"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:
Scienc*e*motion

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/

Technical Part, Chapter 1c

Title of scene:
Polarization of Light

Video clip or still:
Chapter 1c, Technical Part

Author:
Stefan Heusler, Annette Lorke

Scientific keywords:
circular and linear polarization, 3D cinema

Description of scene:

What happens to a light beam which is directed towards two polarizing filters? Each filter only admits transmission of linearly polarized light in just one certain direction. If the filters are arranged parallel to each other (angle $\alpha = 0°$), the light's intensity is maximal because the second filter does not have any effect on the light beam. If the filters are lined up orthogonally to each other ($\alpha = 90°$), they let only pass the opposite polarization direction. The resulting light intensity is zero. For any angle α between the two polarization directions, the light intensity coming through both filters is proportional to $(\text{Cos}[\alpha])^2$.

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Basic level

Light can be *polarized*. What does this mean?
Imagine you want to insert a coin into a slit. The coin can only pass the slit if it is held *parallel* to the slit. Imagine for a moment that a light beam is composed of millions of coins which try to go through a slit. The coins in this light beam may have any direction. All the coins that have passed the slit run parallel to the slit. Those coins that are not parallel cannot go through the slit.
We call light which has passed the slit *polarized*. The polarization direction is determined by the slit.

What happens if the polarized light beam passes through a second slit? Once more, you filter only those coins which can pass through the second slit. If the second slit is parallel to the first slit, then the polarized light beam passes without any change. If the second slit is orthogonal to the first, no light can pass through the second slit.

You may ask why we have chosen coins and a slit as our model for the polarization of light. The coin represents the *photon* (the light energy) and the direction of the slit plays the role of the filter's *polarization direction*. The way in which you try to put the coin into the slit plays the role of the *polarization direction of the photon*.

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Advanced level

In a two-dimensional plane orthogonal to the propagation direction of light, the electric field vector of each photon (the electromagnetic light wave) has a certain direction. In the huge amount of photons in unpolarized light, the directions of the electric field vectors are randomly distributed.
A polarizing filter selects only those photons whose electric field vector has a certain direction determined by the polarizer. Apart from visible light, any kind of electromagnetic wave can be polarized. Of course, the technical principle of a polarizer depends on the wavelength. For example Polaroid filters serve as a polarizer for visible light. They consist of a special plastic which absorbs most of the photons that haven't been polarized in a certain direction (http://en.wikipedia.org/wiki/Polaroid).

Linear polarized light is defined by an electric field vector with a fixed direction. If linear polarized light is filtered once more, the intensity of light passing through the second filter is given by

$$I(\alpha) = I_0 \operatorname{Cos}^2[\alpha]$$

The angle α describes the difference between the polarization directions of the two filters. If the transmission direction of both filters is the same (α=0°), the transmission is maximal. For α = 90° the transmission is zero because the polarization directions are orthogonal to each other.

In the video clip, there is a mistake. Instead of $\text{Sin}^2[\alpha]$ it must be $\text{Cos}^2[\alpha]$. You can easily check the mistake of the formula $I \sim \text{Sin}^2[\alpha]$ by choosing α =0°. The incorrect formula predicts zero intensity for parallel filters. That's nonsense. It is always good to check formulas in simple examples, rather than believing everything that is written in textbooks or movies.

Modern 3D cinemas use the effect of polarization to create a three-dimensional impression of the scene. Two different pictures which are polarized orthogonally towards each other are broadcasted from the screen at the same time. For this reason, spectators have to use polarized glasses that transmit only one polarization direction to the left eye and one polarization direction to the right eye (http://en.wikipedia.org/wiki/Polarized_glasses). Therefore, the right eye sees one picture and the left eye sees the other picture. Our brain puts the pictures together again.

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Scientific level

The electric field vector of light which is *linear polarized* in the 1-direction can be described as

$$\vec{E}_1(z, t) = E\,\mathrm{Cos}[k z - \omega t]\,\vec{e}_1$$

E is the amplitude of the electric field. The coordinate z describes the propagation direction of the light orthogonal to the (1, 2)-plane. The wave vector k is given by k = (2π/λ) with the wavelength λ.

For *circular polarized light*, the polarization direction of the photon always rotates either in clockwise or counter-clockwise direction on the (1, 2)-plane. These field vectors are described as

$$\vec{E}_+(z, t) = E\,\mathrm{Cos}[k z - \omega t]\,\vec{e}_1 - E\,\mathrm{Sin}[k z - \omega t]\,\vec{e}_2$$

$$\vec{E}_-(z, t) = E\,\mathrm{Cos}[k z - \omega t]\,\vec{e}_1 + E\,\mathrm{Sin}[k z - \omega t]\,\vec{e}_2$$

These two types of circular polarized light have positive (+) and negative (-) helicity. With z = 0, it is easy to see that the electric field vector rotates either clockwise (+) or counter-clockwise (-). The linear superposition of circular polarized light with positive and negative helicity leads to:

$$\vec{E}_-(z, t) + \vec{E}_-(z, t) = 2\,E\,\mathrm{Cos}[k z - \omega t]\,\vec{e}_1$$

The result is linear polarized light whose electric field vector does not rotate but stays fixed in the 1-direction all the time. The amplitude of this superposition is given by 2 E.

A famous example for the experimental realization of circular polarized light is the Fresnel rhomb (http://de.wikipedia.org/wiki/Fresnel).

A simple laboratory method to create circular polarized light is the superposition of a light beam linear polarized in the 1-direction with another light beam linear polarized in the 2-direction. The phase difference between both light beams equals +λ/4.

$$\vec{E}_1(z, t) = E\,\mathrm{Cos}[k z - \omega t]\,\vec{e}_1$$

$$\vec{E}_2(z, t) = E\,\mathrm{Cos}[k (z - \lambda/4) - \omega t]\,\vec{e}_2 = E\,\mathrm{Sin}[k z - \omega t]\,\vec{e}_2$$

The superposition of both waves leads to circular polarized light with positive helicity.

$$\vec{E}_{+/-}(z, t) = \vec{E}_1(z, t) \mp \vec{E}_2(z, t)$$

Negative helicity occurs if the phase shift is -λ/4. Note the close relation between the superposition of electric field vectors and Lissajous-figures. (http://de.wikipedia.org/wiki/Lissajous-Figur)

Websites about polarization:
http://en.wikipedia.org/wiki/Polarizer
http://en.wikipedia.org/wiki/Polarization