reproduce and spread in a vacuum. I am looking forward to the Electromagnetism courses to really understand what electric fields and magnetic fields are. More interestingly, lightwave is later found to exhibit particle behavior as well. Don't get me wrong that is a quantum effect that can explain why UV can hurt us so badly in a few minutes while infrared from the fireplace is safe to be exposed to for hours. The quantum concept of "photon" is definitely not the same "particles" mentioned in Newton's light theory.

The different experiments were very interesting to me. My favorite one was the polarization experiment. It's always fun to see how these scientific debates in history progressed and how they affect us now. Now we know what exactly light is and the different phenomena of light are explained thoroughly. Another thing that surprised me was that Newton was wrong in this one, though I did take the other side and guessed that light was a wave after a few experiments. It's just surprising to see such a famous scientist like him be wrong. So I keep what Professor Man said in the lecture in mind: challenge if you have experimentally backed-up evidence, even if you are going against a huge authority figure like Newton that most people would believe. And of course, take nobody's word for it.

NOTES:

I didn't have time to cover all of the topics of Lesson 4, so I just focused on the particle vs. wave theory debate. I only wrote a few paragraphs for the other topics of thin-film interference, EM waves, and the photoelectric effect.

I drew many of your diagrams from the main lectures; they were very helpful. I should've taken more of my personal experiment pictures, but I forgot to do that. I will remember to add photos/videos to the Mechanics drive folder (I already added some) to prepare for that essay.

Lastly, thank you so much for an amazing course, Professor Man! I really enjoyed learning Optics. It was super interesting. I hope you enjoyed my essay. Thanks again!!! :)