Lesson 32: Birth of Quantum Mechanics

End of an Era...

At the end of the 1800s, physicists looked back at a period of 300 years of great growth…

- Newton had explained the motion of objects here on earth (and in the heavens).
- Maxwell had put together electricity and magnetism in his work on electromagnetic radiation.
- Thomson had figured out the mass of atomic particles.
- ...and more!

Altogether, most physicists believed that they had pretty much figured out the whole universe! They were willing to admit that there were still a few questions, but for the most part they were sure they could answer those problems based on what was already known. It was felt that it was only a matter of time (and not much time) before it would all be cleared up… right?

Wrong.

All of the physics you have studied up till now is called "Classical Physics."

- It works great for the kind of physics we've looked at, and you can keep on using it for those kinds of questions.
- The problem was that classical physics (as we now call it) could not explain a few nagging questions in physics right around the end of the 1800's.
  - One of these problems involved something called **blackbody radiation**.

Blackbody Radiation

A blackbody is an object that perfectly absorbs all wavelengths of EMR that strike it.

- This means that all EMR, from the lowest frequency AC radiation to the highest cosmic rays, will perfectly be absorbed by the object.
  - It's called a blackbody, since objects colored black absorb all *visible* light that falls on them. True blackbodies work even better than this, but it seemed like a good name.
- This EMR being absorbed is really energy that the blackbody is absorbing.

Blackbody radiation was also called **cavity radiation** at one time. In this model we imagine a hollow sphere with a single hole drilled in the side (the cavity), through which the EMR enters.

This energy is also perfectly re-emitted, released by the object, as EMR.

- According to classical physics, as the frequency of the emitted EMR increases, so should the intensity.
  - As more and more energy from the EMR was absorbed, it would cause the atoms of the blackbody to vibrate faster and faster at higher and higher frequencies.
  - These vibrating atoms (made of charged particles) would release higher and higher frequencies of more and more intense EMR.
- This classical physics explanation of the emitted EMR could be drawn as a graph (*Illustration 1*).

The problem is, this doesn't happen!

- Instead, the intensity of the emitted radiation does increase, until it reaches a particular frequency that depends on the temperature, and then drops.

- The peak frequency is the reason why different objects at different temperatures appear as different colors, like the red hot burner on a stove.
  - The higher the temperature, the higher the peak frequency shifts up to.
  - So the shift in visible light as the temperature increases is from red to violet.

So, why don't you ever see a burner on a stove glowing green? As the colors shift higher and higher, most of the colors eventually end up being emitted strongly, so they all blend into white light.

- We also have a generic graph of this (for no particular temperature) on the graph in *Illustration 1*.

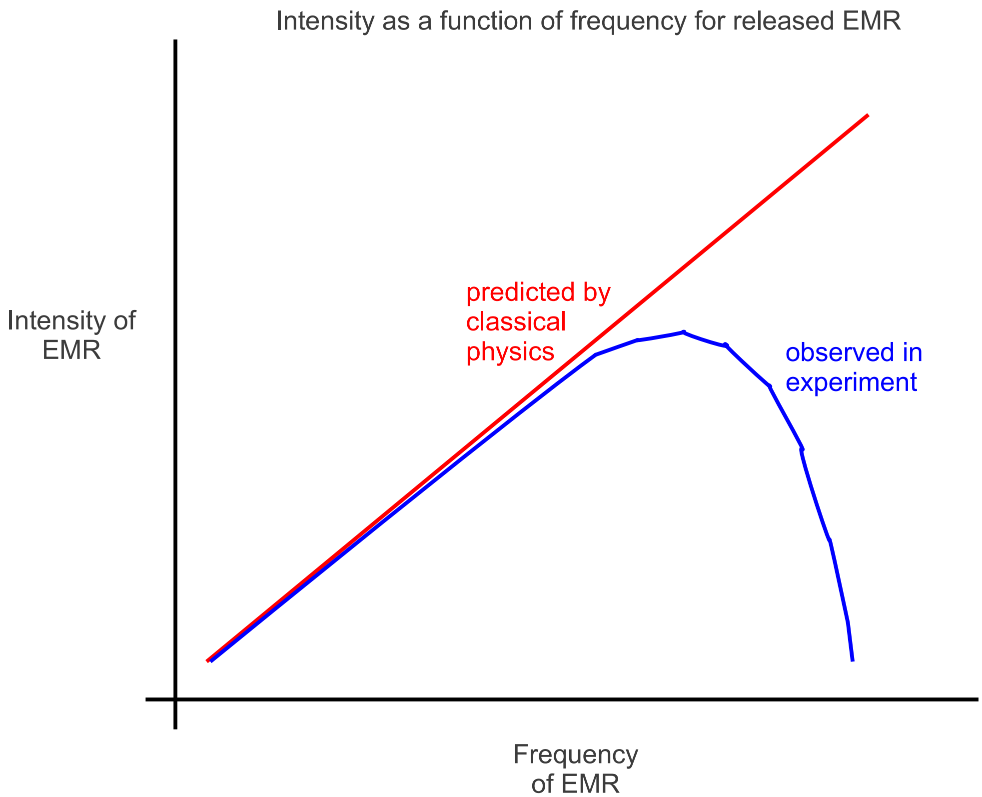

Illustration 1: Blackbody radiation prediction and reality.

Physicists could not explain why the graph suddenly drops off, or why it peaks at the particular frequencies at particular temperatures.

- Some of the best minds of the time worked on this, people like Wilhelm Wien, Lord Rayleigh, and Sir James Jeans.
  - Never heard of these guys? Doesn't surprise me. Although they made important contributions in physics, their attempts at blackbody radiation failed to come up with an explanation.
- Because the frequency that the graph drops of at corresponds roughly to the frequency of ultraviolet radiation, this problem became known as the **Ultraviolet Catastrophe**.

Illustration 2: Max Planck

Max Planck

Late in the year 1900, Max Planck (pronounced "Plonk," not kidding) came up with a new idea that would solve the problems everyone was having trying to explain blackbody radiation.

- Up to this point everyone was assuming that those little vibrating electrons (thought to be absorbing and then re-emitting the blackbody radiation) could vibrate at any frequency.
- Planck suggested that there is a minimum amount of energy that a particular frequency of EMR can transfer to the matter.
- This smallest individual "piece" of energy was called a **quantum**.

Quanta is the plural form of **quantum.** So a bunch of individual pieces of energy is called quanta.

The idea of pieces of energy, **quanta**, was used to explain the shape of blackbody radiation graphs.

- Planck found that a very simple formula could be used to calculate the quantum at a particular frequency of EMR…

$$E = hf$$

E = energy of the radiation (J)
h = Planck's Constant = 6.63e-34 J·s
f = frequency of the EMR (Hz)

Warning! Two Special Notes!

This formula is the amount of energy emitted by a single "piece" of radiation. To have multiple pieces, the formula would look like…

$$E = nhf$$

n = number of "pieces" of radiation emitted

Sometimes we measure the energy in electron volts, so we use a different value for Planck's Constant, h = 4.14e-15 eV·s . Only use this value if you have a really good reason to.

Planck was saying that energy is not continuous, but instead is **quantized**, coming in tiny pieces.

- This is sort of like when you look at a picture in the newspaper.
  - On a big scale it *looks* like a continuous picture.
  - If you can get down to the little details you'll see it's *actually* made up of little dots that blend together. Quanta.

Example 1: **Determine** the smallest amount of energy from a light source that emits light at a frequency of 4.50e14 Hz.

E = hf
E = 6.63e-34 (4.50e14)
E = 2.9835e-19 = 2.98e-19 J

It is normal to state this answer in Joules. If we had calculated it with the other value of Planck's Constant we would have had the answer 1.86 eV.

Example 2: **Determine** the minimum energy transferred by a light source with a 212 nm wavelength in electron volts.

Remember the universal wave equation can apply to EMR...

$$v = f\lambda$$
$$c = f\lambda$$
$$f = \frac{c}{\lambda}$$

This can be substituted into Planck's formula...

$$E = hf = \frac{hc}{\lambda}$$
$$E = \frac{4.14\text{e-}15(3.00\text{e}8)}{212\text{e-}9}$$
$$E = 5.85849 = 5.86\,eV$$

Albert Einstein

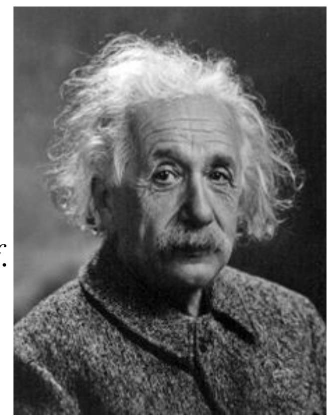

Illustration 3: Albert Einstein... ya mighta heard of him.

In 1905 an unknown physicist named Albert Einstein came up with an idea that built on what Planck had said.

- Planck thought that his ideas of quanta and E = hf was all about how matter absorbed and emitted energy.
  - Remember, he was focused on explaining blackbody radiation.
- Einstein suggested that these ideas were primarily about the *light itself*.
  - He figured that light itself was where it all started, that the light itself was made up of individual pieces.
  - The reason this was so radical an idea was because it meant that light was acting like a **particle**.
  - The light particles were eventually named **photons**.

This idea was not immediately accepted by everyone, since there was so much evidence that light acted as a wave, not a particle.

- As we will see in later lessons, the amount of evidence that light had a particle nature increased to a point it couldn't be ignored.
- This does not mean that we abandon the wave nature. Instead we will bring the two ideas together.

Photon comes from the Greek word for light. Einstein originally called photons a "light quantum." The chemist Gilbert N. Lewis came up with the name photon.

Example 3: You buy a laser at the store and read on the label that it has a frequency of 4.38e15 Hz. The label also says that it runs at 4.06 mW. **Determine** how many photons it can release in one second.

First, determine how much energy the laser can put out in one second...

$$P = \frac{\Delta E}{t}$$
$$\Delta E = Pt$$
$$\Delta E = 4.06\text{e-}3(1)$$
$$\Delta E = 4.06\text{e-}3\,J$$

This is the energy is being released as a bunch of individual photons. We can calculate how many photons by using the special version of Planck's formula that has “n” for the number of photons in it...

$$E = nhf$$

$$n = \frac{E}{hf}$$

$$n = \frac{4.06\text{e-}3}{6.63\text{e-}34(4.38\text{e}15)}$$

$$n = 1.3981005\text{e}15 = 1.40\text{e}15 \ \textit{photons}$$

Homework

p706 #1-3
p707 #1-3
p708 #1-2