HW3 - Lay Article (first 3 sections of the photoelectric effect paper)

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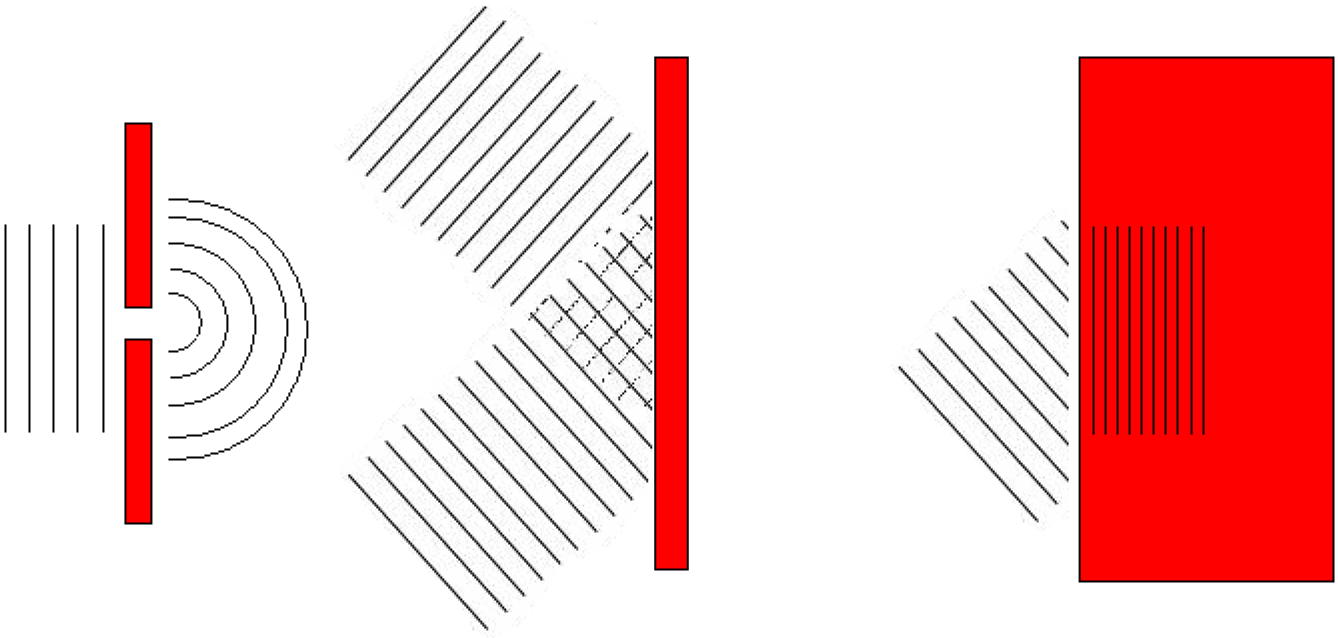
If someone asked you to describe what light really is, what would you tell them? Perhaps you remember hearing how different colours are associated with different wavelengths and you would tell them that light is made up of waves. Or you might tell them that light is made of particles, since you have heard of light particles called photons. But this sounds like two completely different explanations. Can they both be correct?

The nature of light has always been a subject of strong interest in physics. At the turn of the twentieth century, physicists finally had a well accepted and defined notion of light. It was Maxwell's wave theory, which consisted of four equations that could be used to describe and explain phenomena like diffraction, reflection and refraction. It was observed during experiments that light behaved similarly to physical waves that can actually be seen.



Diffraction of a wave through an opening.

Reflection of a wave on a surface

Refraction of a wave entering a denser medium.

Figure A

These light waves are similar to everyday waves, such as water waves on the ocean. The period of the wave describes how quickly successive wave peaks reach an arbitrary point, like the shore. The frequency of the wave is simply the inverse of the period, or how many peaks reach the shore in a given amount of time. The wavelength is the distance between each peak and is measured in nanometers (for example red is 700 nanometers or 0.0000007 meters), when we are talking about visible light waves. The light spectrum, or electromagnetic wave spectrum, is made up of a vast range of wavelengths, and in the visible part of the spectrum we associate different wavelengths with different colours. Violet light has a shorter wavelength and therefore a higher frequency than red light.

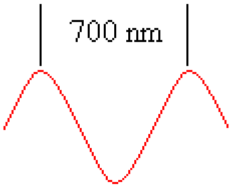


Figure B The wavelength of red light

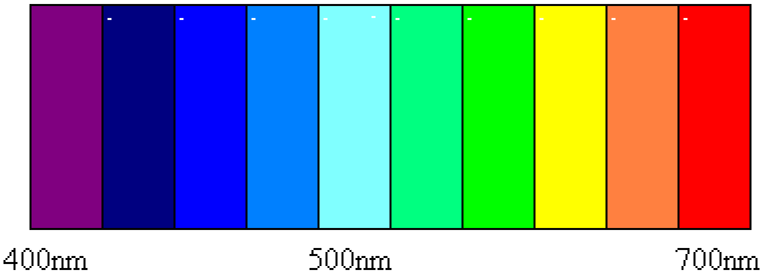


Figure C The visible light spectrum

Even though the wave theory of light was well established there were still experiments that it was not able to explain adequately. In particular, many physicists were interested in investigating something called black body radiation (in this context electromagnetic radiation and light are used interchangeably). This theoretical black body, unlike most everyday objects, is able to perfectly and equally absorb and reflect radiation of any wavelength. Astrophysicists have observed that some stars approximate black bodies very well. Common objects tend to reflect certain wavelengths more than others, which is what gives them their colour. A black body gets its name from the fact that it would appear black since it perfectly absorbs all incoming light.

Experimenters were intrigued with the relationship between the temperature of a black body, and the radiation emitted, particularly the wavelengths of these electromagnetic waves. A physicist named Wilhelm Wien found that the radiation emitted by such a black body was only dependent on its temperature. It was found that this radiation was composed of a distribution of many wavelengths, with a particular wavelength being more intense than the others. This distribution (and thus the predominant wavelength, or frequency) changed with the temperature of the black body. In fact, Wien's law tells us that the hotter a black body becomes, the shorter the wavelengths that are emitted become. However, the relationship between the temperature of a black body and the emitted wavelengths that Wien derived seemed to only work for the higher frequency of the spectrum and did not agree with experimental results dealing with the lower frequencies.

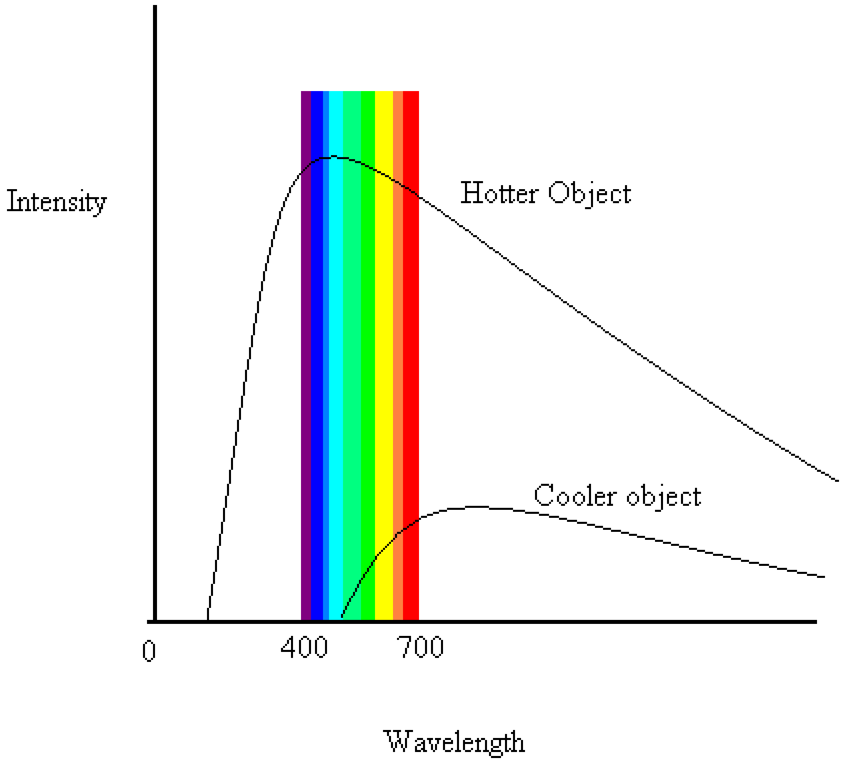


Figure D Wien's Law. A cooler object emits light of longer wavelengths (lower frequency) while a hotter object emits light of shorter wavelengths (higher frequency).

Coincidently, two physicists named Raleigh and Jean were able to come up with a relationship that did describe accurately how temperatures affected lower frequencies in accordance to experimental results. However, its predictions of results in the high frequency range deviated drastically from known results. In fact, it would predict an infinite intensity of ultraviolet light, which is in the high frequency range. This infinite intensity is of course not observed in real life, and the discrepancy became known as the ultraviolet catastrophe.

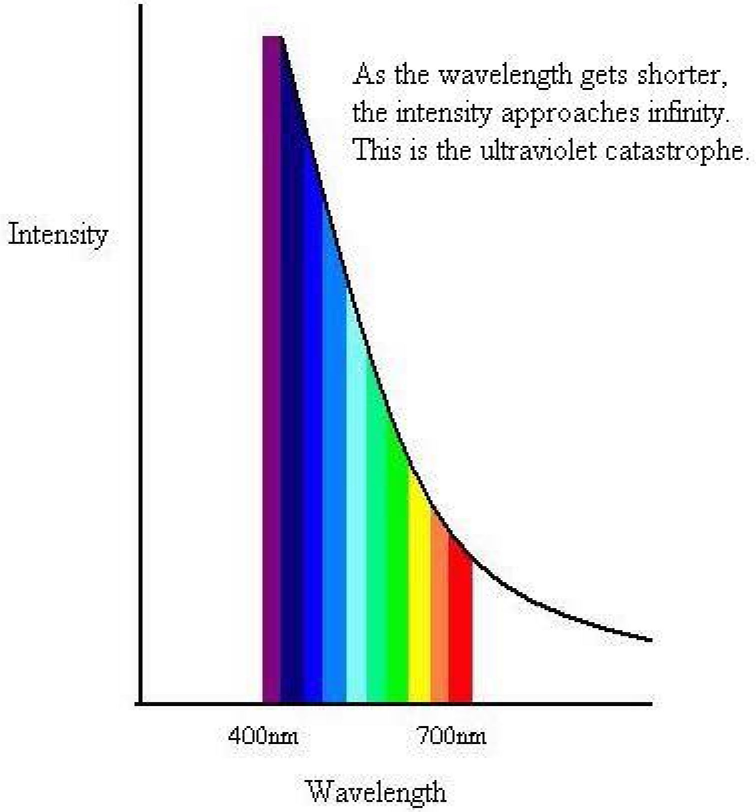


Figure E The Raleigh-Jeans Law and the ultraviolet catastrophe

Max Planck worked on the problem and proposed a solution that would agree with the observed results throughout all the spectrum of frequencies. He introduced the idea of quantized energy which was necessary for his solution to work. Viewed as a calculational trick at the time (even by Planck himself), his solution suggested that the energy absorbed and emitted by this black body (or any object for that matter) could only absorbed or emitted in discrete chunks. These “chunks” can be more precisely described as very small packets of energy (called quanta), which are indivisible while being absorbed or emitted. This was the beginning of the idea of quantized energy.

Einstein put forth exciting new ideas in his 1905 paper titled, “Concerning an Heuristic Point of View Toward the Emission and Transformation of Light.” Einstein was the first to apply Planck's idea. As he points out in his paper that though the wave theory as explained by Maxwell works well with optical phenomena (diffraction, reflection, refraction, etc.), it does not agree with experiments dealing with the emission and transformation of light. The most famous example of such an experiment is the photoelectric effect, where a metal is able to produce a current when exposed to light under the right conditions.

And so, Einstein extended Planck's idea of quantized energy; he suggested that light itself is quantized. Einstein's idea did not exclude the wave-like properties of light. Instead, he was really suggesting that light be viewed as both a wave and a particle. These discrete light particles soon became known as photons. The dual wave-particle model of light is currently the accepted model and has helped explain many phenomena like the photoelectric effect and has even opened the door to quantum mechanics.

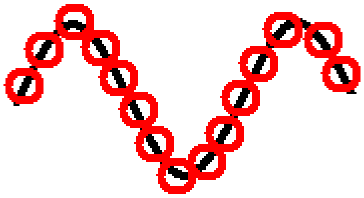


Figure F A quantized picture of light

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