# Chemistry Lecture #23: Energy, Photons, Frequency and Wavelength

We've covered the parts of the atom: electrons, protons and neutrons. There's something that interacts with the electrons in an atom: electromagnetic energy.

The heat we feel from the sun, the light we emitted by a lightbulb, and the ultraviolet rays that give us sunburn are all forms of electromagnetic energy.

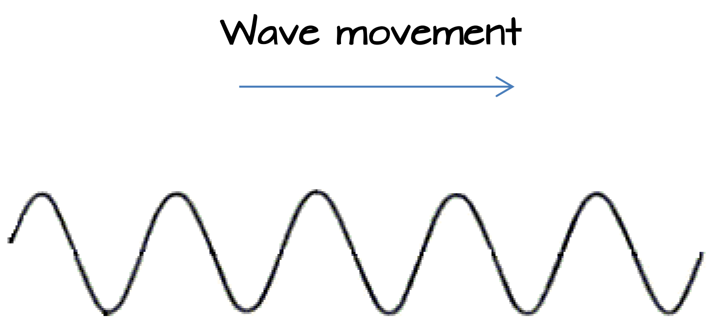
Electromagnetic energy exists as tiny discrete packages called photons. For now, we can think of a photon as a tiny sphere made of energy.

At this point I have to warn you that I'm going to tell you things that might not make sense or sound contradictory. Weird things happen at the atomic level. So you'll just have to trust me when I tell you how the photon behaves. Sorry!

I also apologize to anyone with a PhD in physics who may think I'm not explaining this correctly. Unfortunately, I can't think of any better way to explain the strangeness of the quantum world.

Okay, first of all, a photon moves up and down in a wave pattern (trust me). Here's a picture of a photon moving left to right in an up and down in a wave pattern.


Instead of drawing the photon moving, we just draw the waves and say the waves are moving, like ocean waves toward the beach.




The photon, or the waves, always move at a speed of $3.00 \times 10^8$ m/s. This is the speed of light. We use the letter c to represent the speed of light.

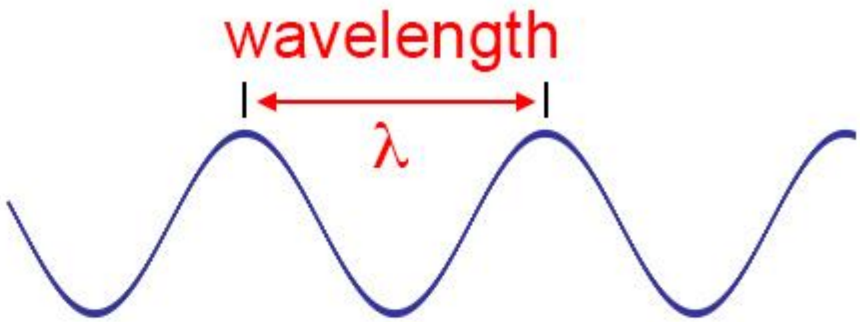
Suppose the wave is moving and 6 of its peaks pass by you in 2 seconds. The frequency (f) of the wave is 6 waves divided by 2 seconds, which gives you 3 waves per second.

$$f = \frac{6 \text{ waves}}{2 \text{ s}} = \frac{3 \text{ waves}}{\text{s}} = \frac{3}{\text{s}} = 3 \text{ s}^{-1} = 3 \text{ Hz}$$

Instead of saying 3 waves/sec, we write 3 Hertz or 3 Hz. Sometimes instead of Hz you see $s^{-1}$ used.

3 Hz means that in 1 second, 3 wave peaks will pass by. Thus, frequency is the number of wave peaks that pass a point in one second.

The distance between wave peaks is the wavelength. We use the Greek letter lambda (λ) to represent wavelength.




Wavelength is measured both meters (m) and nanometers (nm). The distance between wave peaks is very small. For example, a photon of green light could have a wavelength of $5 \times 10^{-7}$ m. It's awkward to say this number, so we convert it to nanometers by multiplying it times a billion ($10^9$) and we get 500 nm, which is easier to say.

Unfortunately, we have to convert nanometers to meters when we do wavelength calculations. To convert nanometers to meters, just tack on " $\times 10^{-9}$" and that will put the answer into meters.

For example, 1 nm = $1 \times 10^{-9}$ m

2 nm = $2 \times 10^{-9}$ m

500 nm = $500 \times 10^{-9}$ m

There is a mathematical relationship between the speed, wavelength, and frequency of a photon. The formula is

$$c = \lambda \times f$$

where c = speed of light = $3.00 \times 10^8$ m/s

$\lambda$ = wavelength in *meters*

f = frequency in Hz

Try this problem: a photon has a wavelength of 500 nm. What is its frequency?

Solution: You need to first convert the wavelength to meters.

500 nm ⟶ $500 \times 10^{-9}$ m

Now substitute terms and solve.

$$c = \lambda \times f$$
$$3.00 \times 10^8 \text{ m/s} = (500 \times 10^{-9} \text{ nm})\, f$$
$$3.00 \times 10^8 = (500 \times 10^{-9})\, f$$
$$f = 6.00 \times 10^{14} \text{ Hz}$$

Try this one: The frequency of a photon is $8.00 \times 10^{14}$ Hz. Find the wavelength.

$$c = \lambda \times f$$
$$3.00 \times 10^{8} = \lambda \times (8.00 \times 10^{14})$$
$$\lambda = 3.75 \times 10^{-7} \text{ m or } 375 \text{ nm}$$

If you know the frequency of a photon, you can calculate its energy from

$$E = hf$$

where E = energy of the photon in joules (J)

h = Planck's constant = $6.62 \times 10^{-34}$ J/Hz

f = frequency in Hz

What is the energy of a photon whose frequency is $6 \times 10^{14}$ Hz?

Solution:

$$E = hf$$
$$E = (6.62 \times 10^{-34} \text{ J/Hz})(6 \times 10^{14} \text{ Hz})$$
$$E = 3.97 \times 10^{-19} \text{ J}$$

Try this one: The wavelength of a photon is 400 nm. Find the frequency and energy of the photon.

Solution:

400 nm $\longrightarrow$ $400 \times 10^{-9}$ m

$$c = \lambda \times f$$

$$3.00 \times 10^{8} = (400 \times 10^{-9})\, f$$

$$\underline{f = 7.5 \times 10^{14}\ \text{Hz}}$$

$$E = hf$$

$$E = (6.62 \times 10^{-34})(7.5 \times 10^{14})$$

$$\underline{E = 4.96 \times 10^{-19}\ \text{J}}$$