## Two Equations Governing Light's Behavior

There are two equations concerning light that are usually taught in high school. Typically, both are taught without any derivation as to why they are the way they are. That is what I will do in the following.

**Equation Number One:**  **= c**

Brief historical note: I am not sure who wrote this equation (or its equivalent) first. The wave theory of light has its origins in the late 1600's and was developed mathematically starting in the early 1800's. It was James Clerk Maxwell, in the 1860's, who first predicted that light was an electromagnetic wave and computed (rather than measured) its speed. By the way, the proof that light's speed was finite took place in 1676 and the first reliable measurements of the speed of light took place in the late 1850's.

Each symbol in the equation merits a discussion.

1)  is the Greek letter lambda and it stands for the wavelength of light. Wavelength is defined as the distance between two successive crests of a wave.

2)  is the Greek letter nu. It IS NOT the letter v, it is the letter nu!!! It stands for the frequency of the light wave. Frequency is defined as the number of wave cycles passing a fixed reference point in one second. When studying light, the unit for frequency is called the Hertz (its symbol is Hz). One Hertz is when one complete cycle passes the fixed point, so a million Hz is when the millionth cycle passes the fixed point.

There is an important point to make about the unit on Hz. It is NOT commonly written as cycles per second (or cycles/sec), but only as sec¯1 (but usually written as s¯1). The "cycles" part is deleted, although you may see an occasional problem which uses it.

A brief mention of cycle: imagine a wave, frozen in time and space, where a wave crest is exactly lined up with our fixed reference point. Now, allow the wave to move until the following crest is exactly lined up with the reference point, then freeze the wave in place. This is one cycle of the wave and if all that took place in one second, then the frequency of the wave is 1 Hz.

In any event, the only scientifically useful part of the unit is the denominator and so "per second" (remember, usually as s¯1) is what is used. The numerator "cycles" is not needed and so its presence is simply understood and, if necessary, a one would be used, as in 1/sec.

3) c is the symbol for the speed of light, the speed at which all electromagnetic radiation moves when in a perfect vacuum. (Light travels slower when passing through objects such as water, but it never travels faster than when in a perfect vacuum.)

As written in your text, we will use the following value as the speed of light:

3.00 x 108 m/sec

The actual value is just slightly less, but the above value is the one generally used in introductory classes. (sometimes you'll see 2.9979 rather than 3.00.) Be careful about using the exponent and unit combination.

An interesting little trivia: light travels about one foot every nanosecond.

**Example problem #1:** What is the frequency of red light having a wavelength of 7.000 x 10-7m?

The solution:

(7.000 x 10¯7 m) (x) = 3.00 x 108 m/sec

Note that I effectively consider 7.000 to be 4 significant figures. The answer is 4.286 x 1014 s¯1

**Example problem #2:** What is the frequency of violet light having a wavelength of 4.00 x 10-7m?

 (4.00 x 10¯7 m) (x) = 3.00 x 108 m/sec

The correct answer is 7.50 x 1014 s¯1

Be aware that the range of 4 x 10-7m to 7 x 10-7 m is taken to be the range of visible light. Notice how the frequencies stay within more-or-less the middle area of 1014, ranging from 4.29 to 7.50, but always being 1014. If you are faced with this calculation and you know the wavelength is a visible one (say 555 nm), then you know the exponent on the frequency MUST be 1014. If it isn't, then YOU (not the teacher) have made a mistake.

**Equation Number Two: E = h**

Brief historical note: It is well-known who first wrote this equation and when it happened. Max Planck is credited with the discovery of the "quantum," the discovery of which took place in December 1900. It was he who first wrote the equation above in his announcement of the discovery of the quantum.

1) E is the energy of the particular quantum of energy under study. When discussing electromagnetic quanta (of which light is only one example, x-rays and radio waves being two other examples), the word photon is used. A photon (the word is due to Albert Einstein) is a quantum of electromagnetic energy. The word quantum (quanta is the plural) is usually used in a more general sense, to describe various ideas of quantum theory or even, as I just did, to describe the entire theory itself.

2) h stands for a fundamental constant of nature now known as Planck's Constant. By the way, the discovery of the quantum had, and continues to have, many profound effects. Enough so that all of science (especially physics) before 1900 is referred to as "classical" and the science since 1900 is called "modern."

The value for Planck's Constant is 6.6260755 x 10¯34 Joule second. Please note that the unit is Joule **MULTIPLIED BY** second. It is not a division, both Joule and second are in the numerator.

3)  is the frequency of the particular photon being studied. The discussion about frequency above applies here.

Before going on, I want to discuss one little issue (heh, heh, heh). Frequency is a wave-based idea. What is it doing in a particle-based idea like the quantum? Good question. So much so that the term "wave packet" is often used in discussing these ideas. Indeed, modern science now speaks of "wave-particle duality" rather than "Light is a wave" or "Light is a particle." This whole area is profound and can lead to years of probing discussion. Albert Einstein and Niels Bohr (who were great friends) discussed these issues (and more) often over a period of many years, especially in the late 1920's and early 1930's. Their discussions are still important enough to merit historical study today. Every year, several books are published which delve into one or more of the implications of "wave-particle duality."

**Example problem #4:** How many Joules of energy are contained in a photon with  = 550 nm?

I will first do the problem step by step, then in a more combined way.

Use  = c /  to get the frequency:

x = (3.00 x 108 m s¯1) / (550 x 10¯9 m)

This equals 5.4508 x 1014 s¯1. I left a couple extra digits in the answer and notice that the wavelength is not in scientific notation. Why? Think about how I got from nm to m for the value used. (I also used 299,792,458 in the calculation, not 3.00 x 108. Sorry!! Using 3.00 x 108 gives 5.454 x 1014 s¯1.)

Now use E = h to get the energy:

x = (6.6260755 x 10¯34 J s) (5.4508 x 1014 s¯1)

This equals 3.612 x 10¯19 J.