EPFL

# Light Detection

## The Universe At Radio Wavelengths

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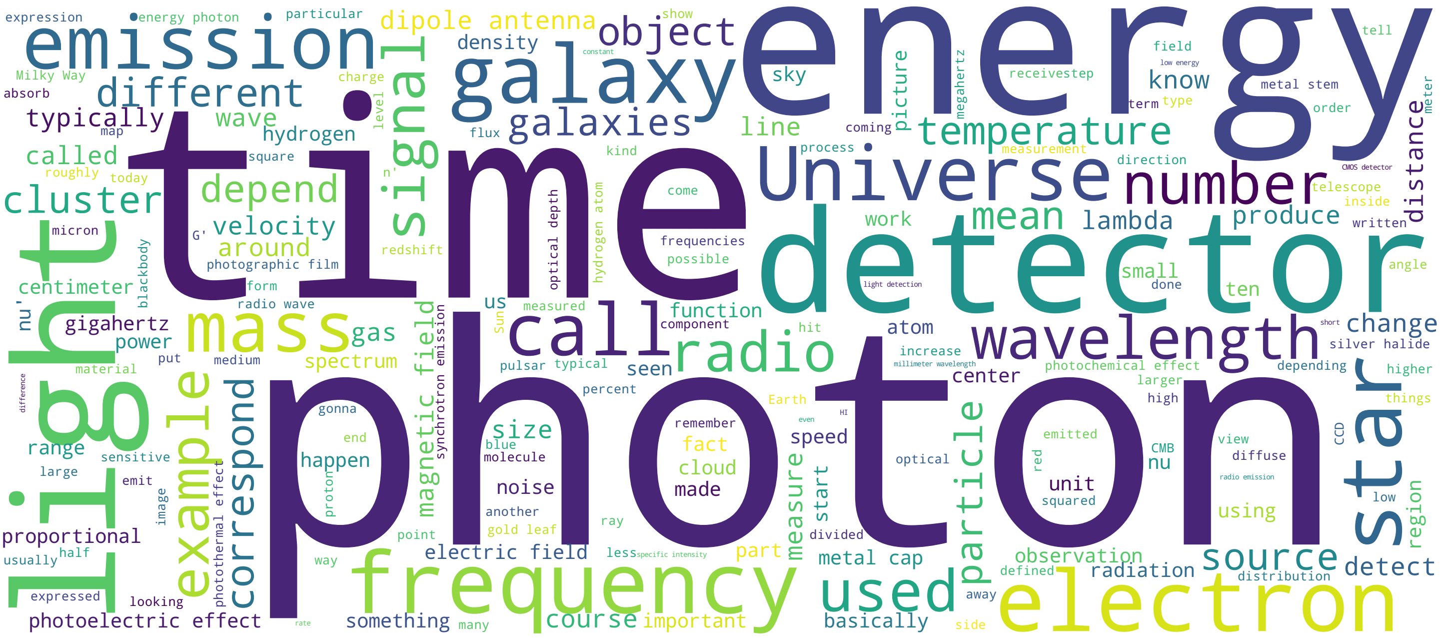


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The light detection technique use the duality of the light. The fact that light can be considered either as particle or as a wave. We will present four different detection techniques. First, the photochemical effect used in photographic film. Second, the photoelectric effect mainly used for detection of UV to Infrared light. Third, the photothermal effect used for signal at submillimeter and millimeter wavelengths. Fourth, the dipole antenna used for the radio domain from centimeter to meters. We will conclude that depending on the energy of the light we have to use different detection techniques.

Notes

Summary

0m 05s

# Principle of Light Detection

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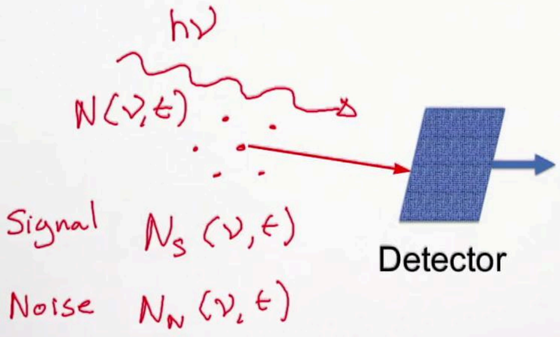
## What do we want to achieve?



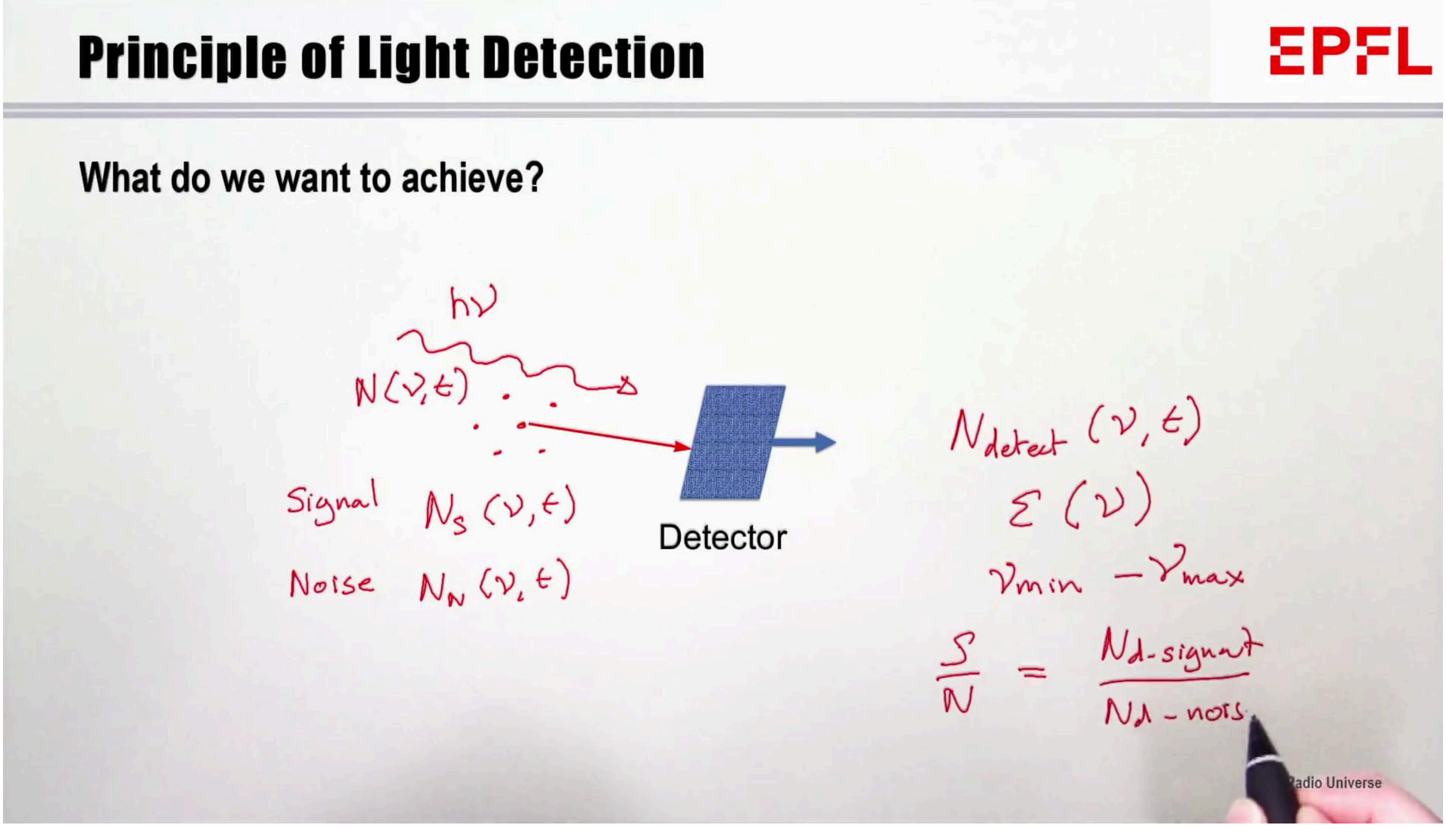

The Radio Universe

So we have our detector here and we are going to receive some light going toward the detector. The light will have an energy 'h nu' so nu is the frequency and we will receive about 'N' photons of energy nu at a time 't'. Light can be seen as a wave but we can also see that as a particle that will hit the detector and, of course, there are many of these particles moving toward our detector. Among those photons that are coming to the detector we'll have photons in which we are interested that what we call the signal. So we'll have 'Ns' photons of the signal and we may also receive some noise some photons for which we are not really interested in that we call noise 'NN'. And, of course, these two quantities will depend on the frequency or the energy and it will also depend on the time at which we receive those photons. So that's are the things the light we're gonna receive and now we want through the detectors, basically convert this signal into something we can't quantify. So the question is how many photons we're gonna receive or how much energy will be received? So we have to have a process that converts those things that are coming to detectors and extracting the signal.

Notes

Summary

0m 52s

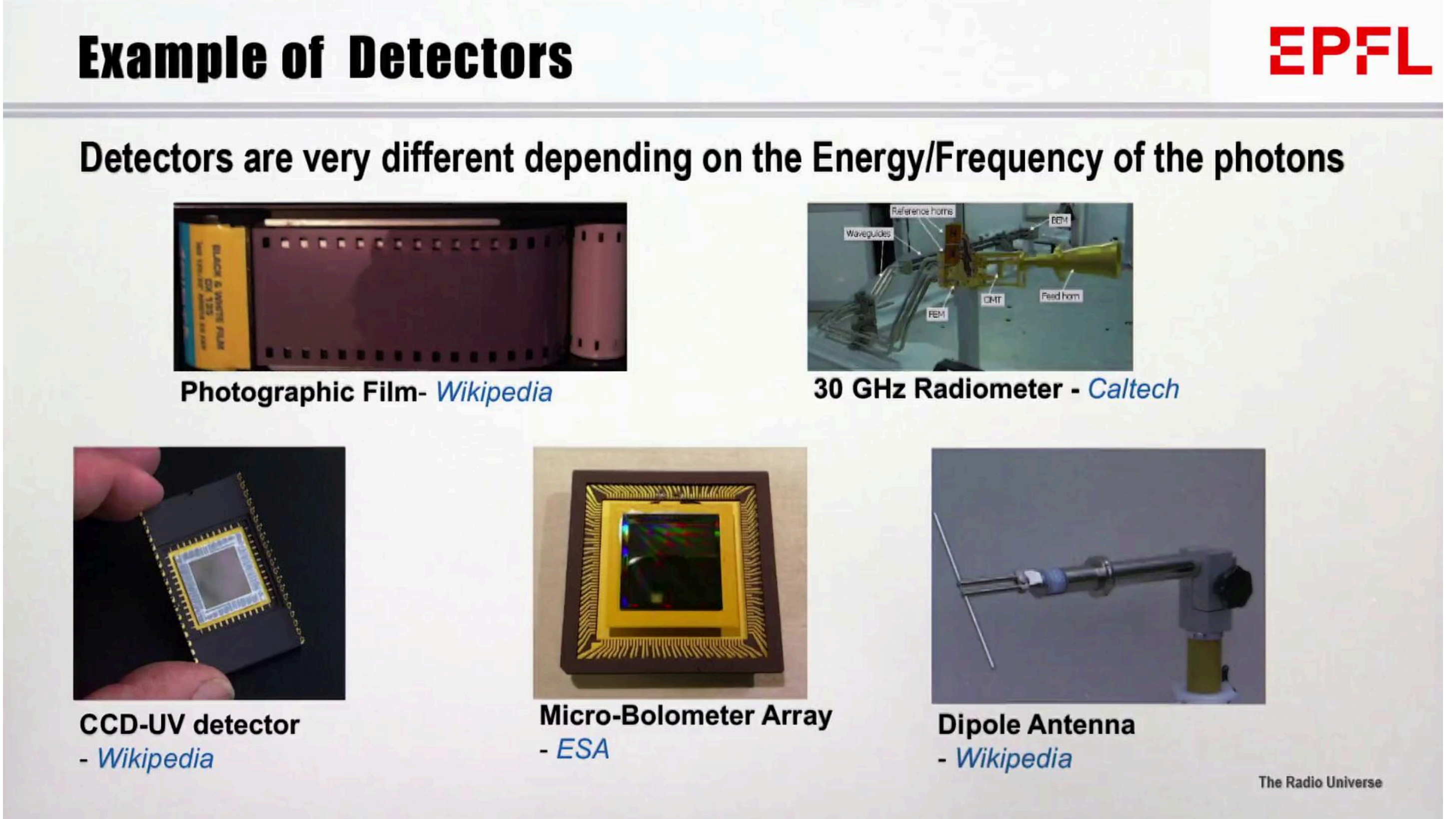



So typically we're gonna receive and detect a fraction of the photons arriving on the detector and we will call that number 'N detect' and those number of photons detected will have a characteristic frequency nu at arrival 't'. Of course, the number of photon detected will be less than the photon received and so we will probably define also the efficiency of the detector and that efficiency will depend on the photon energy or the frequency nu. The detector will be sensitive to range of energy and frequency and this will go from a range in frequency going from nu minimum to nu max. So in this range of frequency our detector will be sensitive and usually outside this range of frequency, our detector will not detect the light. What will be important to define is what we call the signal-to-noise, which is basically just the number of photon detected from the signal divided by the number of detected photons from the noise.

Notes

Summary

2m 56s

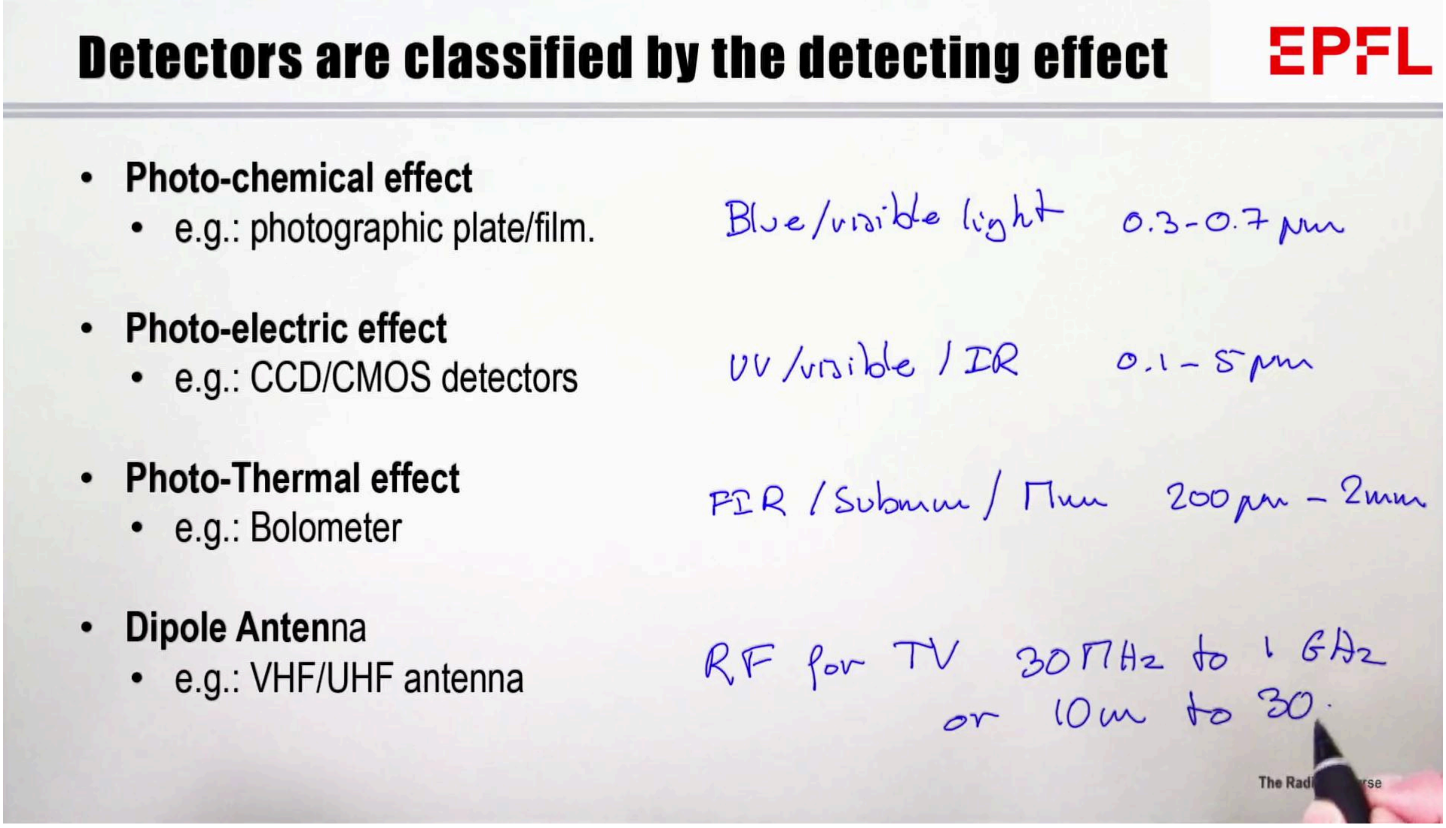



Over here, we have some example of detectors and what we can see here is the detectors are very different and they are very different because they're using different effect to measure the photons and that will depend on the energy or the frequency of those photons. What we used to be familiar with when we were taking pictures was to use photographic film which is not used anymore but that was very common ten to twenty years ago. Today we're using a device electronic device like a CCD or CMOS detector for typical UV visible or even Infrared detector but we can also use a more advanced technology like here we have Micro-Bolometer Array that are used for millimeter wavelengths, for example or we can use radiometer for a relatively high frequency like 30 gigahertz or we use can very simple technology like a dipole antenna for longer wavelengths or low energy photons.

Notes

Summary

4m 32s

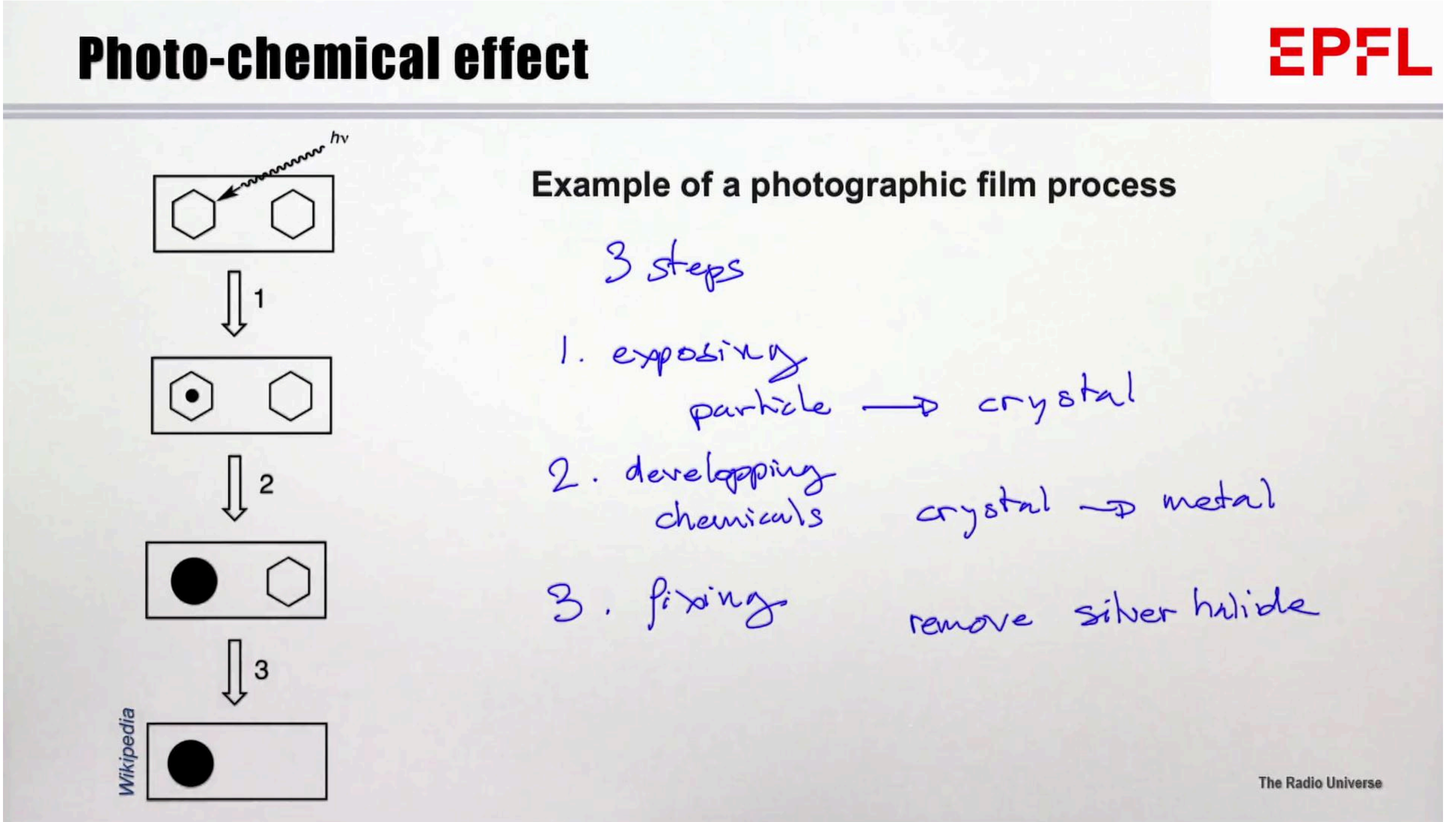



Detectors can be classified by their detecting effect, you know, which effect are being used to produce the detection. So for example, photographic film that I was mentioning are using photochemical effect. This will work well for blue or visible light so typically going from 0.3 to 0.7 micron. A second technique is the use of photoelectric effect and that's what being used in a CCD or CMOS detector that we are familiar with because that's the technology used in your cell phone. This work well for UV visible or Infrared light. So typically this is for wavelengths going from 0.1 to five micron. The third effect is what we call the photothermal effect. This is being used for bolometer device and typically this is used for Far Infrared submillimeter or millimeter wavelengths corresponding to 200 micron to two millimeter. The last technology is the use of the Dipole antenna. So the dipole antenna is used in VHF and UHF antenna which correspond to radio frequency for TV going from 30 megahertz to one gigahertz or 10 meter to 30 centimeter.

Notes

Summary

6m 00s

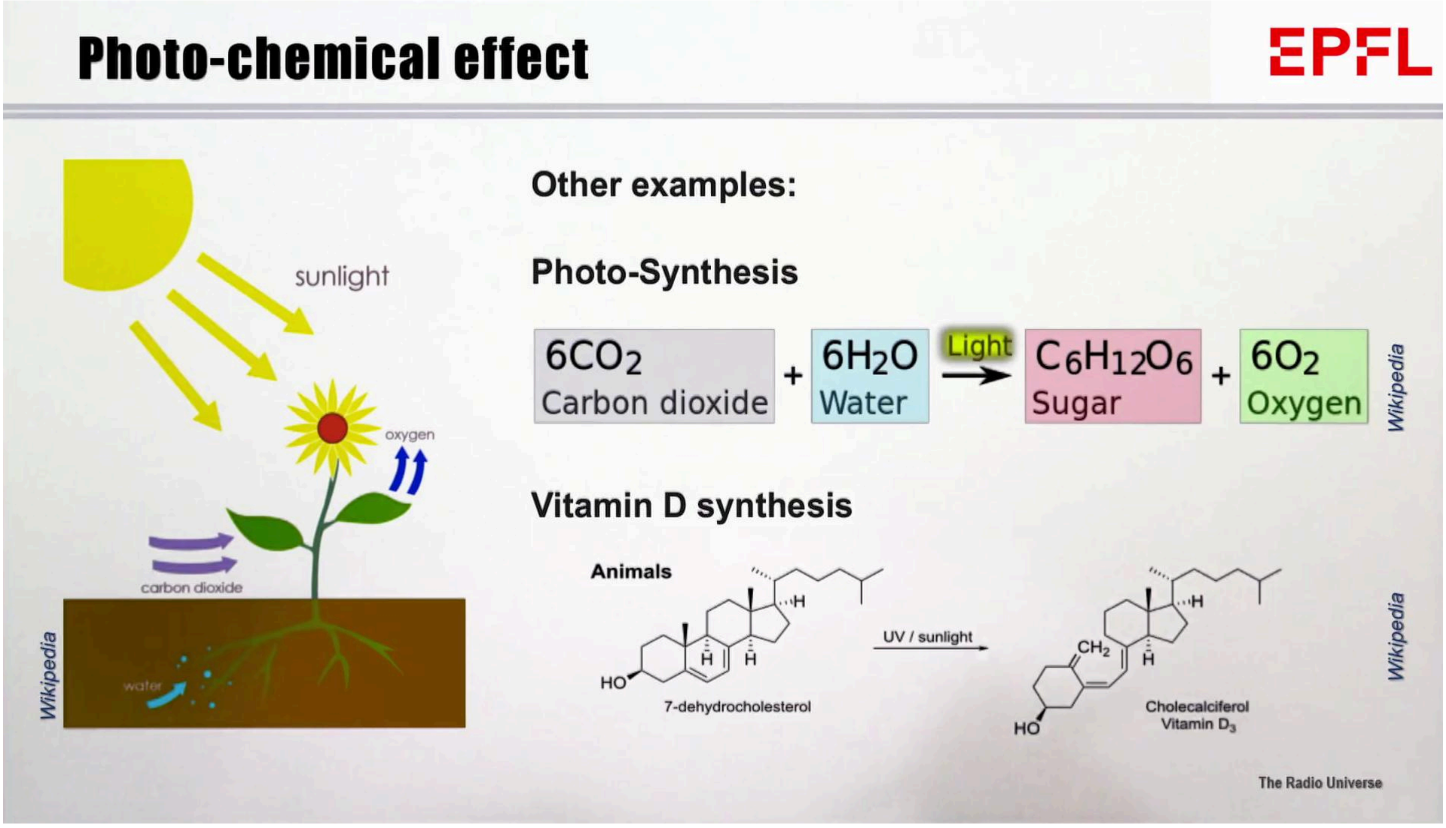



Now let's have a more detailed view on the this different effect and we will start with the photochemical effect and we will have an example of a photographic film process. So the photographic film process is being done in three steps. Here we have two silver halide particles. The first step is the exposing step. So we have this two silver halide particle. One of them being hit by a photon of energy 'h nu'. Being hitted by a photon, the silver halide particle will transform into a crystal. In the second step after the exposure, we're gonna do the developing step. By using chemicals we're gonna transform the silver crystal in silver metal. Finally, the third step is the fixing. In this final step, we are going to remove with some other chemicals the silver halide. So we see in this photochemical effect, we started from film and one part will be hit by a photon and will produce a black image as the part will not receive, a photon will basically become white. So then we have like a negative picture of what we see.

Notes

Summary

7m 37s

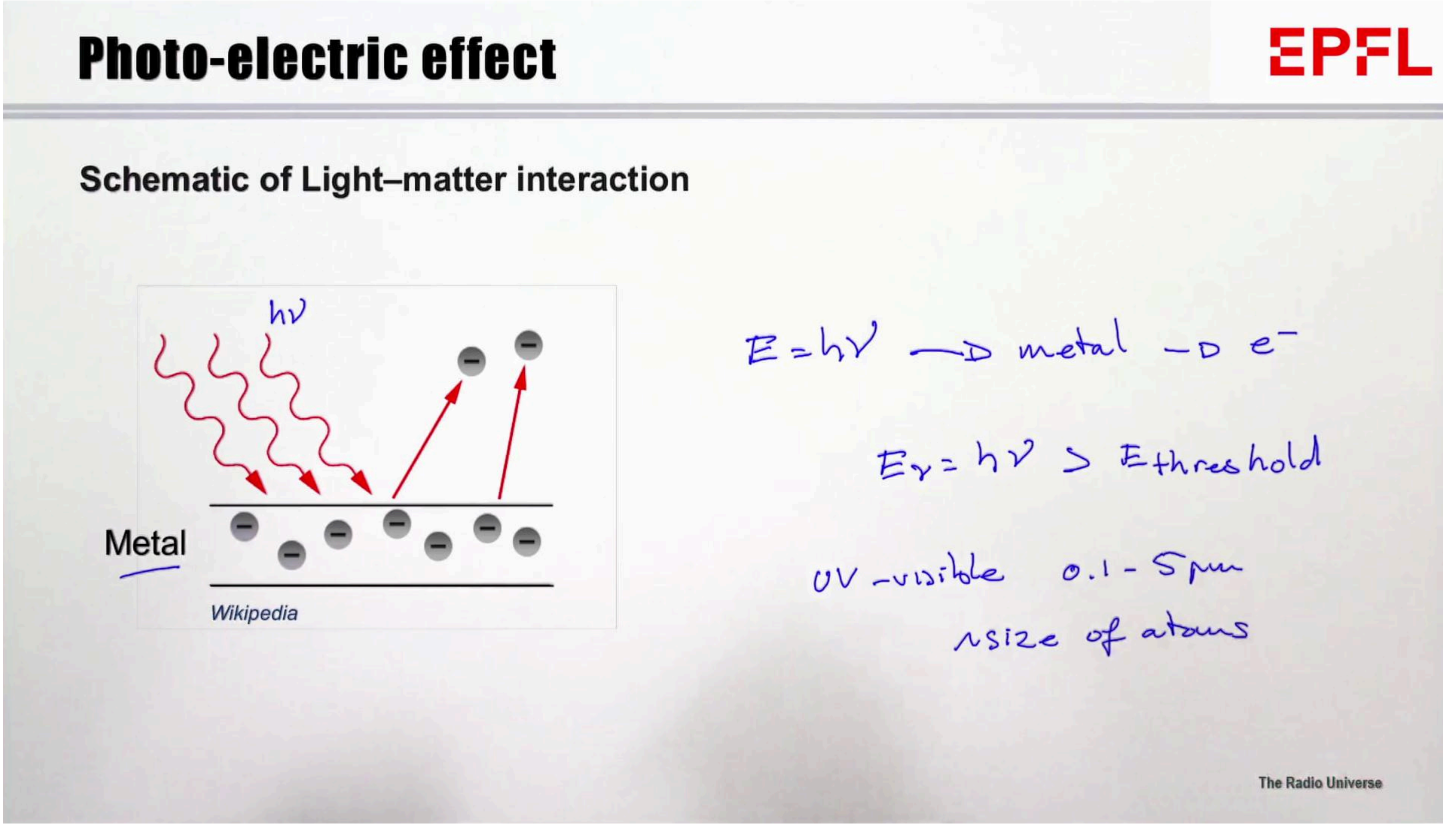



The photochemical effect is widely used in nature process and these are two example. We have the photosynthesis system where light coming from the Sun hitting a plant will transform carbon dioxide and water into oxygen and this is thanks to the light and it will also produce sugar that will be used by the plant. Another photochemical effect is the use of UV sunlight that will transform dehydrocholesterol into vitamin D3.

Notes

Summary

9m 16s

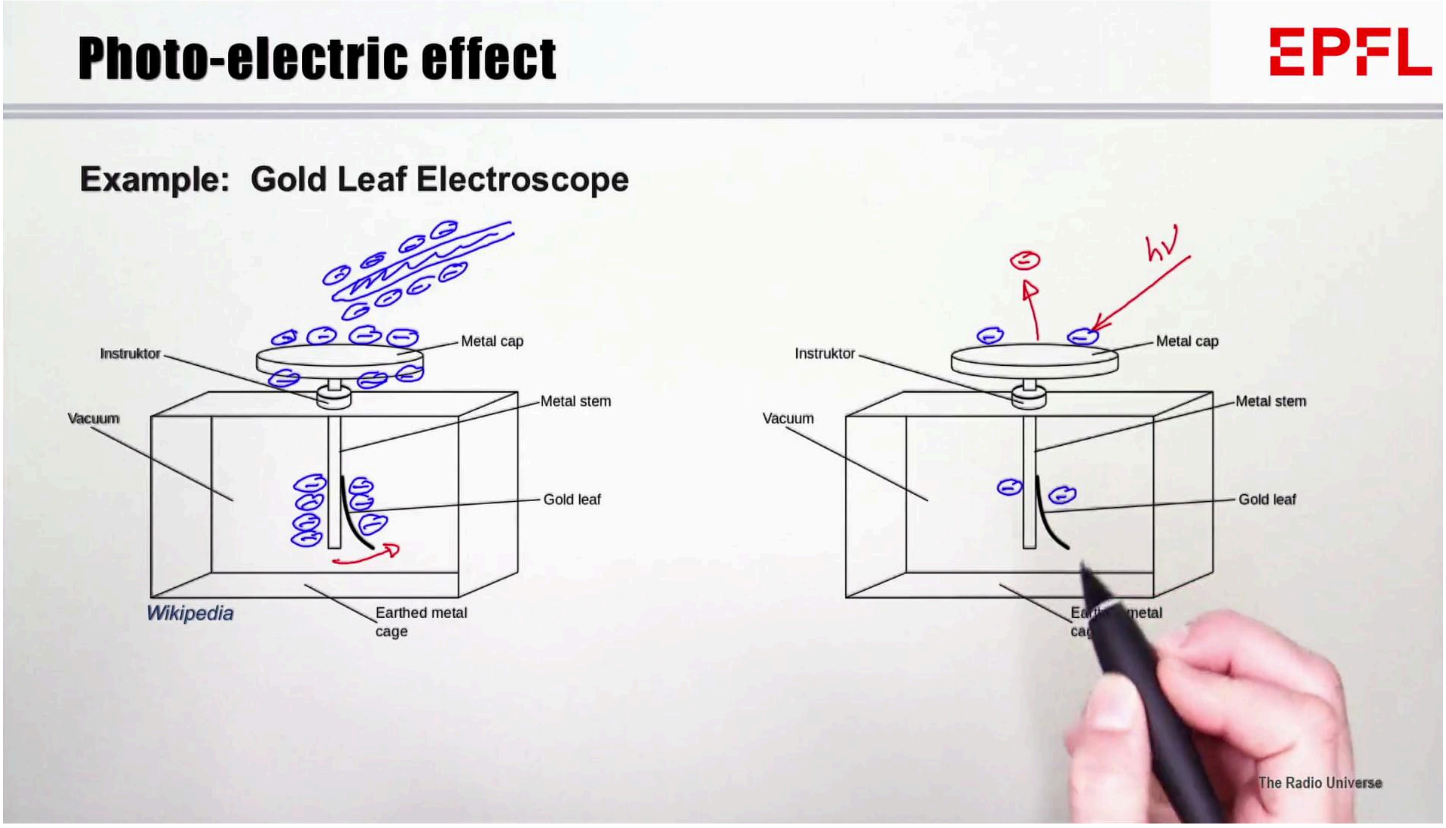



Now let's have a look at the photoelectric effect. This is a very important effect as it is well used in the modern technology. Here we have some photon with energy 'h nu' that are hitting a metal piece. In the metal there are electrons and because of the photoelectric effect, the photons will liberate will free some electrons. So in short, we have some photons with energy 'h nu' which are hitting a piece of metal and these will liberate some electrons which we'll then be able to measure. Such electron liberation will depend on the energy. So for this photoelectric effect to happen we need to have the energy of the photon which is 'h nu' larger than a certain energy threshold that allow the effect to happen. For metal the energy needed is typically of the UV visible wavelength which correspond to typical wavelength of 0.1 to five micron. The reason is that this typical wavelength is about the size of atoms.

Notes

Summary

10m 00s

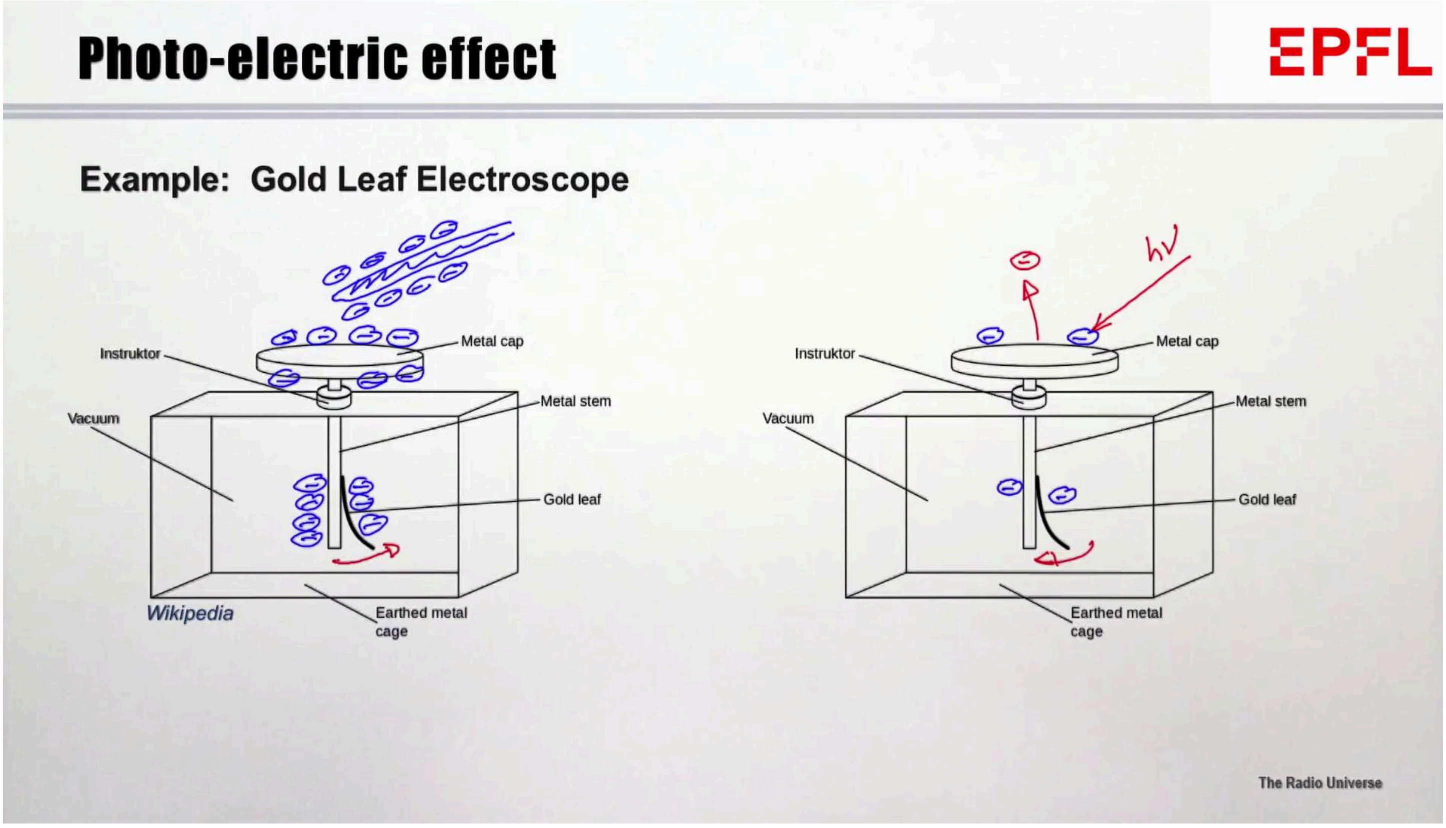



We will now have a look at a photoelectric effect in a following visual example. To put this into context we're gonna use what we call the Gold Leaf Electroscope. The Gold Leaf Electroscope allow you to put in evidence whether an object is charged or not electrically. The electroscope is made of a box where we have vacuum inside. We have a metal cap which is connected to a metal stem and we have a gold leaf attach to the metal stem. The cage is earth to the ground and then it will not be charge and the metal cap and the metal stem are isolated to the box through an instructor. In a first step, let's approach a stick which is charged negatively. In contact of the stick to the metal cap we're gonna transmit negative electrons to the metal cap that will go down to the metal stem and to the gold leaf which then will move away from the stem. In a second step, let's assume we have some photons of high energy that will hit the metal cap. Those photons of high energy will release through the photoelectric effect electrons. So the number of electrons in the metal cap will diminish. So we'll go from a highly charged metal cap to the low charge metal cap and this will be also the case of the metal stem and the gold leaf.

Notes

Summary

11m 36s

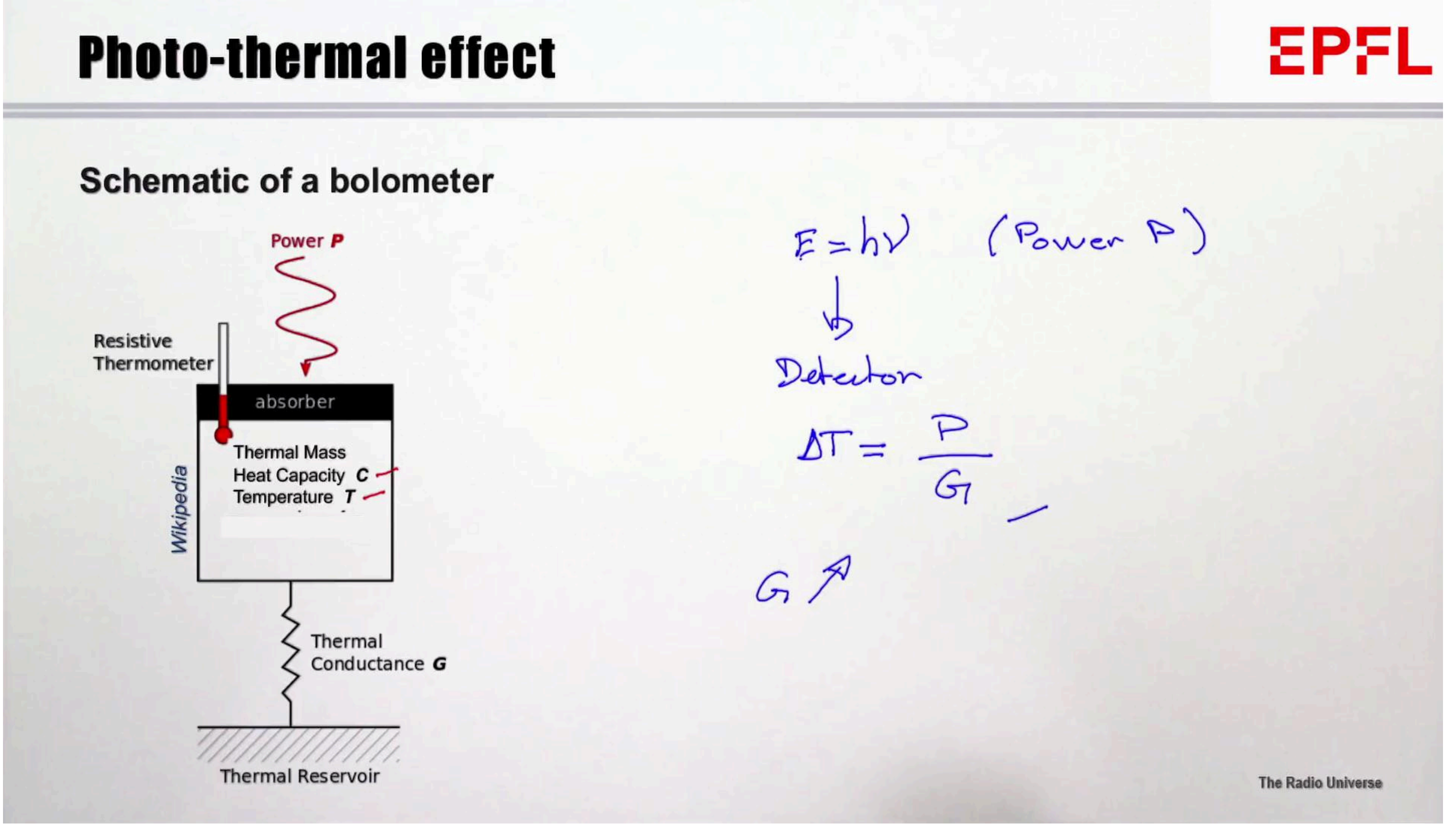



Which means the gold leaf will retract to its initial position. So this is a visual example of the photoelectric effect which is used in modern CCD or CMOS detectors that are at the heart of photographic cameras.

Notes

Summary

13m 49s

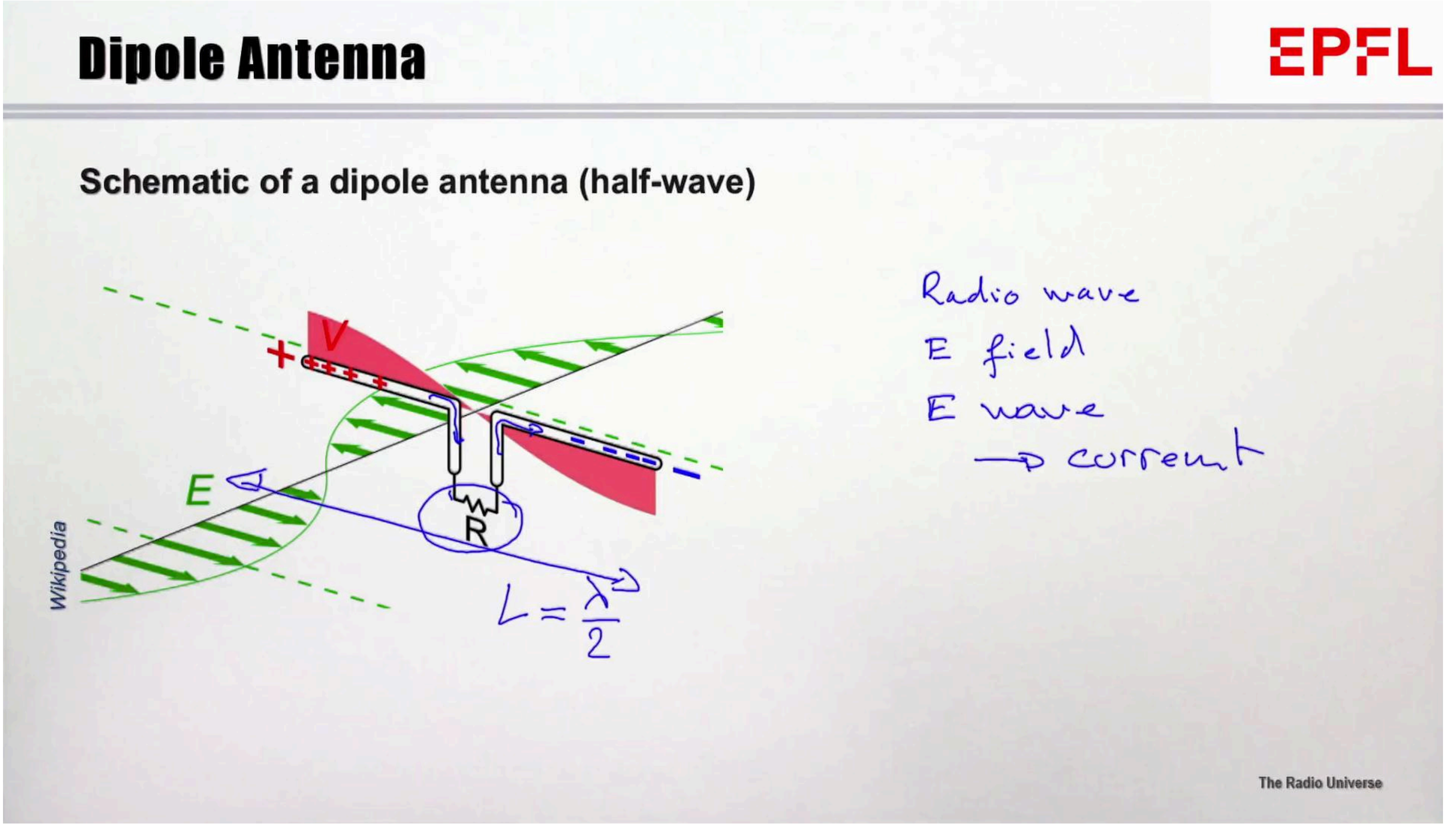



Now let's have a look at the photothermal effect. The photothermal effect is using the increase of temperature produced by the incident light. So here we have a concept of a bolometer. Here we have a thermal mass which has a heat capacity 'C' and is currently at temperature 'T'. That thermal mass is linked to our system which is a thermal reservoir and it's connected through a thermal conductance 'G'. We have a resistive thermometer that allow us to measure the temperature difference. So the process is the following. We have some photons with energy 'h nu' which are going to hit our detector. The detector will absorb the light and absorb its energy which is basically a power 'P' and it will increase its temperature and the temperature difference can be written as delta 'T' equal 'P' over 'G'. 'P' is the power received and 'G' is the thermal conductance that link our detector to the thermal reservoir. As we can see through this equation here, we need to have 'G' as small as possible in order to detect the larger temperature difference. So we want to have 'G' as large as possible. So we need to isolate our detector to the thermal reservoir. This technology is used in bolometer, in particular, for detection of submillimeter or millimeter radiation.

Notes

Summary

14m 11s

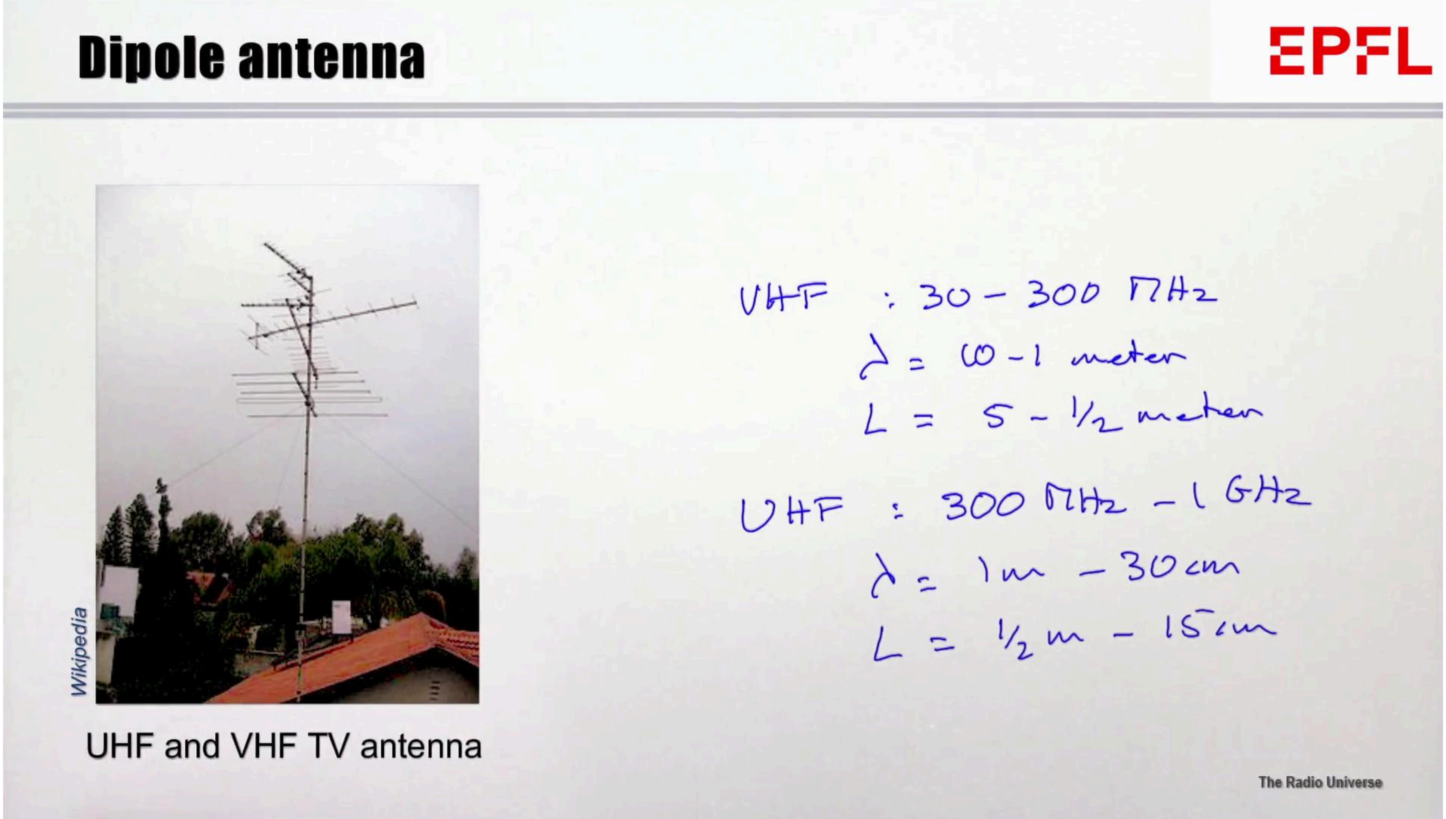



Finally, for low energy photons we are using dipole antenna to be able to detect the light. In this case, we are considering photons as a wave. As we have seen radio wave are made of two field, an electric field and a magnetic field. The dipole antenna will use the electric field. So here we have what we call our dipole antenna which is linked by a resistor 'R'. It has a certain dimension 'L' and we can show that it work best if the length of the dipole antenna is half of the wavelength. So we have a radio wave and what is interesting to us is the electric field. The dipole antenna is made of metal and because of the displacement of the electric field, it will displace the charge in the metal. So depending on the electric field we'll have positive charge on one side, negative charge on the other side. The charge difference will produce a current that we can measure through the resistor. So the electric weight will produce a current, an alternative current. So the flow of charge from one side to the other as the wave going through the dipole will produce an electric signal that can be detected through the radio receiver which is shown on the picture as the resistor 'R'.

Notes

Summary

16m 34s




A typical example of a dipole antenna is the UHF or VHF TV antenna that are installed on the roof of houses. VHF frequency correspond to 30 to 300 megahertz that correspond to lambda of ten to one meter which correspond to antenna size of 'L' going from five to one-half meter. The UHF radio domain goes from 300 megahertz to one gigahertz hence correspond to lambda going from one meter to 30 centimeter. And the antenna size thus will go for half meter to 15 centimeter. So in this picture here we see at the bottom larger dipole which correspond to the VHF detection and on the top, smaller dipoles which correspond to the UHF detection.

Notes

Summary

18m 28s


As we have seen, light detection is achieved through the use of detectors. For energic photons, the detector use different effects either chemical, electric or thermal for which the representation of light as a particle is the most adequate. When considering the light as a wave, the electric part of the wave produce an electric current in the dipole antenna that can be measured using an electric receiver. This is most useful for low energy photons or radio wave. We thus conclude that the light detection critically depends on the frequency or wavelengths of the photon to detect. Hence the detector technology has to adapt to the energy of the photon probe. In the following videos, we will further explore the different properties of some of these detectors.

Notes

Summary

19m 46s