Light

> Previous chapter: 5.1.2 Generation of electromagnetic radiation

Light, otherwise known as electromagnetic radiation, is different from anything else in the universe. **Light is not matter**, and it is not made up of pieces of matter. Since it is different, we must think of ways to explain light. We will consider two analogies to things we know. **We will model light as a wave and as a particle**. These analogies will not be perfect, but they will allow us to relate the properties of light to things we have experience with.

Light as a wave

First, let's consider light as a wave. A light wave, like a wave on a beach, has two characteristics:

- one is the distance between two waves, i.e., the distance between two peaks (or two troughs). This is called the wavelength. For example, the waves may be five feet apart.
- The other characteristic is the wave's frequency, or how many waves pass you each minute.

These two properties are related in a fairly obvious manner. If the waves are 5 feet apart and 10 waves pass you each minute, then the water must be traveling at 5 x 10 = 50 ft per minute. **The speed of the wave is equal to the wavelength times the frequency**. In equation form, **$c = \lambda . f$** .

For light waves, there is one other, very special property. (And it's the oddest property you will ever encounter.) **The speed of light is always the same**, 3 x 10^{10} cm/sec. This means that the frequency of light is related to its wavelength through a constant. For every frequency, there is a wavelength. **The higher the frequency, the smaller the wavelength**; the lower the frequency, the larger the wavelength.

It also makes sense to ask how much energy a wave of light carries. It turns out that **the energy is related to the frequency of light only by a constant**. In other words, **$E = h f$** , where h is the number that makes the units come out right. This means that **the higher the frequency, the higher the energy**. High frequency (short wavelength) light carries alot of energy. Low frequency (long wavelength) light carries little energy. Note: energy, frequency, and wavelength are related only by constants. Any one uniquely defines the other two.

For light, the wavelengths can be ANY size. The waves can be several hundred yards apart, or millions of waves can fit on the head of a pin. **Our bodies, however, react differently to different types of light**.

  - Very long wavelength light passes right through us. (It will, however, move electrons in a copper wire. This will cause an electric current, which can then be amplified and put through some electronics which reproduce sound. This is why long wavelength light is called a **radio wave**.)
  - Slightly shorter than radio waves (about 1 millimetre in wavelength) are **microwaves.** These can be absorbed by water to heat food.
  - Smaller wavelengths are called **infrared**. We don't see these, but our skin can react with them, and we feel heat.
  - A wavelength between about 4000 angstroms and 7000 angstroms (where 1 angstrom is 10-8 centimetres) causes sensors in our eye to send a message to our brain. We call this the **visible light**. We see 4000 A light as blue and 7000 A light as red.
  - **Ultraviolet light** has a wavelength that is smaller than 3000 A, and our eye does not register the light, but the energy carried by these wavelengths can hurt our skin.
  - Even shorter wavelength light can pass right through our skin and only be stopped by denser parts of our body, these are called are **x-rays**.
  - Finally, the shortest wavelength (highest energy) light of all is **gamma-rays**.

Not all photons of the electromagnetic spectrum can make it through the earth's atmosphere. Gamma rays and x-rays are absorbed. So are most infrared and ultraviolet rays. The only types of light that make it through easily are visible light and radio waves.

Doppler shift

Note that **the wavelength at which you see a light is not necessarily the exact wavelength at which the light was emitted**. Imagine yourself floating in an ocean. You count 5 waves per minute passing you. Now, swim towards the source of the waves. You will find that you encounter more waves per minute: the frequency at which the waves pass you will be larger. Now swim away from the waves. Fewer waves will pass you per minute. The frequency of the waves will be less. **The shift in frequency due to your movement** (or, equivalently, the movement of the source of waves) is called the Doppler shift. Chances are you have heard the Doppler shift in action with a train whistle (or even a bicycle horn). The pitch (frequency) of the whistle changes from high frequency to low frequency as the source of the whistle passes you.

Since the speed of light never changes, **a change in light frequency also means a change in its wavelength (and energy)**. Therefore, if you are moving towards a source of light (or the source of light is moving towards you), you will see the light at a slightly higher frequency, or smaller wavelength. This is called a **blue shift**. Conversely, if the source is moving away from you, its light will be shifted towards longer wave lengths, i.e., it will have a **red shift.**

Mathematically, the amount of the shift is small: the change in wavelength divided by the wavelength is approximately equal to v/c, where v is the velocity of the source and c the speed of light. So, unless the object is moving at a substantial fraction of the speed of light, your eye will not be able to notice the difference. But Doppler shifts are easy to measure in the laboratory.

Light as a particle

So far, we have considered light only as a wave. But some of the properties of light can be better described by thinking of light as a particle. **“Particles” of light are called photons**. Each photon can be thought to carry a specific amount of energy. A source of light, such as a light bulb, will emit photons in every direction. The number of photons you will detect will depend on your distance from the source. As you go twice as far away from the source, the area of a sphere surrounding the source will be 2 x 2 = 4 times greater. There will therefore be four times less photons per each square centimetre of area, and you will see four times less light. This is **the inverse square law of light.**

When photons encounter specks of dust, they can bounce off the dust, i.e., be **scattered.** It turns out that the shorter the wavelength, the easier it is for light to be scattered. Therefore blue light gets scattered more than red light. That's why the sky is blue, light from the Sun has been scattered all over the place, especially blue light. When you look away from the Sun, you will see some of that scattered blue light. Similarly, that's why the sunset is red. When you observe the Sun through a large amount of atmosphere, so much of the blue light has been scattered away that all that's left is red light.

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