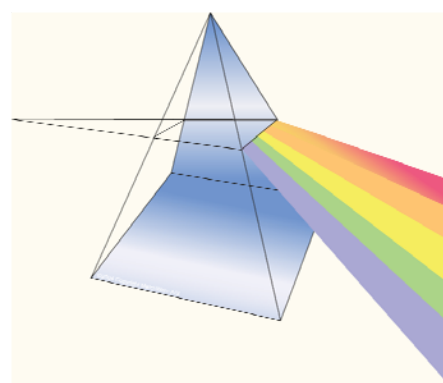


|        |                     |
|--------|---------------------|
| Topic: | THE NATURE OF LIGHT |
|--------|---------------------|

| General topic  | Objective ID | Objective   |
|--|--------------|---|
| FK_B1_03<br><br>Bohr's atomic theory and atomic emission spectra | FK_B1_03_01  | <p><b>Given</b> the wavelength (<math>\lambda</math>) of a radiation (in nm or Å) and the equivalence between energy units (J and eV)</p> <p><b>determine:</b></p> <ul style="list-style-type: none"> <li>• the period (T) of the radiation</li> <li>• the frequency (f) of the radiation</li> <li>• the energy (E) of a photon of this radiation (in J and eV)</li> </ul> <p><b>using</b> Planck's constant and the relationships between period, frequency and wavelength</p> |

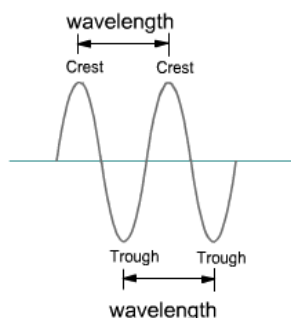
### Light as a wave: the wave model of light

Isaac Newton was the first scientist to observe that white light could be dispersed by a prism into the **spectrum** of colors.



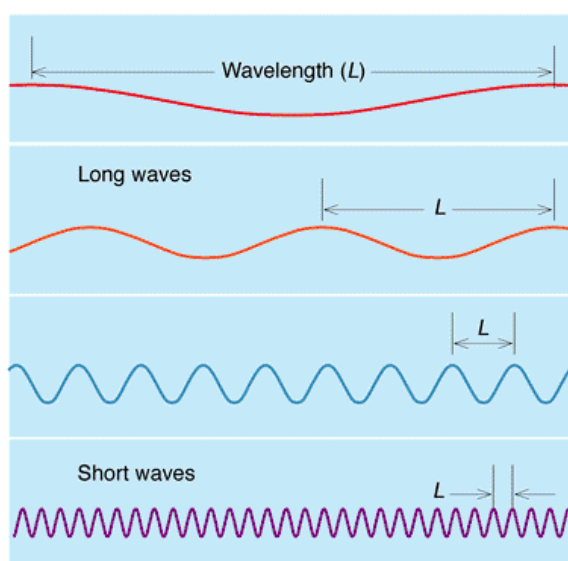
The different colors of light are characterized by their wavelengths and frequencies.

The wavelength ( $\lambda$ , lambda) is the distance between two identical points (crest, trough, node...) in the adjacent cycles of the wave.



<http://library.thinkquest.org>

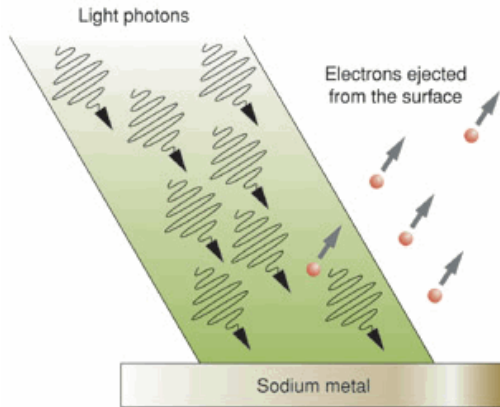
The relation between the color of a monochromatic (one color) ray and the wavelength is as follows: a ray of violet color (one end of the visible spectrum) is shorter (the wavelength is smaller) than a ray of red light (at the other end of the spectrum).



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## The corpuscular model of light: light as photons

The wave model of light can't explain some experiments, like the photoelectric effect. In the photoelectric effect, when light shines on a metal surface, electrons can be knocked out of the surface. Electrons can be knocked out of the metal by high frequency light (short waves).



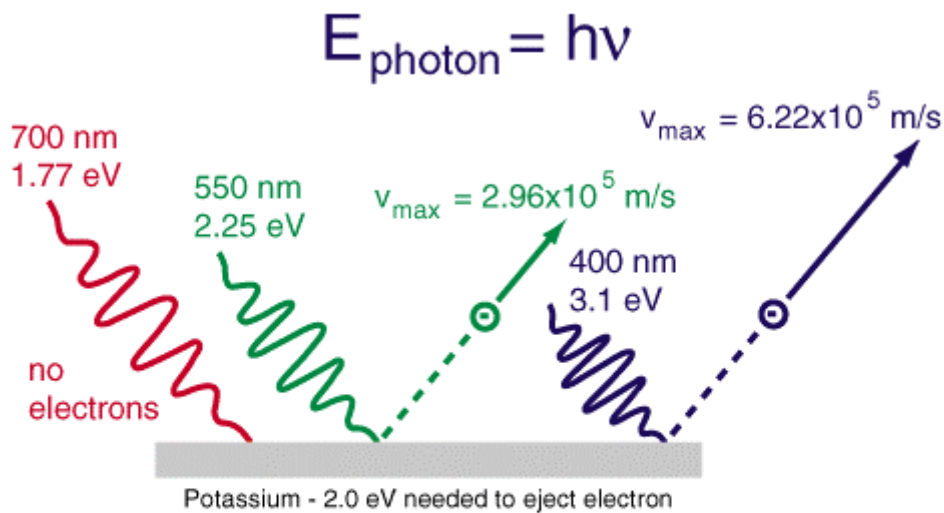
<http://www.llnl.gov>

It seems that light consists of wave packets or **photons**.

The energy of the photon depends on the frequency of the light, as expressed in the Planck's equation:

$$E = h.f$$

where E is the energy of the photon, f is its frequency and h is the Planck's constant. The value of the constant is  $6,63 \cdot 10^{-34}$  J.s



## Photoelectric effect

<http://hyperphysics.phy-astr.gsu.edu>

## Properties of light

The properties of waves that we are going to study here are:

- wavelength ( $\lambda$ , lambda)
- velocity of propagation ( $v$ )
- period ( $T$ ) and frequency ( $f$ )

As mentioned before, wavelength is the distance between two adjacent similar points (crest, trough...). That distance can be measured in metres, cm ( $10^{-2}$  m),  $\mu\text{m}$  ( $10^{-6}$  m), nm (nanometre,  $10^{-9}$  m), Å (angstrom,  $10^{-10}$  m).

All electromagnetic waves propagate in vacuum at a velocity of  $3 \cdot 10^8$  metres per second (m/s) (speed of light)

Period is the interval of time between two adjacent similar points (crest, trough, node...). Period is measured in seconds.

Frequency is the number of times a wave is repeated in a second. Frequency is measured in Hertz (Hz or cycles/second)

The relation between period and frequency is:

$$f = 1/T \leftrightarrow T = 1/f$$

The relations between velocity of propagation ( $c$ ), wavelength ( $\lambda$ ), period ( $T$ ) and frequency ( $f$ ) are as follows:

$$c = \frac{\lambda}{T} = \lambda \cdot f$$

In order to help remember the previous equations, we can write:

$$c \text{ (velocity)} = \frac{\lambda \text{ (space of a cycle)}}{T \text{ (time of a cycle)}}$$

$$c = \frac{\lambda}{T \text{ (= } 1/f)} = \frac{\lambda}{1/f} = \lambda \cdot f$$

Given the wavelength of a monochromatic light (only one type of light) we could determine the energy carried by a photon of that light in two steps: 1) determine the frequency and 2) determine the energy, using the Planck's equation.

### Energy of a photon

Lightwaves carry energy that is determined by the Planck's equation:

$$E = h.f$$

"h" is the Planck's constant and the value is  $6,63 \cdot 10^{-34}$  J.s. That equation gives us the energy of each photon of that light.

The energy can be given in J (Joule) or eV (electron-volt). The equivalence between both units is:

$$1 \text{ eV} = 1,6 \cdot 10^{-19} \text{ J}$$

$$1 \text{ J} = 6,2 \cdot 10^{18} \text{ eV}$$

The relations between the previous variables are:

$$\lambda \xrightarrow{\lambda=c.T} T \xrightarrow{f=1/T} f \xrightarrow{\substack{\text{PLANCK} \\ E=h.f}} E$$

$$\lambda \xrightarrow{f=c/\lambda} f \xrightarrow{\substack{\text{PLANCK} \\ E=h.f}} E$$

### Worked example

A monochromatic light has a wavelength of 650 nm. Determine the energy carried by a photon of this light

a) Determination of the period

$$\lambda = c.T \rightarrow T = \frac{\lambda}{c} = \frac{6,5 \cdot 10^{-7} \text{ m}}{3 \cdot 10^8 \text{ m/s}} = 2,17 \cdot 10^{-15} \text{ s}$$

b) Determination of the frequency

$$f = \frac{1}{T} = \frac{1}{2,17 \cdot 10^{-15} \text{ s}} = 4,62 \cdot 10^{14} \text{ Hz}$$

c) Determination of energy

$$E = h.f = 6,63 \cdot 10^{-34} \text{ J.s} \cdot 4,62 \cdot 10^{14} \text{ s}^{-1} = 3,06 \cdot 10^{-19} \text{ J}$$

$$E = 3,06 \cdot 10^{-19} \text{ J} \cdot \frac{1 \text{ eV}}{1,6 \cdot 10^{-19} \text{ J}} = 1,91 \text{ eV}$$

### Problem

Determine the wavelength of a monochromatic light, knowing that the energy of each photon is 3,2 eV

Solution: 385 nm