

Hello. In this video we'll talk about photoelectric effect and discuss the concept of particle nature of radiation. Here is the outline of this talk. So the learner will be able to understand the photoelectric experiment, explain the observation of the photoelectric effect using the particle nature of light and understand Einstein's concept of photons and the photoelectric equation. Photoelectric effect was discovered by Hertz in 1887, so when light of short wavelength is incident onto a metal, electrons were emitted out. And those electrons are called the photoelectrons. So this effect is observed in solid liquid's as well as in gases. Einstein supported his photon concept by using it to explain this effect. Here is a set up of the photoelectric experiment which I would like to show you on the PHET simulation. Here is the PHET simulation of photoelectric effect. As you can see, there is a lamp here which emits light and is incident onto this metal terminal. There are two terminals which are connected by a battery. So let's increase the intensity of light, as you can see now the photoelectrons are coming out. Now the potential is zero but still you can see that the electrons have some velocity and the electrons are emitted out with some kinetic energy. Let's look at the current versus voltage plot. If I make this potential positive and increase the potential, the current will slightly increase and it will reach saturation. And as I increase it further, electrons will get faster and faster. The current will remain the same. Now if I change the polarity of the battery, then in this case this becomes positive and this terminal becomes negative the cathode. So the electrons coming over here will be repelled from the surface and won't reach the cathode. I'll go back so that we have some small current. The electrons in the circuit are detected as current. So as I increase the negative potential a point will reach that the current will be zero. That is an electron having my maximum kinetic energy won't be allowed to reach the cathode and won't be detected as a current. So this potential when the current just becomes zero is the stopping potential. And this is the graph of current versus voltage. OK, now we've talked about the observation of the photoelectric effect. The energy distribution in the emitted electrons is independent of intensity. Now we see that in the simulation. So the energy distribution of an electron is independent of intensity. As we can see here, if I increase the intensity, the number of photoelectrons coming out increases but the energy distribution of electrons remains the same. So as I as a decrease intensity, the number coming out will be less but again the energy distribution remains the same. Second observation is that the energy distribution depends on the frequency of light, not an intensity. So let's check this out. So if I increase the frequency, as you see, the kinetic energy of the electron increases. As you can see in this plot as well. This plot is of kinetic energy versus frequency and as I increase the frequency the kinetic energy increases. As I decrease the frequency kinetic energy decreases linearly till I reach a point where the kinetic energy becomes zero. That is the threshold frequency. If I decrease the frequency further then no electrons will be emitted. If the frequency is below the threshold frequency no electrons are emitted.

Third observation is the current in the circuit is directly proportional to the intensity, so we'll see that. As I increase the current you see that the intensity increases linearly. So there are three main features of classical physics that could not explain the observations of photoelectric effect. According to classical wave theory, light of greater intensity should impart greater kinetic energy onto the ejected electron. So if you consider light as a wave, it's an oscillating electric field. If you increase the amplitude of the electric field, we increase the intensity of the wave and the force acting on the electron because of this radiation is equal to e charge into the electric field. So greater the amplitude of the electric field greater is the force on the electron and the kinetic energy of the electron should be greater if you increase the intensity of the radiation. But as you have seen that is not observed. The velocity of the ejected electron should not depend on the frequency of light. So no matter what the frequency electron should come out if the intensity is high enough. But as we have seen below the threshold frequency electrons are not emitted. And third is, there should be a time lag between the incident beam and the ejected electron. If you can consider light as a wave then the energy is uniformly distributed over the entire wavefront. So if the light is feeble enough there should be a time lag between the incident radiation

and the ejection of the electron. But no time lag experimentally was ever observed. So these were some problems with classical physics. In view of this discrepancy, Einstein proposed in 1905 that the electromagnetic radiation is quantized in quanta of energy $h\nu$. He proposed that the radiation is quantized and is formed of packets, each of quantized energy $h\nu$. This quanta of energy is called as photons. Einstein carried the idea of Planck forward, so Planck had assumed that the energy transfer between the electromagnetic radiation and the oscillator is quantized. That is equal to $n h\nu$, that is integral multiple of $h\nu$. So Planck suggested that the energy transfer is quantized but it travels like a wave. Einstein said electromagnetic wave is itself quantized. Also Planck suggested that the energy transfer is equal to $n h\nu$ and Einstein said that the energy photons is $h\nu$. If the energy transfer is equal to three $h\nu$, so that means there are three photons involved, each with energy $h\nu$. So if the initial energy of the photon is $h\nu$, it interacts with electron then the photon is absorbed by the electron as some amount of energy is required to remove the electron from the metal surface and rest of the energy goes into the kinetic energy of the electron. Hence we have this photoelectric equation. $h\nu$ is equal to that is the energy of the incident photon is equal to $\frac{1}{2}mv^2$ that is the kinetic energy of the electron plus $h\nu_0$ which is the work function. So the work function is the minimum energy required by the electron in order to escape from the metal surface. This is also called as the work done, the work done by the attractive forces of the atom and the loss in kinetic energy because of collisions with other electrons. So using this theory, Einstein successfully explained the observation of photoelectric effect.

So this theory predicts correctly that the maximum photoelectron energy depends on the frequency of incident light. As we see in this equation, the maximum energy depends on the frequency of the light. It is also able to explain why even the feeblest light can lead to immediate emission of photoelectrons. Now the energy is quantized into packets, so an entire energy is concentrated. As soon as the electron absorbs a photon, it has enough energy to come out of the atom. So one photon can emit one electron, five photons can emit five electrons and so on. Also, this theory gave explanation as to why no photoelectrons were observed below threshold frequency.

If you rearrange the photoelectric equation, we can write the Kinetic energy is equal to $h\nu - h\nu_0$. If the kinetic energy is zero then we have $h\nu$ is equal to $h\nu_0$. So we can see here the minimum frequency has to be threshold frequency to just remove the electron outside the metal surface. So if the frequency is less than the threshold frequency, electrons won't be emitted out. One more thing I would like to mention here. So as we saw the kinetic energy is equal to $h\nu - h\nu_0$. If we plot kinetic energy versus frequency the slope that we get is the Planck's constant. So you see in this plot. This is the plot of kinetic energy versus the frequency. If you plot this and find the slope, the value of the slope should be equal to that of the Planck's constant. OK, so to conclude the photoelectric effect was discovered by Hertz in 1887 and explained by Einstein in 1905. He got a Nobel Prize in physics in 1921 for this.

If you shine a beam of light of short wavelength onto a metal surface, electrons will be emitted out of the surface. Energy of the electrons is independent of the intensity and higher the frequency higher is the velocity of the ejected electron. So these observations Einstein was able to explain using the concept of photons and the photoelectric equation. So these are the sum of the important references for this video. Thank you.