The Quantum Theory of Light

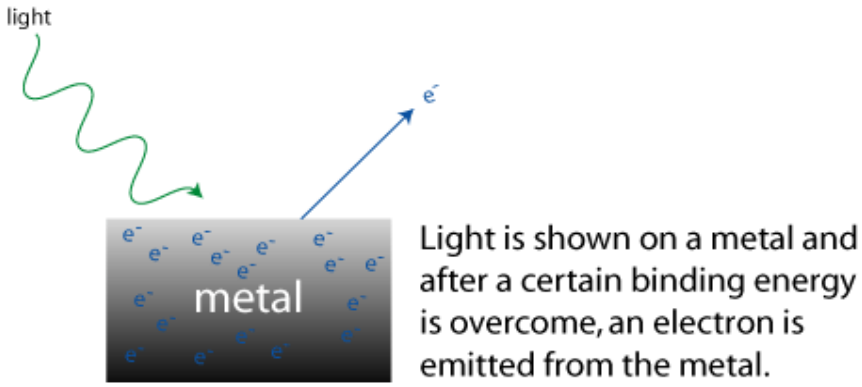
In 1900, the German physicist Max Planck proposed that energy of a packet being directly proportional to the frequency of the radiation, $E = hf$. He called the packet as “quanta”.

But Planck did not offer a physical basis for his proposal; it was largely a mathematical construct needed to match the calculated blackbody spectrum to the observed spectrum.

In 1905, Sir Albert Einstein proposed the quantum theory of light.

According to the quantum theory of light, ***light is a composition of small packets of energy which are called photons and have wave-like properties***. Energy of an photon is hf.

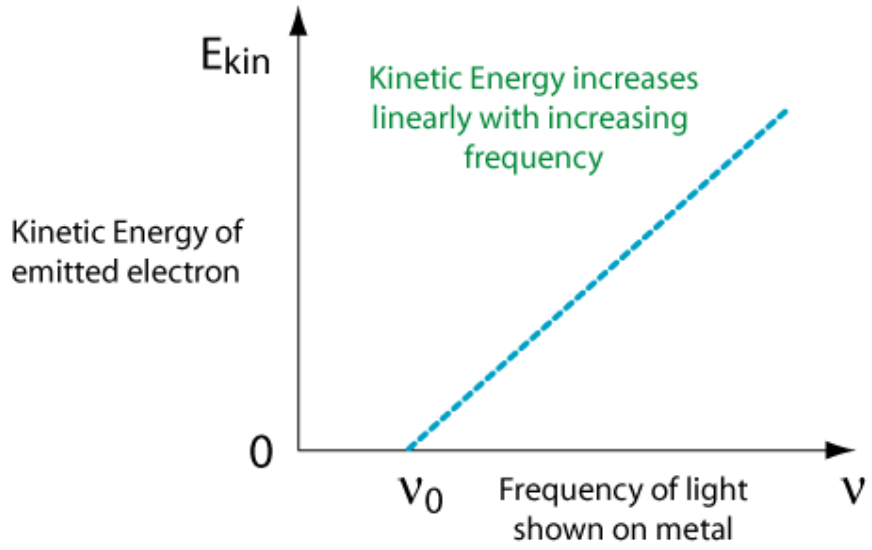
Its true that Einstein’s theory was more complex than Max Planck’s theory, but it was more physical. He supported his photon hypothesis with an analysis of the photoelectric effect, a process, discovered by Hertz in 1887, in which electrons are ejected from a metallic surface illuminated by light.



An important feature of this photoelectric effect is that the electron is emitted from the metal with a specific kinetic energy.

Now anyone who is familiar with the behavior of waves knows that the energy associated with a wave is related to its amplitude or intensity. For example, at the ocean the bigger the wave, the higher the energy associated with the wave. It's not the small waves that knock you over it's the big waves! So everyone who thought light is just a wave was really confused when the intensity of the light was increased (brighter light) and the kinetic energy of the emitted electron did not change. What happens is that as you make the light brighter more electrons are emitted but all have the same kinetic energy.

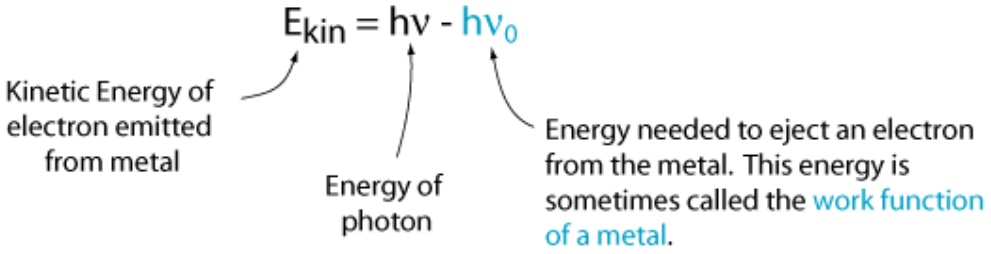
Well, they thought the kinetic energy of the emitted electron must depend on something. So they varied the frequency of the light and *this* changed the kinetic energy of the emitted electron.



However, there is a critical frequency for each metal, ν_0, below which no electrons are emitted. This tells us that the kinetic energy is equal to the frequency of the light times a constant. That constant is called Planck's Constant and is given the symbol h.

$$h = 6.63 \times 10^{-34}\ J \cdot s \leftarrow \text{Planck's Constant}$$

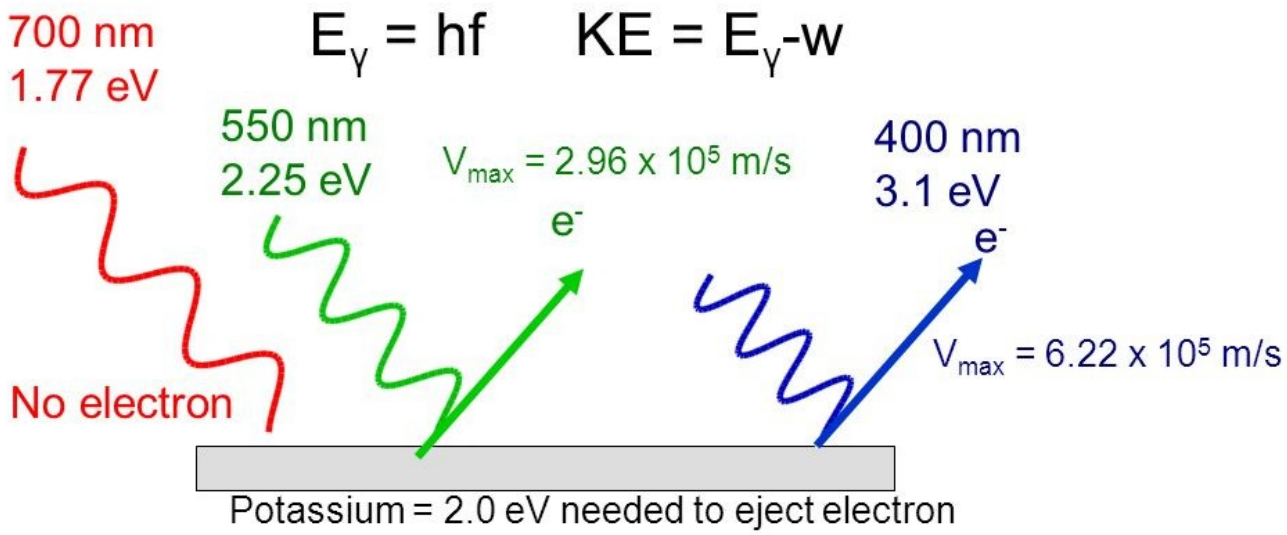
Now we can write an equation for the kinetic energy of the emitted electron.



This result is not consistent with the picture of light as a wave. An explanation that is consistent with this picture is that light comes in discrete packages, called photons, and each photon must have enough energy to eject a single electron. Otherwise, nothing happens. So, the energy of a single photon is:

$$E_{photon} = h\ \nu$$

When this was first understood, it was a very startling result. It was Albert Einstein who first explained the photoelectric effect and he received the Nobel Prize in Physics for this work.



Photoelectric effect

From the theory we can explain,

1. how photoelectric effect works.
2. how light carry outs energy from one place to another place.
3. we can also explain that the energy of a light is depend on it's frequency, not on it's amplitude or brightness.
4. Blackbody radiation in bigger picture.

Question Answer:

1. What is photoelectric effect?
= The photoelectric effect is the emission of electrons when electromagnetic radiation, such as light, hits a material.

2. What is photon?
= A particle representing a quantum of light or other electromagnetic radiation. A photon carries energy proportional to the radiation frequency but has zero rest mass

3. What is quantum?
= A quantum is a minimum amount of any physical entities involved in a intersection.

4. Why photon has no mass?
= Because they travel at the speed of light. And as the equation $E = mc^2$ says , if an object travel at the speed of light, all the mass of the object will converted into energy. So photon has energy (hf) but don't have any mass.

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