What exactly is quantum mechanics (In other words, why are we learning physics in a chemistry course?!?!)

Chemistry starts with the structure of the atom, which is the build block of matter. We would like to be able to describe an atom's structure. In the earlier days, people like Rutherford used classical mechanics (laws of motions proposed by Issac Newton) to describe the structure of an atom.

Sadly, good old physics may work on everyday objects but it FAILED when dealing with the atomic structure. This failure give rise to a series of new laws of physics we collectively called quantum mechanics. We good so far?

Electromagnetic Radiation:
Chapter 8.1
Pg 278.

<u>Key equations:</u>
c = $\lambda \upsilon$
where c = speed of light (2.998 x 10^8m/s)
$\lambda =$ the wavelength
$\upsilon =$ frequency (looks like small v)

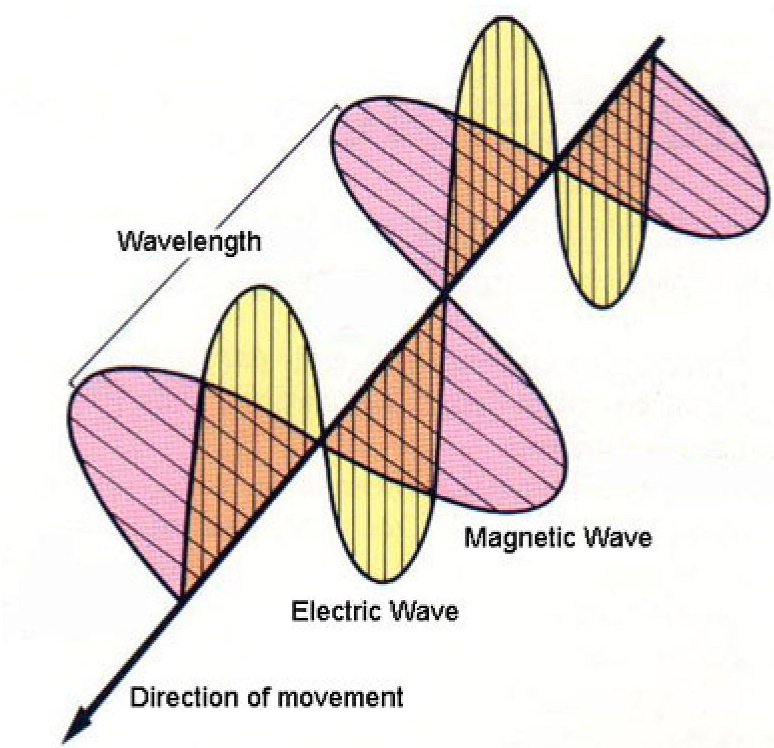
First topic of every chemistry textbook on Quantum Mechanics starts with Electromagnetic Radiation, which is a fancy term for what we commonly associate with light. Why do they do that? What's the connection? How is understanding light going to help me with Quantum mechanics?

Well, you see, the entire foundation of quantum mechanics lies on light, or more specifically, the energy associated with light. To really understand the quantum stuff, you must know light !

Ok, I said just above that electromagnetic radiation is a fancy name for light. Now, I am going to contradict myself and for a good reason. You see, light is only part of the EMR (ElectroMagnetic Radiation). EMR is really composed of visible light (which we simply call light), microwaves, x-rays etc.. The important thing is.. they all contain energy! This energy is the key to understanding quantum mechanics and chemistry (maybe physics too!)

Well, lets explore this EMR family. All members of this family are made from oscillating (oscillate means time-varying, now that is a very bad definition. What we mean by oscillating is moving up and down, over and over again) electric and magnetic fields. (Field as a region where this thing has influence) Now don't panic. Electric and magnetic fields are nothing special. They share a common property and that is opposite charges attract and same charges repel each other.

Think of the magnetic field as a magnet. You know how it behaves. The electric field is a bit hard to visualize but think of it as a magnet also but instead it is powered by electricity. The key thing about these two fields that as the fields oscillate and interact with each other , they each generate a wave that is self – propagating (they can travel by themselves) To apply this to a real life example. If you take a string and shake it at one end, you will see a wave pattern on the string. Your hand is the oscillating electric and magnetic field and this oscillation causes a wave. Here is a picture to help you get around this concept.



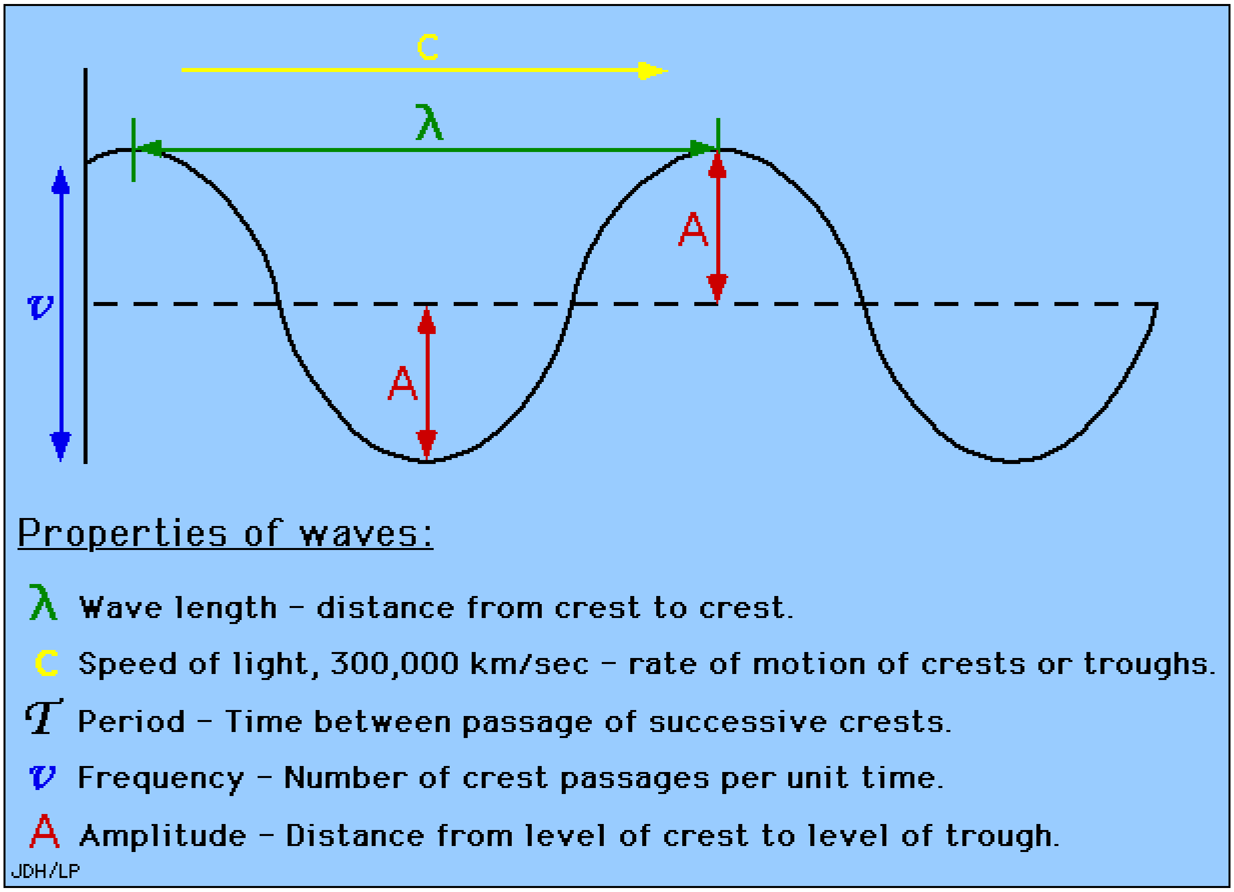
So, this wave thing travels from its oscillating source. Can you follow me so far?

You must be wondering.. in the picture, you clearly saw two waves. Yes, that's right. EMR are composed of two waves that are perpendicular to each other (90 degrees to each other) However, to make things easier to explain, we commonly just use a single wave. (Think it like this. DNA is a double helix made up of two strands. When we try to explain things to people who are new to Biology, we commonly use a single strand to explain how its nitrogenous base stores the genetic code etc..)

Physicists like to label things. They took this wave and labelled its parts. Here are some common terms we associate with waves.

Amplitude
Frequency

Wavelength
What are those? Lets look at a diagram.



Amplitude is commonly associated with how strong the wave is. (Think of the wave as an ocean wave) Frequency- how fast each successive waves comes. (How frequent are the waves) Wavelength is the distance between crests/troughs (think of it as how long each wave is).

Maybe you have already deduced this or maybe not. EMR are waves made from the oscillating electric and magnetic fields. The frequency characteristic of EMR waves is very significant because it distinguishes between members of the EMR family. For example, visible light, microwaves, and radio waves have different characteristic frequency ranges, and the frequency of visible light determines its color. Our eyes detect different colors because they respond in different ways to light of different frequencies.

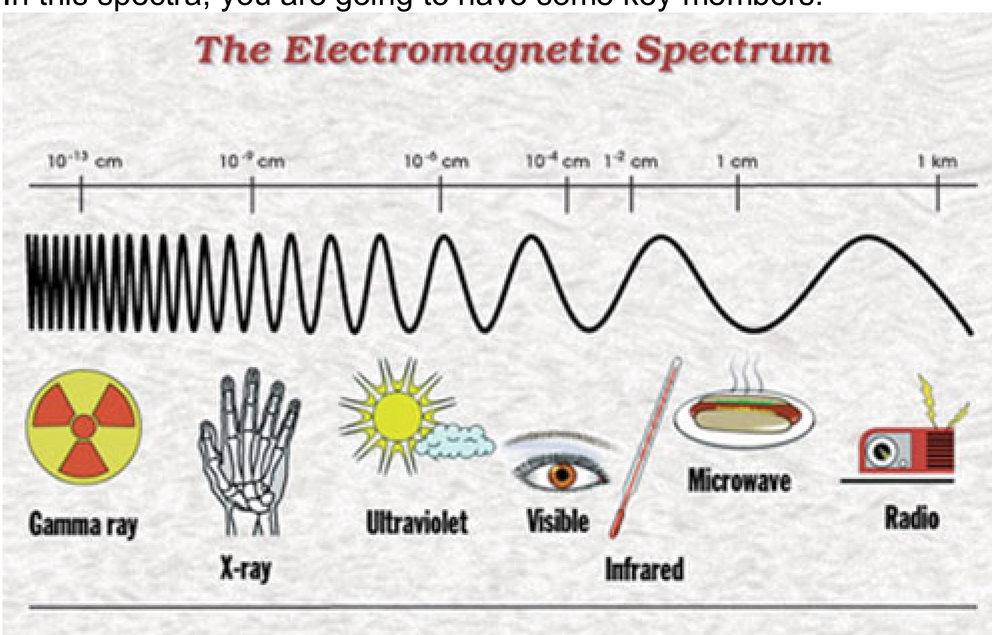
All EMR waves have a fixed speed of 2.998 x 10^8 m/s in a vacuum (this is only true in a vaccum!!). This is what we commonly called the speed of light, or c. Now imagine the wave is zooming along at the speed of light. If its wavelength is very short, very many complete oscillations pass a given point in a second. If the wavelength is long, the light still travels at the speed of c, but fewer complete oscillations pass the point in a second. A short wavelength therefore corresponds to a high-frequency radiation and a long wavelength corresponds to low – frequency radiation. The precise relation is

Wavelength x frequency = speed of light
Or
c = $\lambda\upsilon$

We can rewrite this equation in the form $\upsilon = \frac{c}{\lambda}$, which is VERY VERY useful for Bohr atom calculations. (Trust me!)

The other important thing about EMRs is that we have to know the members in this "family". Instead of calling it EMRs, we call the entire family electromagnetic spectra. (Don't ask why)

In this spectra, you are going to have some key members:



I mentioned earlier that frequency of electromagnetic spectra is very important because it distinguish its members. Well, the way frequency does this is by the energy that is associated with it. For now, just know that high frequency = higher energy. I won't explain why because I will do that when we are talking about Planck's hypothesis in section 8.3. On the diagram above, you can see that gamma rays have very high frequency (hence very short wavelength. Remember, c = $\lambda\upsilon$. c is constant, thus by increasing its frequency υ, you are lowering its wavelength. For example. If we let c = 3, then we assume $\upsilon = 2, \lambda = 1.5$. Thus, by changing υ to 3, λ has to decrease to 1 because c is a constant number and can't change)

Ok, with frequency varies with energy concept in mind, lets take a look at the diagram.

Starting at the left, we have gamma rays with very high frequency and hence very very high energy. There is no trick to memorize this, just remember that gamma has the highest energy.

Next highest in energy and frequency are the x-rays. You know that x-rays are very high energy right? Well, x-rays can't be too high in energy or they would kill you when you do a x-ray. Thus, x-rays are behind gamma rays in energy.

Next comes the UV. You hear about the UV index all the time. You know it is harmful because UV have high energy and can cause skin cancer blah blah blah…Well, UV can't be as damaging as x-ray because you experience UV radiation everyday.

After UV, comes the visible lights. Easy to remember. What you have to know for the visible section is that it starts at 320 nm (wavelength) and ends at 760 nm. Knowing this and the formula c = $\lambda \upsilon$, you can find out the starting and ending frequencies. Neat eh?

Visible section ends.. What's next? Most people are clueless from this point on. There is a thing called infrared (IR). The problem is.. we commonly associate IR with heat. This association mess up the order of the EMR spectrum because we tend to think that heat would have higher energy than light right? (Well, YOU are WRONG). IR comes after visible light, remember that!

After IR, we have microwaves, commonly written as μ waves. Again, this part can be a bit against the common sense. We all have microwave ovens and we think that it has a lot of energy because it can pop a bag of popcorns under 2 minutes. Well, sorry to say this, but microwaves have less energy than IR.

At last, we arrive at the radio waves. This should be ok because we know that radio waves have very low energy because we use radios and cellphones all the time and it hasn't killed us.. yet.

Ok, lets recap.

From highest energy (left) to the lowest (right)
γ (gamma) rays →x-rays → UV → Visible → IR → microwaves → Radio.

Wait.. wait. Before you think you are done with this section, here is something to memorize.
1 millimeter (mm) = 1 x 10^{-3} m
1 micrometer (μ m) = 1 x 10^{-6}m
1 nanometer (nm) = 1 x 10^{-9} m

1 picometer (pm) = 1 x 10^{-12} m

1 Mega something (i.e. MHz) = 1 x 10^{3} of that thing.

These are the very important unit conversions you have to know by heart. There is no alternative other than memorizing them. You are good at biology right? Then these should be no problem for you! If you know deoxyribouse acid, chemlito whatever graph, etc.. these numbers are a piece of cake.

Now, how to use them.. Say you are given 100 nm of something. To convert to meters, you would divide 100 nm by (1 x 10^{9}) because doing so would give you a much smaller number.. Which is correct considering the fact that nm is much smaller than m. Thus if you have 100 nm of something, you would have much much smaller of that quantity in meters. Got it?

End of 8.1, 8.2 coming right up!