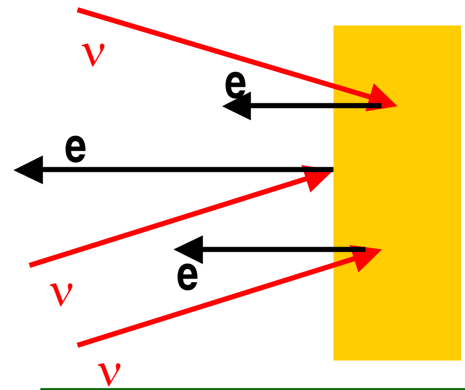
Note on the existence of photons

03/28/2005

Is the particle structure of light a good picture, or is it only an artifact of the tools that have been used to investigate light ?

After all, the quantized number of leaves falling from trees does not force one to adopt a quantum picture of wind.

While Einstein received his Nobel Prize for his interpretation of the photo-electric effect, ironically, his conclusions about properties of light were not totally justified, other interpretations of the photoelectric effect are possible.



$$K_{max} = h(\nu - \nu_0)$$

Observations about the photoelectric effect that have to be explained are:

1) When the incident light has a frequency below a threshold, no electrons are emitted.
2) The energy of the electrons increases linearly with the light frequency.
3) The number of electrons increases linearly with the light intensity.
4) Electrons can be emitted at times very shortly after the onset of illumination.

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Alternate explanation of the photoelectric effect

03/28/2005

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Investigating an electron immersed in a classical sinusoidally varying electric field, where the electron is bound in an energy level E_0 and can make a transition to a free electron with energy E_k above E_0, then the time dependent Schroedinger equation leads to:

1) An appreciable transition probability only if $h\nu = E_k$. A emission thus only occurs when there is a free state available at energy $h\nu$ above the ground state.
2) The energy Ek is thus linearly related to w.
3) The probability of the transition is quadratic with the electric field.
4) The probability to have a transition to any energy turns out to increase linearly with time, leading to some probability even at very small times.

<u>The photoelectric effect does not consitute a prove of existence of photons.</u>

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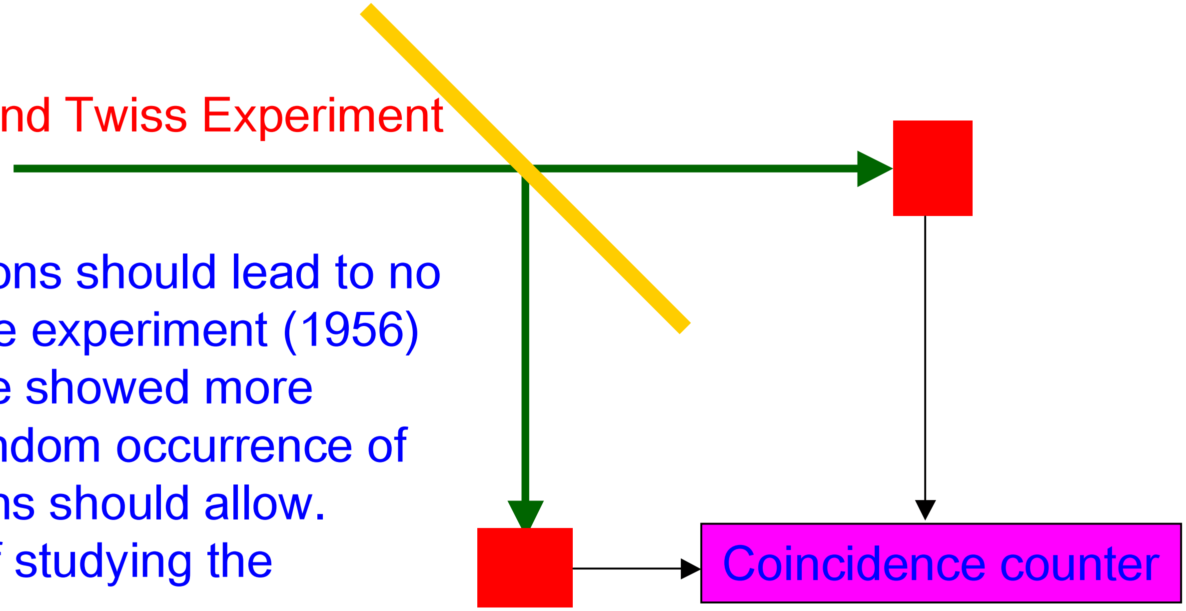
Experimental verification of photons

For a photon to have particle characteristics it can only be at one place at any time.

Test: The Hanbury-Brown and Twiss Experiment



While the existence of photons should lead to no coincidence of detection, the experiment (1956) with a mercury emission line showed more coincidence than even a random occurrence of coincident electron emissions should allow.
This lead to the discipline of studying the quantum nature of light.

Reason: Conventional light sources are not in a state with a well defined number of photons so that coincidence is likely to occur.

$$|\Psi\rangle = A_1|1\rangle + A_2|2\rangle + A_3|3\rangle + \ldots$$

Finally (Clauser,1974), a single photon state was produced, and in deed no coincidences were counted: Photons at last !

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Photons and waves

Now coincidence is counted: Photon is detected only at one point at each time.

Interference when the photon can take two paths: Some information about the photon must have taken both paths.

How can these two concepts be combined?

One try: The conspiracy theory

The photon changes its nature from particle to wave depending on which experiment is chosen, i.e. sometimes it acts as a particle, sometimes as a wave, depending whether the experiment is chosen to test for particle properties or for wave properties.

This has been refuted by delayed choice experiments (John Wheeler, 1978)

Another try: Non-local theory

The photon is influenced by the existence of the second path, even though it does not travel through it (David Bohm, 1952). Problems: This influence is instantaneous and does not diminish with the distance to the second path. It is therefore not favored.

What is left: The probability interpretation of quantum mechanics.

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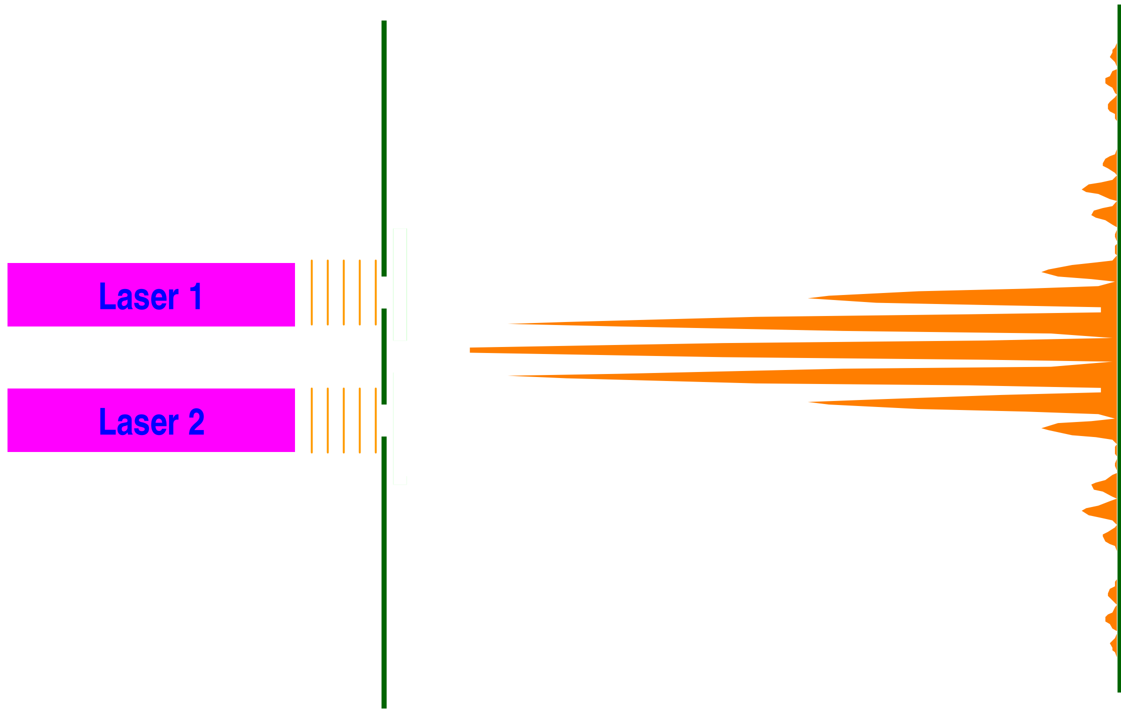
The uncertainty of birth

03/28/2005

Interference from two lasers (Pfleegor-Mandel, 1967)



Light from two lasers can interfere, even when light is emerging with very low intensity:

The photon wave function interferes as if the photon could have been born in either laser.

There is quantum uncertainty of the birth place of the photon.

$$|\Psi\rangle \propto |\text{born at } 1\rangle + |\text{born at } 2\rangle$$

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