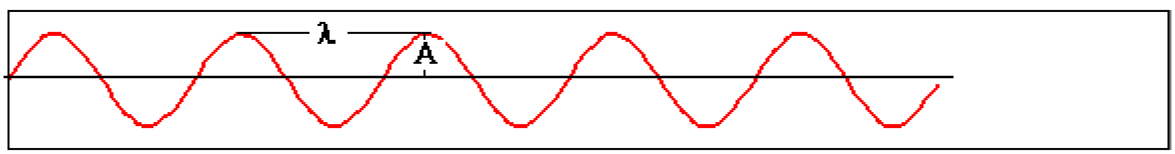
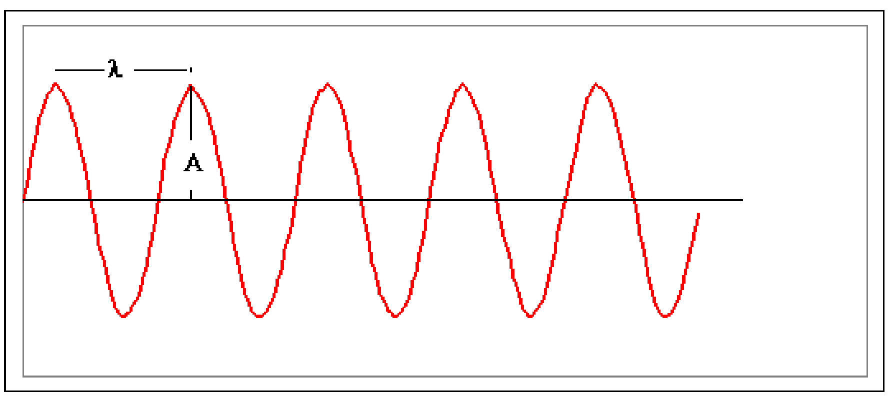
Electromagnetic Radiation

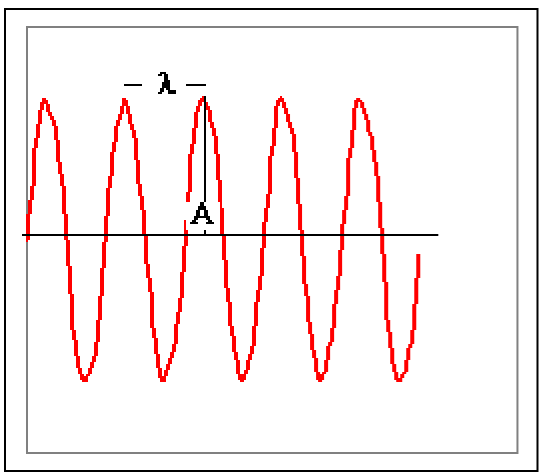
There are various kinds of radiation, such as, gamma rays, X-ray, ultraviolet, visible, infrared, microwaves, and radio waves. These are known as **electromagnetic radiation or electromagnetic wave** because they emit and transmit energy in the form of electromagnetic wave that has electric field component and magnetic field components, which are mutually perpendicular to one another. Electromagnetic wave, commonly known as the **speed of light**, travels 3×10^8 meters per second (186,000 miles per second) in a vacuum. This speed does not change significantly from medium to medium. The symbol c is adopted to indicate the speed of light.

$$c = \text{speed of light} = 3.0 \times 10^8 \text{ m/s}$$

There are, of course, different forms of waves that come in various shapes and sizes. For example, if you go to the beach and observe the waves coming towards the shore, you will notice that each wave is different than the one it follows.







In any event, the waves are characterized by three parameters, wavelength (λ , Greek symbol pronounced as *lambda*), frequency (ν, Greek symbol pronounced as *nu*), and amplitude (A), which are defined as follows.

The ***wavelength (λ)*** *is the distance between any two identical adjacent points*. As you can see that the above shown waves have different wavelengths; the top one has the longest wavelength and the bottom one has the shortest. Wavelengths are typically measured in the units of centimeter (cm), meter (m), micrometer (mm), and nanometer (nm).

The ***frequency (ν)*** *is the number of waves (cycles) passing through a point in one second*. In the above shown three waves, the top wave has the lowest frequency and the bottom one has the highest frequency. The frequency is expressed in the units of cycles/s or simply 1/s, which is renamed as hertz (Hz) in honor of Heinrich Rudolf Hertz (1857 - 1894), a German physicist.

Therefore,

$$1 \text{ Hz} = 1 \text{ cycles / s} = 1/\text{s} = \text{s}^{-1}$$

You might see something like kHz or MHz on your car radio dial, they mean kilohertz and megahertz:

$$1 \text{ kHz} = 1 \times 10^{3} \text{ Hz (thousand hertz)}$$

and $$1 \text{ MHz} = 1 \times 10^{6} \text{ Hz (million hertz)}$$

The speed of light (c), wavelength (λ), and frequency (ν) are related to one another as follows:

$$\nu = \frac{c}{\lambda}$$

or $$\lambda = \frac{c}{\nu}$$

Example

The wavelength of the red light from the traffic signal is 625 nm. What is the frequency of this light?

Answer

In order to solve for wavelength, the required equation is

$$\nu = \frac{c}{\lambda}$$

The speed of light is given in meters/s, the most convenient way is to first convert the given wavelength to meters using the fact that 1 m = 1 x10^9 nm.

$$\lambda = 625\,\text{nm}\,\text{x}\,\frac{1\text{x}10^{-9}\,\text{m}}{1\,\text{nm}} = 625\,\text{x}\,10^{-9}\,\text{nm} = 6.25\,\text{x}\,10^{-7}\,\text{nm}$$

Substituting this value and also the value of the speed of light into above equation yields the frequency.

$$\nu = \frac{c}{\lambda} = \frac{3\text{x}10^{8}\,\text{m / s}}{6.25\text{x}10^{-7}\,\text{m}} = 4.8\,\text{x}\,10^{14}\,\text{Hz}$$

Example

Find the wavelength in nanometers (nm) of the X-rays whose frequency is 6.45 x 10^{18} Hz.

Answer

To solve for wavelength, the following equation is useful.

$$\lambda = \frac{c}{\nu}$$

Substituting the given frequency and the speed of light gives the wavelength in meters.

$$\lambda = \frac{c}{\nu} = \frac{3\,\text{x}\,10^{8}\,\text{m / s}}{6.45\,\text{x}\,10^{18}\,\text{/ s}} = 4.65\,\text{x}\,10^{-11}\,\text{m}\,\text{x}\,\frac{1\,\text{x}\,10^{9}\,\text{nm}}{1\,\text{m}} = 4.65\,\text{x}\,10^{-2}\,\text{nm}$$

Energy of a Photon

Prior to 1900s, the light was thought to be purely wave phenomenon, i.e., traveling in the space like a wave, the concept that was formulated within the realm of classical electromagnetic theory that treated electric and magnetic fields that make up a light as waves propagating through the space. That means the energy absorbed or emitted by atoms and molecules is continuous. However, later discoveries, notably, black body radiation and photoelectric effect, shed a doubt on this concept. Hence, the quantum mechanics was invented.

According to quantum mechanics, atoms and molecules absorb or emit energy in small bundles (packets) but not in a continuous manner. This small bundle of energy was called a **photon** or a **quantum** of light. As a matter of act, our world is a quantum world; things are always in discontinues fashion. For examples, when we walk, we do not walk continuously without skipping the space between the legs but we take steps (quantum). When we climb up the steps, we jump from one step to the next. These are quantum phenomenon.

The amount of energy (E) in a light packet depends on its frequency (ν) according to the following equation.

$$E = h\,\nu$$

where h is called Plank's constant, which has the value of $h = 6.626 \times 10^{-34}$ J.s. Thus knowing the frequency of any light, the energy associated with it can be calculated using the above equation. Since $\nu = c / \lambda$, the above equation can also be written as,

$$E = \frac{h\,c}{\lambda}$$

This equation enables us to calculate the energy of a single photon of light by knowing its wavelength.

Example

Calculate the energy in joules of a photon with a wavelength of 7.25×10^{6} nm (microwave region).

Answer

First the nanometer (nm) is converted to meters (m).

$$\text{nm} = 7.25 \times 10^{6}\,\text{nm} \times \frac{1\,\text{m}}{1 \times 10^{9}\,\text{nm}} = 7.25 \times 10^{-3}\,\text{m}$$

Then this value along with the values of c and h are substituted in the above equation to give energy.

$$E = \frac{h\,c}{\lambda} = \frac{(6.626 \times 10^{-34}\,\text{J.s})(3.0 \times 10^{8}\,\text{m/s})}{7.25 \times 10^{-3}\,\text{m}} = 2.741 \times 10^{-23}\,\text{J}$$

This is the energy of a single photon with a wavelength of 7.25×10^6 nm. If you want to calculate the energy of one mole of photons, multiply this number by Avogadro's number. Try it!

Click on
Hands on Practice to Calculate Wavelength, Frequency, or Energy

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