Lesson 34 – Light, Color, Wavelength, Frequency

In common speech the word "light: typically refers only to visible light. The light we can see seems to come in a variety of colors. This is called the visible spectrum. These colors are not inherent to the light itself. The colors are inherent only to the color detection system built into our eyes. In fact, most of the light in the universe is invisible to our eyes. We see only a tiny friction, one narrow slice, of what is more properly called the electromagnetic spectrum.

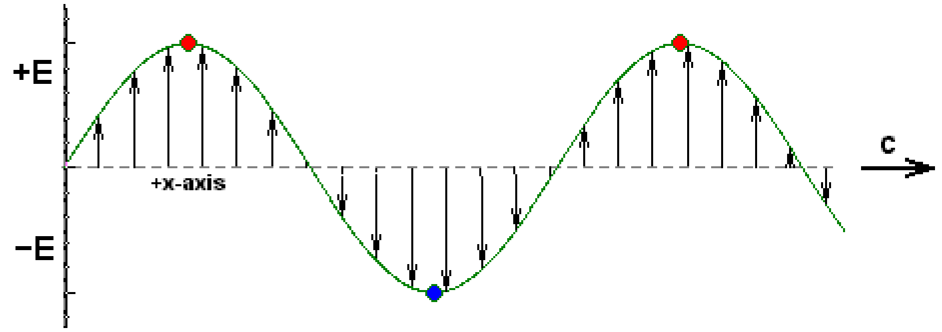
Visible and Invisible Light – Electromagnetic Radiation

We will learn much more about electricity and magnetism later. The nature of light will make more sense after we have worked through those lessons. For now it is enough to say the all light, both visible and invisible, is made up of oscillating electric and magnetic fields. The inherent properties of light with which we will be most concerned for now are:

Velocity – the speed of light varies with the medium through which it travels. Nothing in the universe travels faster than light when it is traveling thought empty space. Unlike all other waves, light needs no medium to carry it. Traveling through a transparent medium only slows it down. The speed of all light in a vacuum is

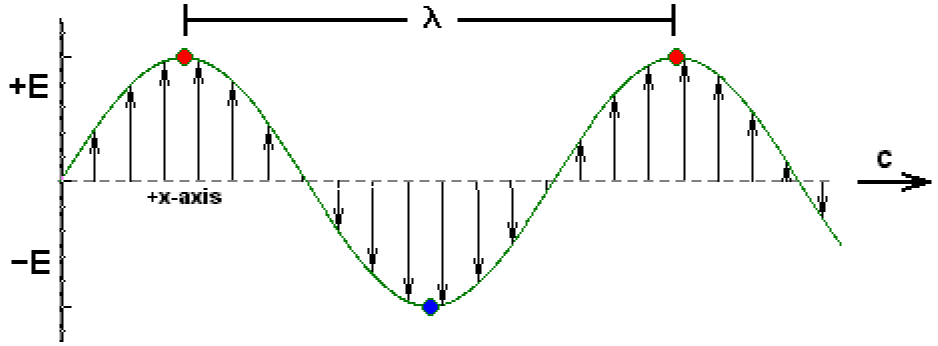
$$\mathbf{c} = 2.99792458 \times 10^8 \text{ m/s} \approx 3.00 \times 10^8 \text{ m/s}$$

Wavelength – As with all other wave-like phenomena, light oscillates with a characteristic spatial pattern. To consider only the electric field component of the wave, we say that the electric field strength oscillates with varying intensity perpendicular to the direction of wave propagation. The electric field is a vector quantity. It intensifies from zero to a maximum and then back to zero. Then it intensifies in the opposite direction from zero to a maximum and then back to zero. Then the cycle repeats. The changes in intensity of the electric field occur while the light continues to move through space. At each point there is only one value of the electric field. The distance the light travels between successive maxima of the electric field is known as the wavelength. Here is a diagram showing a reasonable visual model.



The vertical arrows show a small sample of the electric field vectors. Each point along the +x-axis has such a vector attached to it. The green line shows what we call the envelope defined by these vectors. Typically, we only show the envelope, but you must always remember that the envelope is defined by the collection of individual electric field vectors creating the light wave. Each electric field vector exists for the briefest of instants. Light itself is the ripple in space created by this cascade of electric field vectors. The magnetic part of the electromagnetic wave consists of a similar looking set of vectors that oscillate into and out of the page perpendicular to the electric field vectors. There is a corresponding ripple of magnetic field vectors in our electromagnetic wave. The electric and magnetic ripples in this diagram are traveling to the right at the speed of light.

The envelope around the electric field vectors looks like, and is, a sine or cosine wave. Which you choose to use depends only on where you set the zero on your x-axis. I've marked the maxima with red and blue dots, but of course light waves do not have these dots. They are in this diagram only as reference points for the following discussion.



The distance between successive maxima in the same direction (red dots) is known as the wavelength. It is usually symbolized with the Greek letter lambda, λ. Wavelength is measured in meters. It is distance along the axis of travel between successive maxima. The distance between a red dot and the next blue dot is one-half a wavelength, $\lambda/2$.

Frequency – Light travels very fast and the typical wavelength is very short. So, typically, light travels many wavelengths each second. If we count the number of wavelengths the light travels each second instead of the number of meters it travels each second, we get a value called the frequency. Frequency in this course is symbolized with an italic f. Another common symbol for frequency is the Greek letter nu, ν. The unit of frequency can be written many different-seeming ways, but they all mean the same thing.

Wavelengths per second = cycles per second = cycles/sec = 1/s = s^{-1} = hertz = Hz

The word "cycle" is thrown in to distinguish between frequency and angular frequency, which is always given in radian per second = rad/s, never in Hz. The symbol for angular frequency is always the Greek letter omega, ω. The words cycle and radian are not real units in the usual sense. They are distinguishing labels.

The inverse of the frequency is called the period, **T**. The period is the time it takes the light to travel a distance of one wavelength along the direction of travel. Here are the important relationships involving the speed, wavelength, frequency and period of electromagnetic radiation. If the light is traveling through a medium then use the actual velocity, **v**, in these equations instead of **c**.

$$\mathbf{c} = \lambda / \mathbf{T} = \lambda f \qquad \lambda = \mathbf{c}\,\mathbf{T} = \mathbf{c} / f \qquad f = \mathbf{c} / \lambda = 1/\,\mathbf{T} \quad \mathbf{T} = 1/f = \lambda / \mathbf{c}$$

When light travels through a medium its speed is less than **c**. Call it **v**. **The frequency is remains constant.**

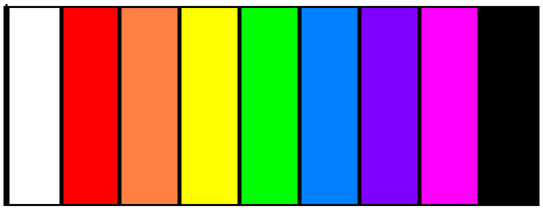
Color – Human Vision

Of the entire range of frequencies in electromagnetic spectrum we can see only a certain range of frequencies and wavelengths. The wavelength range, from red to indigo, is about 450×10^{-9} m to about 700×10^{-9} m. These wavelengths correspond to frequencies in the range, again from red to indigo, of about $6.6 \times 10^{+14}$ Hz to about $4.3 \times 10^{+14}$ Hz. Of all the possible wavelengths and frequencies that one can imagine, those in this range are the only ones we can see.

Color is not inherent to the light itself. Humans have three different types of sensors capable of distinguishing color. the sensor are sensitive to separate but overlapping parts of the range given above. Since most light contains many frequencies in this range all three sensor types are usually stimulated by the light from most objects or light sources. The relative amount of stimulation reported by each sensor creates the colors we see.

It is entirely due to the way our color sensors work that we tend to see seven primary colors. Each color covers a portion of the visible spectrum. We tend to see more than just seven colors because light tends to include frequencies from more than one primary color range at a time. It is possible to describe millions of colors by using various proportions of these primary colors.

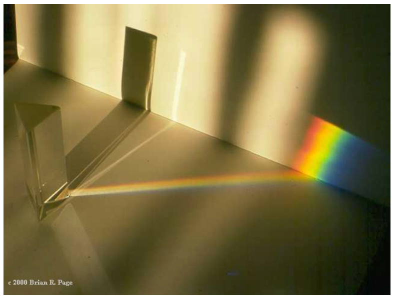
As shown in the following slightly idealized graphic, the seven primary colors cover the full range of the visible spectrum. The millions of non-primary colors consist is light with frequencies from many parts of this visible spectrum at one time. Our eyes are almost totally insensitive to any frequencies out side this limited. Even if light from outside this range reaches our eyes, we derive no sense of color from those frequencies.



Red Orange Yellow Green Blue Indigo Violet = **ROY G BIV** = seven primary colors

This color sense is unique to humans. Our ancestors needed to be able to distinguish between ripe and unripe fruits. Dogs and cats are carnivorous hunters. They see only in black/white/gray. For them color is not as important as motion of their prey. They are very sensitive to motion but almost totally insensitive to color. Bees see color, but from light at higher frequency than humans see. It turns out that flower petals have distinguishing markings that are only visible in the higher frequency range. To humans the colors may look uniform; to a bee the same petals exhibit a pattern that allows them to distinguish one plant species from another.

What we call white light is just one specific combination of all seven primary colors. What we call black is lack of color. Thus, white objects tend to reflect most of the light that falls on them. Black objects tend to absorb most of the light that falls on them. Even among what we call black and white there is a huge amount of subtle variation. White objects can be distinguished from each other by subtle changes in the frequencies that are absorbed rather than reflected. Black objects seldom absorb all the frequencies completely. Thus, black objects can be distinguished from each other by subtle changes in the frequencies that are reflected rather than absorbed.



Here is an example of “white” light being broken by a prism into its component primary colors. Typically, the blue fades so rapidly that the indigo and violet are difficult, or as in this case impossible, to see. The human definition of white light is determined by the light naturally emitted by a hot object at the same temperature as the Sun; say 5000ºC. Even for objects at that temperature, indigo and violet are hard to see. For objects at much higher temperatures the indigo and violet are more readily apparent, but at such temperatures the light has a distinct emphasis on the blue end of the spectrum and would no longer register to our eyes as white.