# 1.3 Photons

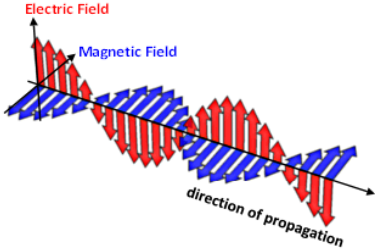
## Electromagnetic Radiation

In addition to space and time, the fabric of the Universe consists of matter and radiation. Matter is composed of what we traditionally call particles: protons, neutrons, electrons and many others we shall meet later. We shall also see that these "particles" often behave as if they were waves. Radiation, on the other hand, was thought to be composed of electromagnetic waves of a variety of wavelengths, from gamma at the shortest end to radio, with wavelengths a million trillion times longer. But these waves can also behave as if they were particles. Matter and radiation are different manifestations of the same thing and are probably neither waves nor particles. More on this later.

## The Electromagnetic Spectrum

| Radiation | radio | microwave | infrared | visible | ultraviolet | X-radiation | γ-radiation |
|---|---|---|---|---|---|---|---|
| Range of wavelengths | > 0.1 m | 0.1 m – 1mm | 1mm - 700nm | 700nm-400nm | 400nm-1nm | < 1nm ($\sim 10^{-10}$ m) | < 1nm ($\sim 10^{-15}$ m) |

Electromagnetic waves are transverse and consist of vibrating electric and magnetic fields. They oscillate at right angles to each other and in phase, as shown opposite.




Electromagnetic waves are emitted when charged particles accelerate of decelerate and when electrons in atoms lose energy and fall to lower energy levels.
All electromagnetic waves travel at the same speed in a vacuum. This is known as the speed of light, ($3.0 \times 10^8$ m $s^{-1}$).

The wavelength ($\lambda$) and speed ($c$) are related by the equation

$$c = f\lambda$$

Where $f$ is the frequency of the radiation, in hertz (Hz).

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## Photons

As we shall see later, electromagnetic radiation often behaves as if it were composed of particles. Einstein called these **photons**. They are discrete "packets" of energy. The energy of a photon is given by the equation

$$E = hf \quad \text{or} \quad E = \frac{hc}{\lambda}$$

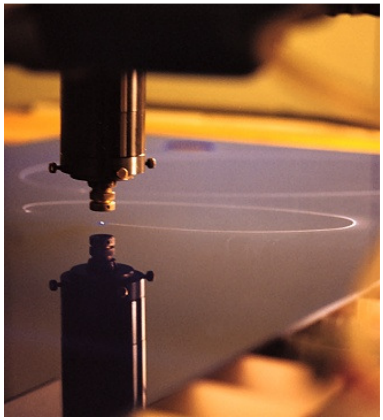
Where $h$ is a tiny number known as Planck's constant, ($6.63 \times 10^{-34}$ J s).
(Max Planck was the father of the Quantum Theory. We shall meet this later).

## Laser Beams

A laser beam is a stream of identical photons. We call this **coherent** light. Laser beams can be very powerful – enough to cut through steel, for example – and lasers are also being used now to drive the process of thermonuclear fusion.
The power of a laser beam can be calculated using the equation

$$power = nhf$$

Where $n$ is the number of photons arriving per second.
(Remember, power = energy per second).



A laser beam being used to cut sheet metal