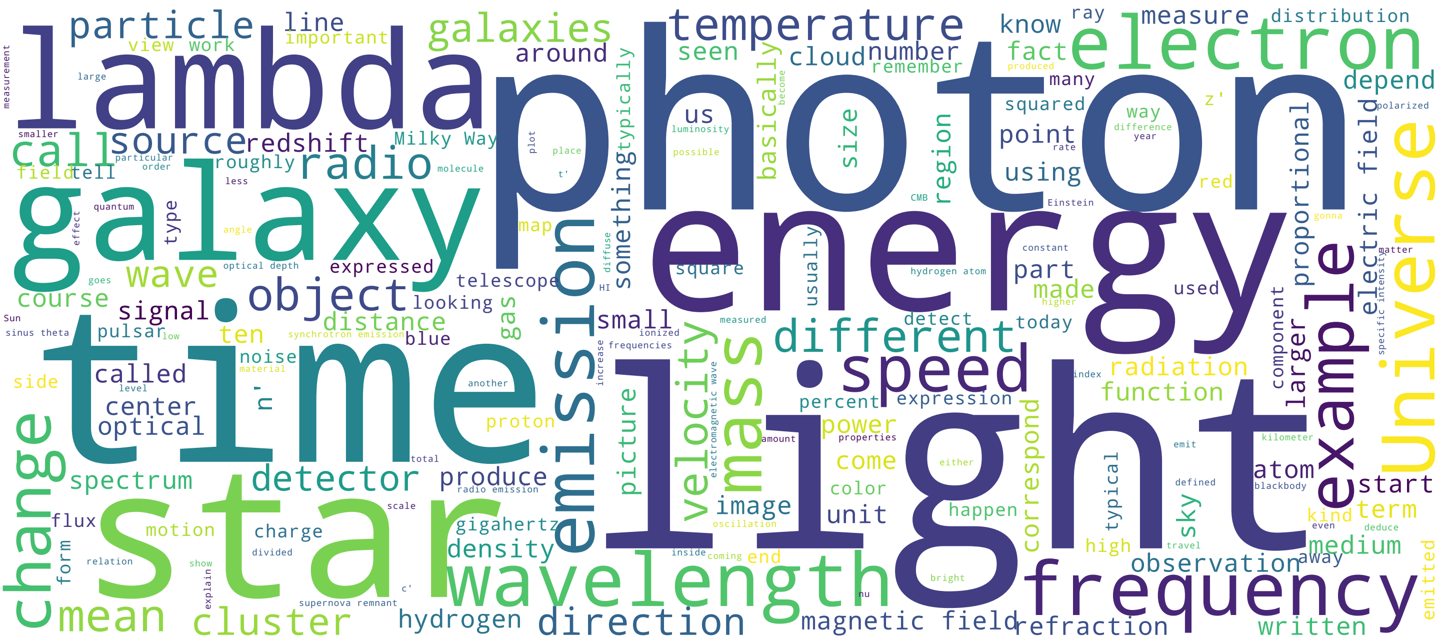
Photon: the light particle

The Universe At Radio Wavelengths

Jean-Paul Knieb



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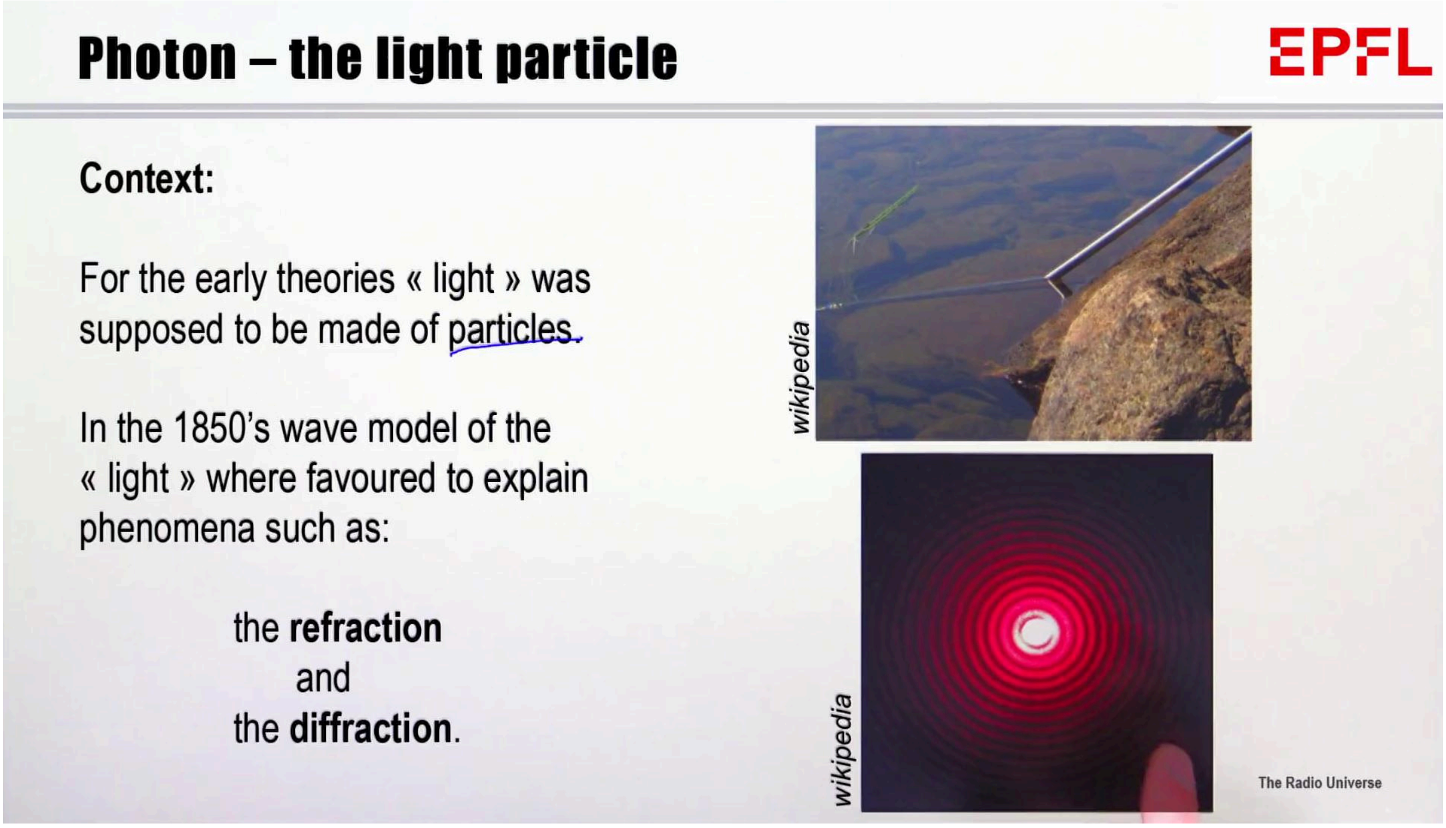
Today we will explore the property of photons. Early theories considered the visible light made of particles. Yet the wave model is the best theory to explain the light refraction and diffraction. Nowadays, the standard model of particle physics describe a photon as a massless and chargeless particle and it is the quantum of the electromagnetic field. Photons can have different energy and they can travel easily through the Universe.

Notes

Summary

0m 05s

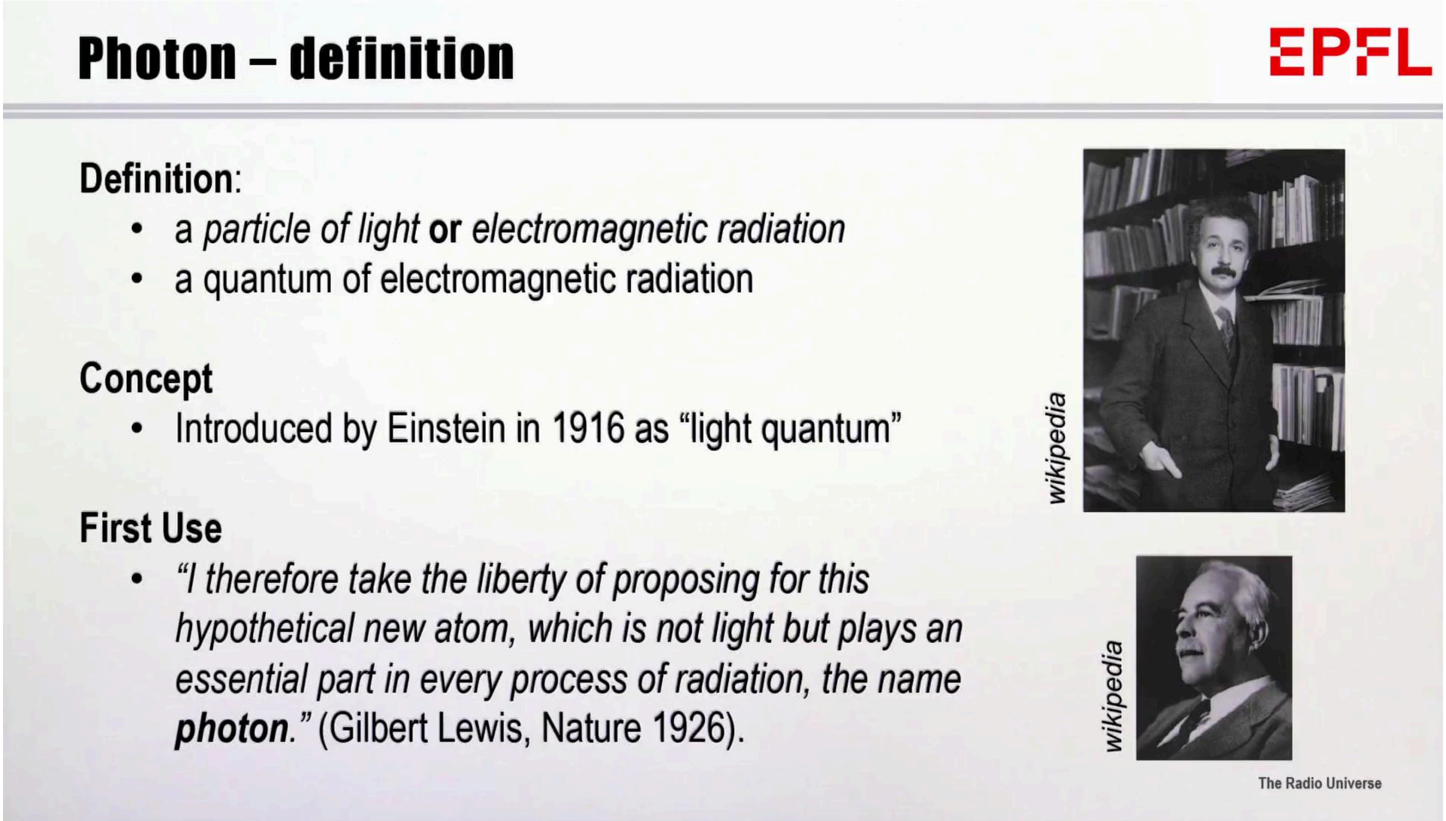


Okay. Let's have today a look at photons. Photons are the light particle. It's because of light that we can see objects and the first description of light was the one of made of particles. In 1950s, wave model of light were favoured to explain phenomena such as refraction here or diffraction here.

Notes

Summary

0m 48s



Now let's have a look at the modern definition of photon. Commonly the definition of a photon is of a particle of light or electromagnetic radiation. In physics, photon is described as a quantum of electromagnetic radiation. The concept was first introduced by Einstein in 1916 as light quantum but the first use of the term photon was made by Gilbert Lewis, a physical chemist who wrote in Nature paper a sentence like this. I therefore take the liberty of proposing for this hypothetical new atom, which is not light but plays an essential part in every process of radiation, the name photon. Then after the term photon was common and represent the light quantum of Einstein.

Notes

Summary

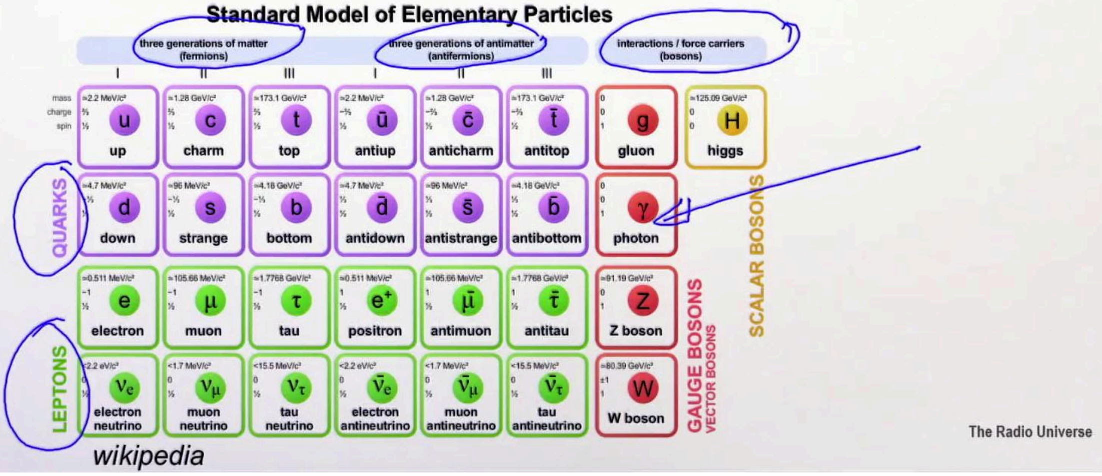
1m 18s

Photon – elementary particle

EPFL

The photon is considered as:

1. an *elementary particle of the standard model of particle physics*
2. the quantum of the *electromagnetic field*
3. the force carrier of the *electromagnetic force*

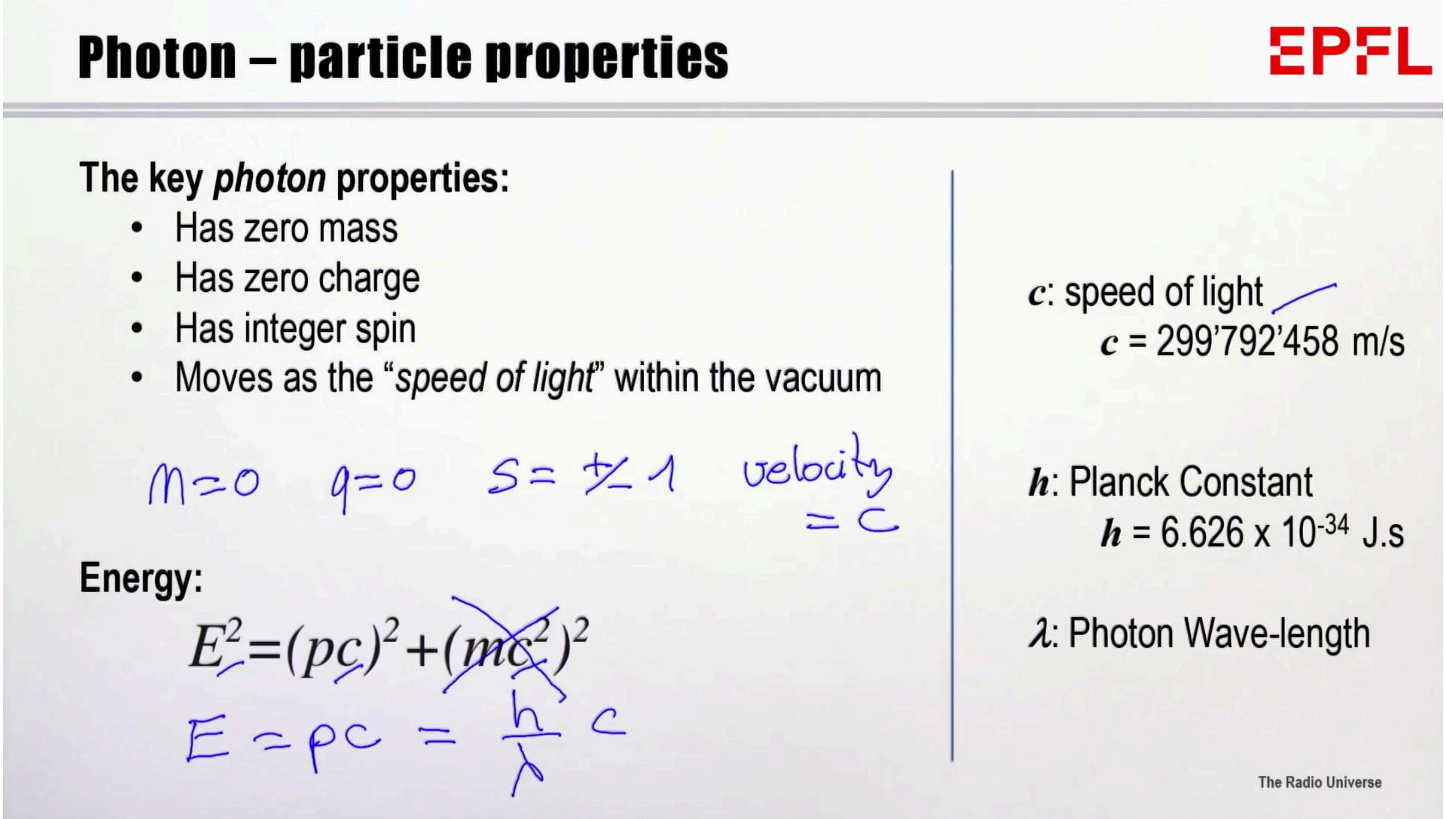


The photon as a particle is part of the standard model of particle physics. As we can see here in the standard model of elementary particles, which describe all the particles in a model. We can see the photons here. Photons are part of bosons family and so it is different than the fermions and the anti-fermions, which basically contain the quarks and lepton particles. Moreover, photon is considered at the quantum of the electromagnetic field or the force carrier of the electromagnetic force.

Notes

Summary

2m 20s

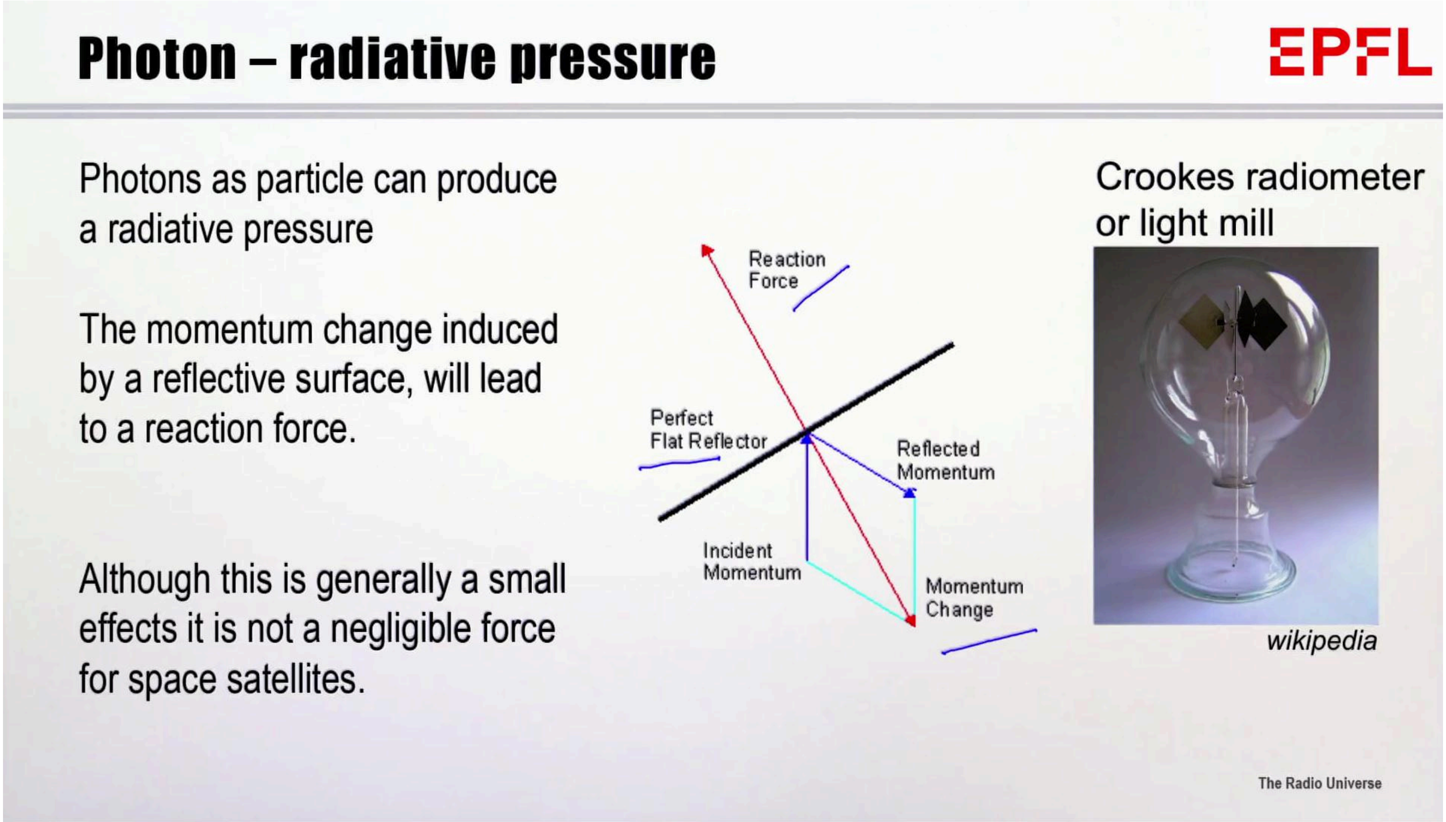


But what are the particle properties of the photon? The key photon properties are the following. It has a zero mass. It has a zero charge. It has an integer spin. Its velocity is equal to 'c', 'c' is the speed of light. The velocity is exactly 299,792 kilometer per second. Its energy is given by the particle physics and can be written as 'E-square' as a function of the momentum 'pc' and the rest mass 'mc-square'. Of course, for a photon the mass is zero so we can get rid of this term here. So the energy 'E equal pc', 'p' the momentum, 'c' the speed of light, and this can be written also as 'h' over lambda times 'c', 'h' being the Planck constant and lambda the photon wavelength.

Notes

Summary

3m 11s

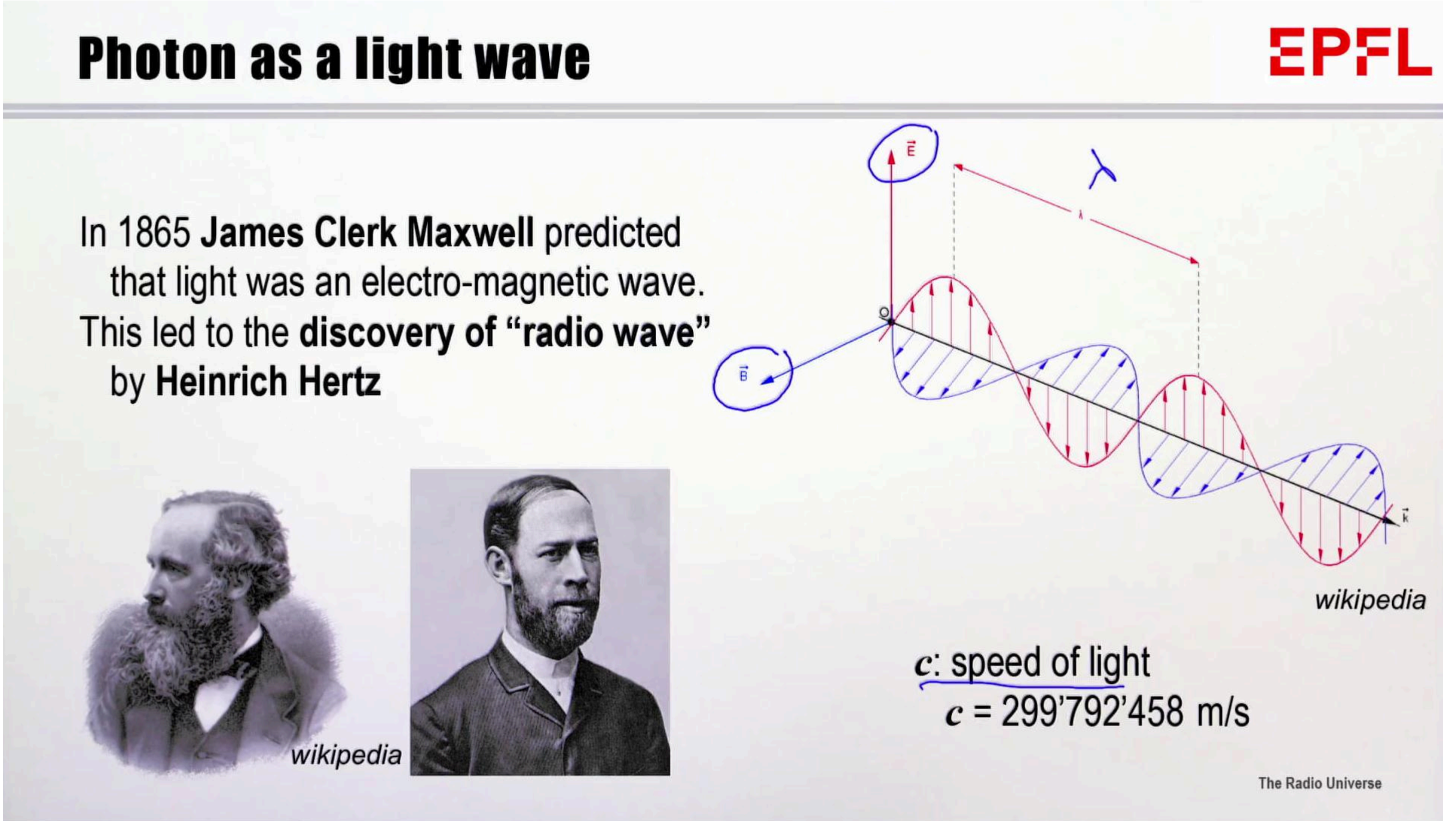


One of a nice property of photon is the radiative pressure. Photons as particle can produce radiative pressure. Let me explain. Assume here we have an incident photon. It will be reflected on the surface here and it will give a reflected momentum. So the sum of the incident momentum and the reflected momentum will give a momentum change. To equal this momentum change, this will produce a reaction force on our reflector. In this we can then demonstrate this by looking at a Crooke radiometer. The Crookes radiometer is basically a bulb where we have a reflector, a perfect reflector on one side and something which is absorbing the light. So only part, only one part of the little wing can reflect the light and by illuminating the Crookes radiometer, it will start to spin depending on the amount of light. So we call all this a light mill. Generally, the radiative pressure can be neglected but for space satellite this is something to take into account.

Notes

Summary

4m 24s

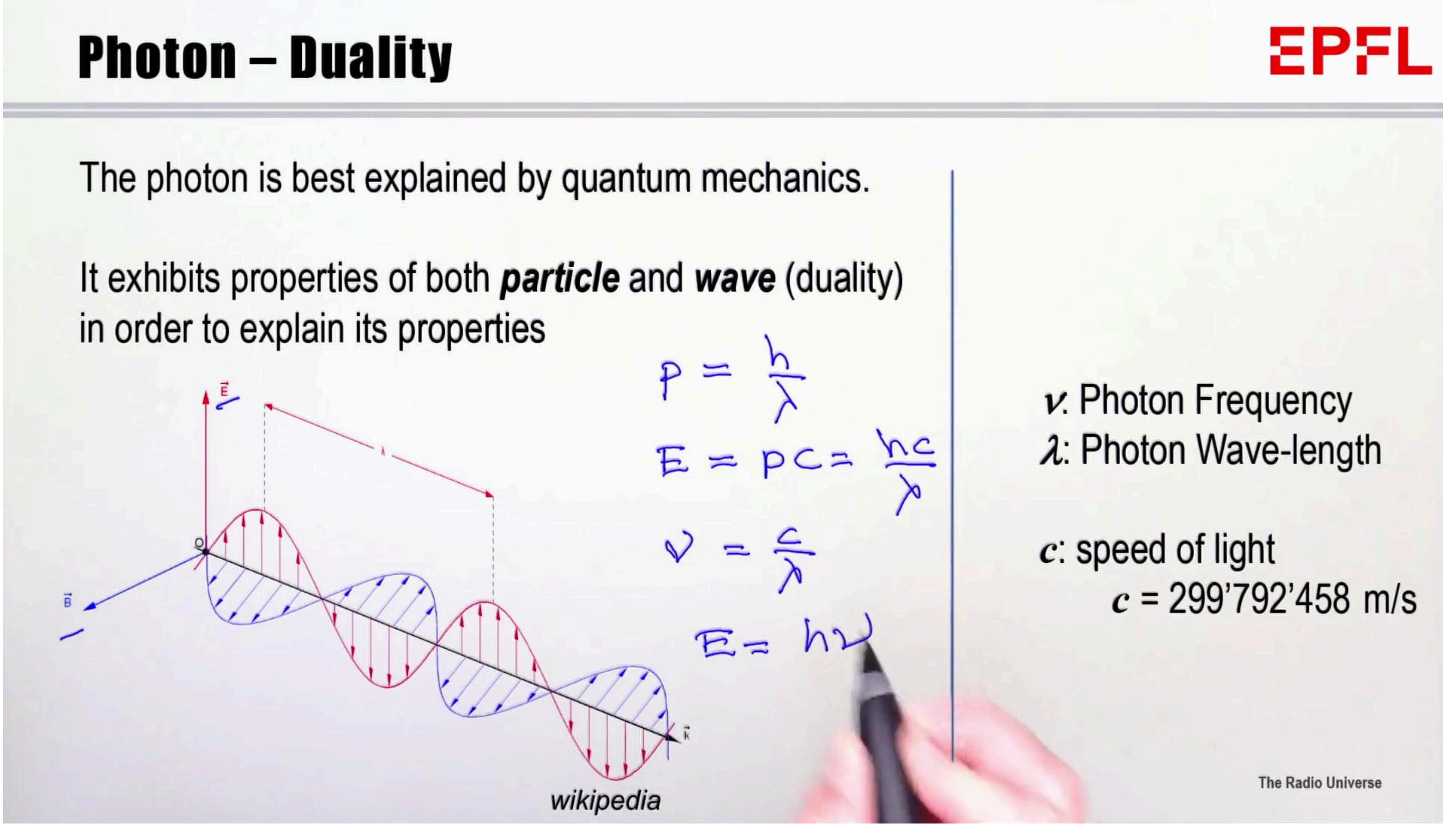


Now let's turn to look at the photon as a light wave. In 1965, James Clerk Maxwell predicted that light was an electromagnetic wave. It is thus made of two components; the electric field E and the magnetic field B. Both are propagating along the direction of motion of the light particle and is characteristic by the wavelength lambda. The speed of motion is the speed of light again and that it be expressed in meter per second and this discovery of the light being a wave has also led to the discovery of radio wave by Heinrich Hertz that we will see later on during this lecture.

Notes

Summary

5m 58s

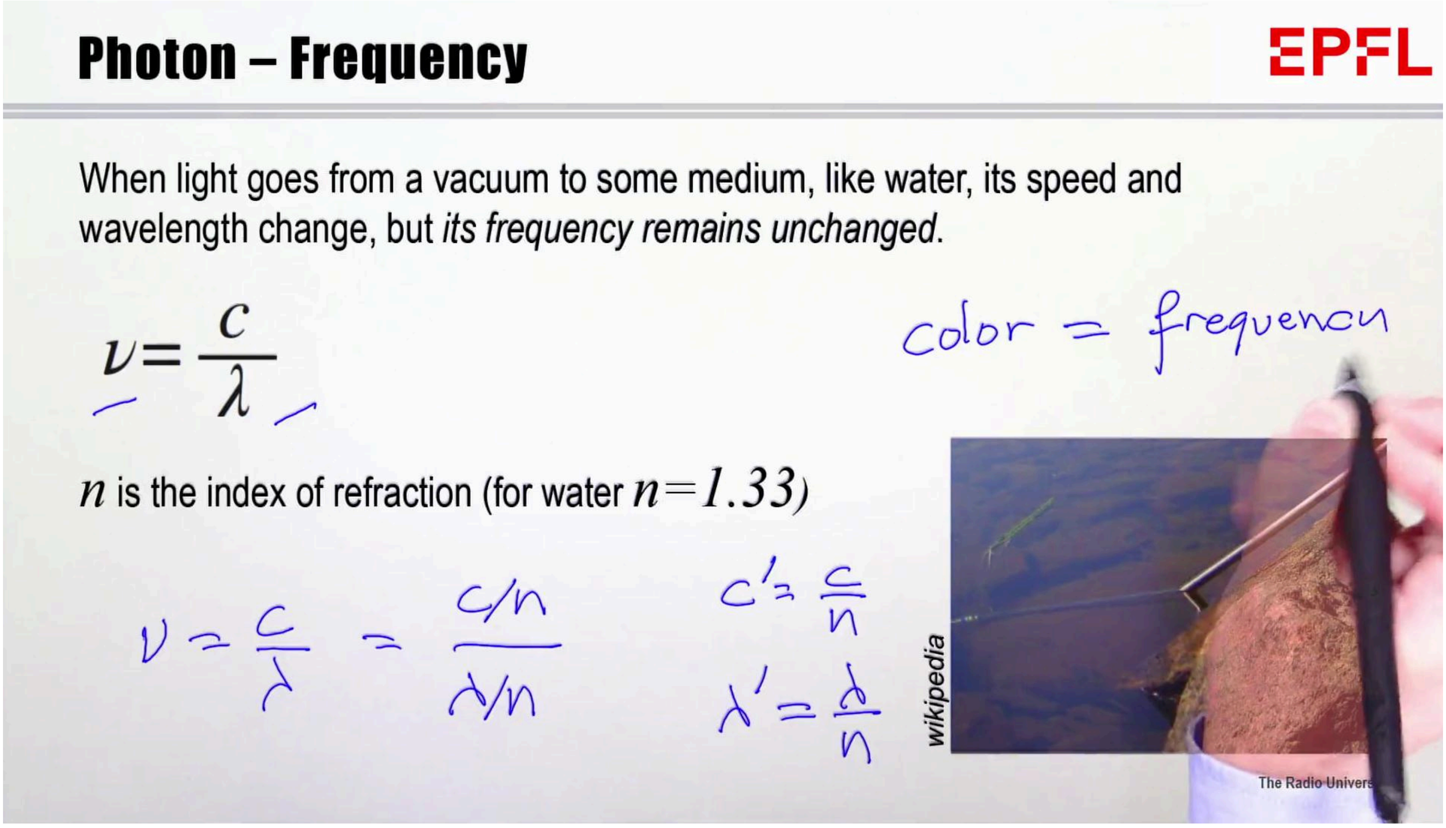


So let's recap. The photon duality. The photon is best explained by quantum mechanics and it exhibits properties of both particle and a wave. That's what we call duality. So to explain its properties here we have the representation of the wave where we have the electronic field, the magnetic field. We can define the momentum ‘p’ is equal ‘h’ over lambda. We can define its energy as 'pc' equal 'hc' over lambda. We can define its frequency nu equals 'c' over lambda. That means we can write the energy as 'h' times nu.

Notes

Summary

6m 59s

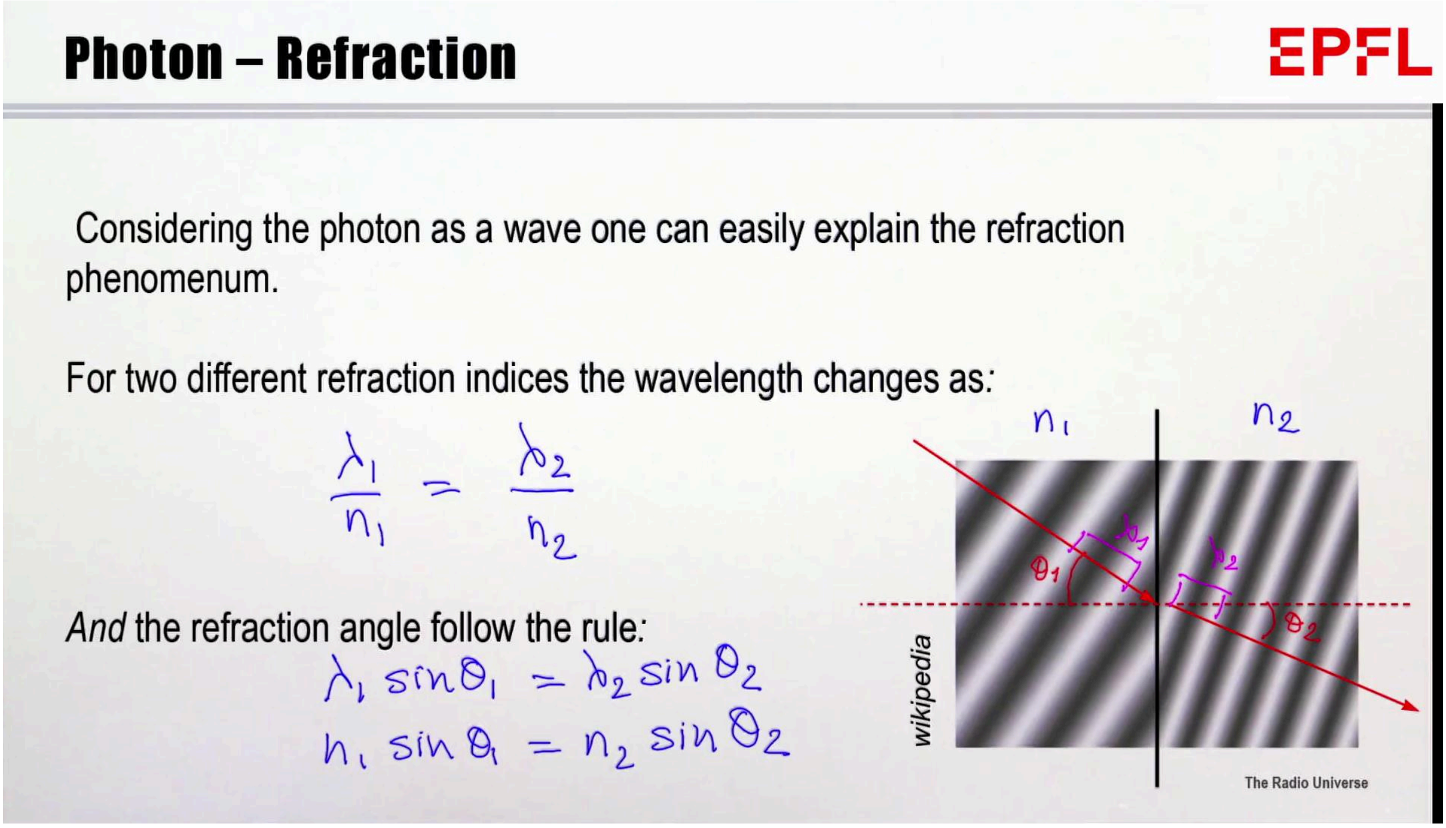


Let's have a look at the photon frequency. This is quite important and let's consider two different medium. Up to now we were considering the vacuum as a place where we have an electromagnetic wave, the photon going through but it can go also through different medium. In particular, for example, you can go through medium like water or air and what will change is its speed and its wavelength but its frequency will remain unchanged. So remember frequency nu equals ‘c’ over lambda and now let's consider that 'n' is the index of refraction. For example, for water 'n' equals 1.33. So if I’m gonna change medium, I will have to change 'c' and lambda but nu kept constant. So we will have nu, the frequency, equal 'c' over lambda and this being equal, I need to divide 'c' by 'n', the index of refraction and lambda by 'n'. So my new velocity will be 'c-prime' equal 'c' over 'n' and my new wavelength will be lambda-prime equal lambda over 'n'. As you can see here, we have a phenomenon of refraction and what we can notice is that there is a change of direction of the stick that goes in the water but there is no change in color. So what I can deduce is that color is equivalent to frequency.

Notes

Summary

7m 48s



So let's have a closer look at this effect of refraction and let's consider the photon as a wave to explain this refraction phenomenon. So let's consider two medium. One medium with index 'n1', another medium with index ‘n2’ and let's have a wave propagating and going through the medium interface. So my light will come through the main medium perpendicular to the wavefront and then it will hit the interface. When it will come out my light direction will be change and it will be perpendicular also to the wavefront. I can define two angle theta one and theta two and I have the relation between these different component knowing that my wavelength has change according to the change of indices. I can identify lambda one in my medium one. This is lambda one. This is lambda two. As a relation I have lambda one over 'n1' equal lambda two over 'n2'. Looking at the geometric figure here I can deduce that lambda one sinus theta one is equal to lambda two sinus theta two which can also be written as 'n1' sinus theta one equals 'n2' sinus theta two. So knowing the index of refraction, I can deduce the change in angles.

Notes

Summary

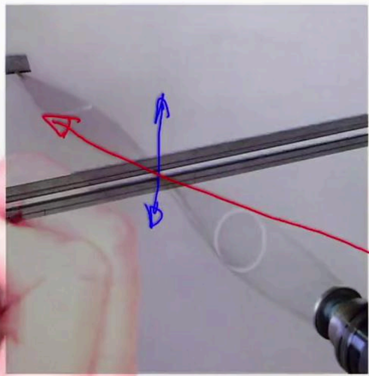
9m 41s

Photon - Polarisation

A wave can be "polarised": the transverse direction of oscillation can be vertical/horizontal or can change with time.

Example of a vibrating string:

thread transform the polarisation from linear



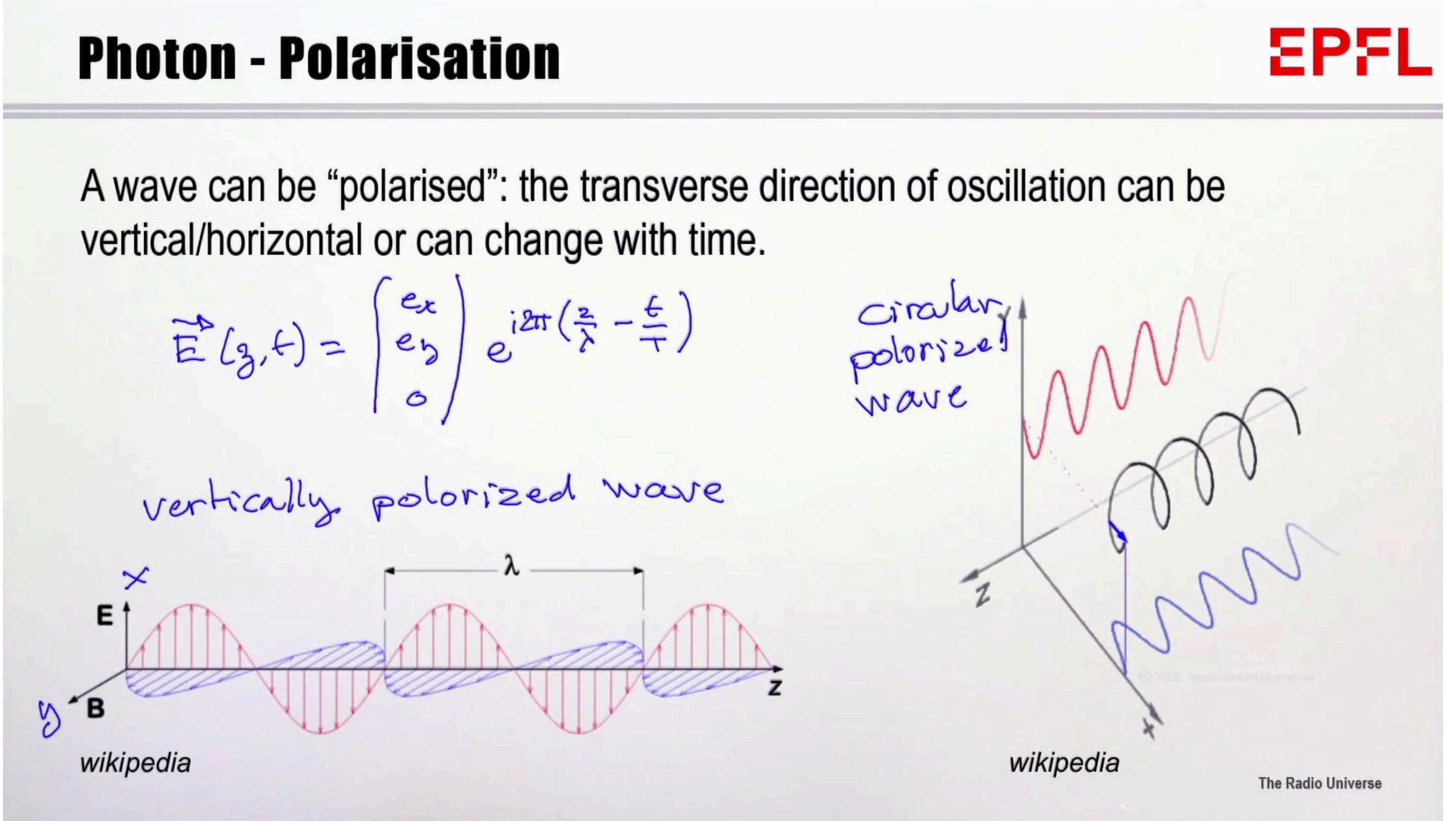
The Radio Universe

Another important property of a wave is its polarization. Indeed, a wave can be polarized as the transverse direction of oscillation can be either vertical, horizontal or can change with time. Now let's have a look at an example of a vibrating string. A string can oscillate as a wave. So let's devise an experiment where we have a string attached here and over there. The string go through a rubber thread. Now I have a rotating motion here that will produce a circular oscillation. That circular oscillation will be damped by the rubber thread and the only oscillation that will remain will be horizontal because all the vertical oscillations will be damped by my rubber thread. So I can conclude that the thread transform the polarization from circular to linear.

Notes

Summary

11m 42s

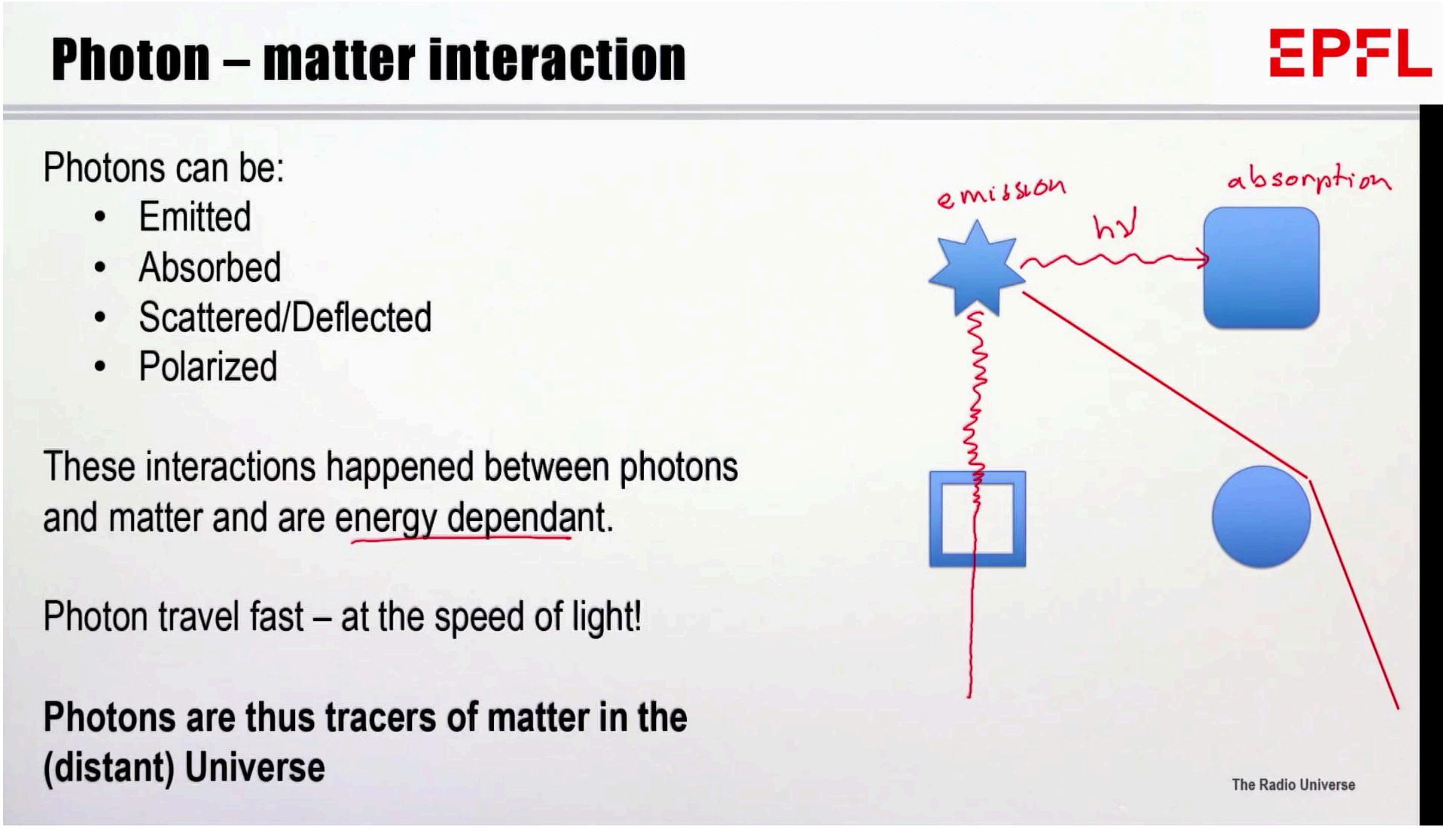


So what does it mean in terms of mathematics that a wave can be polarized? Okay. The transverse direction of oscillation can be vertical, horizontal or can change with time. So how do we write that? Well, we're going to look at, for example, the electric field. So let's take these axes. We have the 'z' the direction of motion. We have 'x' the direction of here the E field and 'y' here the direction of the B field. Here we have a vertically polarized wave. Here we have a circular polarized wave. So how can we write the electric field? So we can write the vector electric field 'E' as a function of 'z', the displacement of the wave 't' the time and that's equal to vector ex ey zero, zero because there's no electric field in the direction of motion, times exponential 'i two pi' of 'z' over lambda minus 't' over capital 'T'. Lambda here is what we see here it corresponds to the wavelengths and 't' is the period of the wave, which basically depends on the speed of light.

Notes

Summary

13m 07s



So to finish, we can also mention that it's because there are matter interaction that we can see light and this for different reason. Photons can be emitted. For example, thanks to the light coming from a star so we usually represent photons like a little wave emitted by the star. We call this we write the energy of the photon 'h nu'. Here we have the process of emission. That light can be absorbed so we have absorption by a medium. Light can be also scattered or deflected. So for example, in this case where light would go for example close to an object, it could be deflected by, for example, a gravitational force gravitational lensing. Light can also be polarized. So if light going through a medium coming through as a circular polarization can be outside coming out the medium being polarized. These interaction happen between photons and matter and those interaction are energy dependent. So by looking at photons because they travel fast at the speed of light in vacuum, we can learn a lot about the distant Universe.

Notes

Summary

14m 51s

We just have seen a few key properties of photons. In particular, photons travel at the speed of light at about 300,000 kilometer per second. While the speed of light and the wavelengths can change depending on medium it travel through, the frequency remain constant and define the color of the light. Moreover, photons can be represented as an electromagnetic wave and it can be polarized. Finally, as photons interact with matter we can use them to discover the Universe.

Notes

Summary

16m 54s