"QED – Matter, Light and the Void"

Scientific subject and topic:
Physical properties of light

Title / year:
"QED – Matter, Light and the Void" (2005)

Movie producer:
Sciencemotion

Director:
Stefan Heusler

Website of movie:
http://www.sciencemotion.de/

Description of movie:
In the first part of the DVD, the properties of light are shown in a puppet animation movie (30 Min.). Prof. Ethereal and his colleague Nick perform experiments about the physical properties of light and try to explain their results by using models. Not all of their explanations are complete, and not all of their ideas lead to correct conclusions. But their discussions and experiments impart methods of scientific research in a humorous way: A scientist should not be satisfied with just one theory and a corresponding experiment but should try to refine his methods of understanding nature, in this case with the final goal to comprehend the fascinating properties of light better and better.

In the second part of the movie, all the models and experiments are explained on a scientific level using mathematical formulas. In this part, facts of modern research are presented, culminating finally in the theory of quantum electrodynamics (QED). The level of the scenes (about 30) varies between high-school and university level, depending on the difficulty of the specific topic related to the question "What is light?"

Link to Trailer Site:
http://www.sciencemotion.de/

Buy DVD:
Order the DVD for EUR 20.00 plus shipping charge on the website
http://www.sciencemotion.de/

Artistic Part, Chapter 2

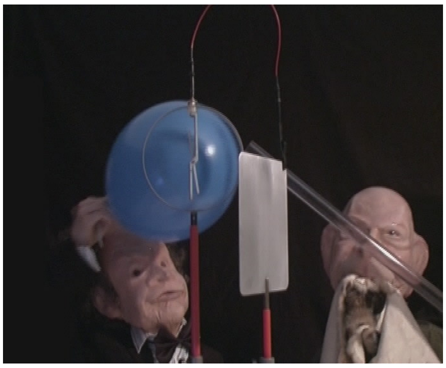
Title of scene:
Light and electron

Video clip or still:
Chapter 2, Artistic Part

Author:
Stefan Heusler, Annette Lorke

Scientific keywords:
photoelectric effect, absorption and emission of photons

Description of scene:



Prof Ethereal and his assistant Nick demonstrate the photoelectric effect with an experiment: A neutral metal plate is charged with extra electrons. The electrons can only escape from the metal plate into the air if they absorb ultraviolet radiation. Neither blue nor red light can release the electrons from the metal plate even if the light intensity is increased. Einstein was the first to find the correct explanation for the experiment. All kinds of radiation (visible light, infrared, ultraviolet rays, etc.) are *quantized,* that means radiation consists of discrete portions of energy. These portions are called *photons.* A single photon can only have a certain portion of energy, which then can be absorbed completely by one electron. Only if the energy of the single photon is high enough, the electron can escape from the metal plate.
After the experiment Prof Ethereal introduces his model to explain the observations. Electrons in a metal plate are like frogs in a prison yard. They can only escape over the wall if they leap high enough in a *single* jump. If the leap is not high enough, no matter how *often* they leap, they're unable to escape over the wall.
The crucial observation already made by Einstein is that all radiation is quantized. In our model this is expressed by the frogs which make single, successive jumps. The *portions of energy* which stimulate the jumps are the energy quanta of radiation, the *photons.*

Prof. Ethereal and Nick also perform the "inverse" of the experiment: Instead of the absorption of photons by electrons, they study the emission of photons by electrons. In fact, this is easily done. In a simple toaster photons are emitted by the heated wire. Both the heat and the red light emitted by the toaster contain a myriad of photons with different portions of energy.

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Film Studio: Science*e*motion, www.sciencemotion.de

Basic level

Light consists of many, many small portions of energy, called *photons*. These photons vary in their energy. For example, photons in blue light have more energy than in red light. These energy portions are absorbed or emitted by electrons in the atoms. If an electron absorbs a photon, it gains energy. If the electron emits a photon, it loses energy. This process happens all the time. For example, while you are reading this text, your eye absorbs a myriad of photons each second through the electrons in the atoms of your eye.

In the movie, we show two experiments explaining these two processes:
In the photoelectric effect, light is *absorbed* by electrons in the metal. Only when the energy of the absorbed photons is high enough, the electrons can escape from the metal plate into the air. Conversely, in a toaster, radiation is emitted by the electrons in the metal. For that reason the heated wire is glowing red. But most of the radiation is invisible because our eyes are adapted only to a small range of photons. If the energy of the photon is too high (in the case of ultraviolet radiation) or too low (in the case of infrared light) the human eye cannot see it. But you can feel infrared radiation emitted by the wire as heat radiation. Ultraviolet radiation causes the highest jumps of the electrons in the photoelectric effect so they can escape into the air. You neither can see nor feel ultraviolet radiation but you can see the consequences as overexposure to ultraviolet radiation causes sunburn.

You can think of many more examples for the absorption and emission of photons (a radio antenna, a candle, etc). It is quite impossible to find a place in the world without any absorption or emission of photons.

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Advanced level

Let's estimate the number of photons emitted by a light bulb of 100 Watt in one second (1 Watt = 1 Joule*s). Let's assume that only red light is emitted. In reality, most of the photons emitted by a light bulb are heat radiation (infrared). How many photons per second come from the "red" light bulb? For the red light with a wave length of λ = 750 nm and a frequency of $v = c / \lambda = (3*10^8$ m/s$) / (7.6*10^{-7}$m$) = 4*10^{14}$ Hz, one photon has the energy $E = h*v = (6.62*10^{-34}$ Joule*s$) * (4*10^{14}$ Hz$) = 2.65*10^{-19}$Joule. In one second, the light bulb of 100 Watt emits the energy of 100 Joule, which corresponds to the huge number of $2.65*10^{21}$ photons with a wave length of λ = 750 nm.

In the photoelectric experiment photons are absorbed by conducting electrons in the metal plate. The metal is a conductor because the valence electrons in the metal detach completely from their atomic trunk and move freely in the metal. These electrons gain both potential and kinetic energy by the absorption of photons. As explained more in detail in chapter 2a this simple experiment was sufficient for Einstein to deduce that light energy must be quantized. As light is quantized, absorption becomes an elementary process with a discrete number of photons and electrons involved. A single photon is absorbed by a single electron. This absorption only depends on the energy of this specific photon and not on the properties of the other photons.

The "toaster-experiment" is in some sense the inverse of the photoelectric effect: Electrons do not absorb photons and gain energy, but they *emit* photons and lose energy. In the thin wires of the toaster a current is flowing when a voltage is applied. The drift velocity is quite slow. For example, in a copper wire with a cross-section of 0.5 mm^2 the drift velocity of electrons is about 1 mm per second for a current of 5 Ampere at room temperature. Note that even currents of 50 mA = 0.05 A can cause the death of a human being! The free electrons in the wire permanently collide with atomic trunks, lose kinetic energy and emit photons. Speaking metaphorically, the emitted photon is the skid mark of the electron.

Websites about metal electrons & electric current:
http://en.wikipedia.org/wiki/Free-Electron_Model_of_Metals
http://en.wikipedia.org/wiki/Electric_current

Websites about the photoelectric effect and the light bulb:
http://en.wikipedia.org/wiki/Photoelectric_effect
http://en.wikipedia.org/wiki/Light_bulb

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Scientific level

In general, photons couple to any electrically charged particle. The most important charged particles are electrons and protons.

In contrast to the electron the proton is not an elementary particle. The proton consists of a very complicated mixture of quarks and gluons. As a first approximation the proton is composed of three “valence” quarks: Two up quarks (electric charge +2/3 each) and one down quark (electric charge -1/3). The total electric charge of the proton is the sum of the charges of the three quarks, 4/3-1/3=+1. Neutrons can be described as the composition of one up quark and two down quarks. The total electric charge of the neutron is zero, 2/3-2/3=0. Therefore, the neutron is electrically neutral and does not effectively couple to photons.

Not only electrons can absorb or emit photons but also protons. An example for the emission of photons by protons is the X-ray emission of excited atomic nuclei. In comparison to the emission of photons by electrons in atomic spectra the energy of photons emitted by the protons in the nucleus is many times higher.

Even higher energies of photons are reached in the so-called gamma-ray bursts which are part of the cosmic radiation. These gamma-ray bursts are signatures of supernovae (explosion of stars at the end of their life cycle) such as the famous Crab nebula. The centre of our galaxy which is suspected to host a giant black hole is another well-known source of gamma-ray bursts. Gamma-ray bursts are an interesting topic of modern research and can be observed on earth as the so-called Tscherenkov radiation.

Highest energy of emitted photons known so far: Gamma ray bursts
http://en.wikipedia.org/wiki/Gamma_ray_burst
http://en.wikipedia.org/wiki/Crab_nebula