

# Linear Polarization, Graphical Representation

Kamal L. Rajpal

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No light passes through two crossed polarizers. However, if a third polarizer is inserted, at let's say 45 degrees, in between the two crossed polarizers then, light does go through the three polarizers in series. This behavior can be explained with the help of a mathematical analysis. This article explains it using a simple graphical approach.

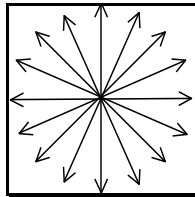


Figure 1

Figure 1 is a representation of un-polarized light. It can be viewed as eight photons traveling along a ray of light, perpendicular to the plane of this paper. Each double arrow represents the transverse vector direction of polarization of a photon.

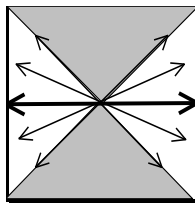


Figure 2

Figure 2 is a representation of linearly polarized light (H or horizontal). The four double arrows can be viewed as four photons traveling along a ray of linearly polarized light (H). The **bold** double arrow along the X-axis is the resultant direction obtained by the vector addition of the four double arrows.

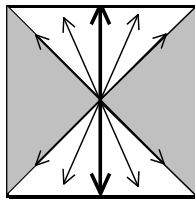


Figure 3

Figure 3 represents linearly polarized light (V or vertical).

It is easy to visualize that a ray of un-polarized light consisting of eight photons (Fig.1) can be split up into two rays of linearly polarized light, horizontal (Fig.2) and vertical (Fig.3), each consisting of four photons.

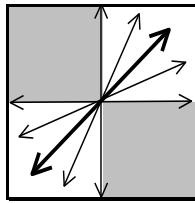


Figure 4

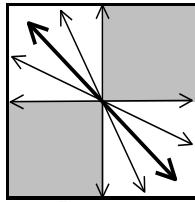


Figure 5

Figures 4 and 5 are the vector representation of linearly polarized light at (+45 degrees) and (+135 or minus 45 degrees) respectively. A ray of un-polarized light in Figure 1 can also be split up into two parts, each of one half intensity of the incident light, as in Figures 4 and 5.

In fact, from a ray of un-polarized light, we can get an infinite pairs of two, equal intensity, orthogonal, linearly polarized light rays; say for example, at 30 degrees and 120 degrees.

The shaded areas in Figures 2, 3, 4 and 5 represent the non-transparent opaque region of a linear polarizer. No light can pass through this region. If Figures 2 and 3 are placed on top of each other, we get a pair of crossed polarizers. No light can pass through this pair since, the transparent region of each polarizer lies on the opaque region of the other. Similarly, no light goes through a pair of crossed polarizers represented by Figures 4 and 5.

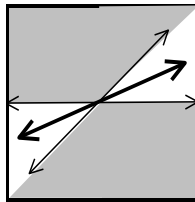


Figure 6

Next, let's place Figures 2 and 4 on top of each other. Light will pass through the common transparent region as given by Figure 6. This is linearly polarized light at +22.5 degrees and consists of two photons only.

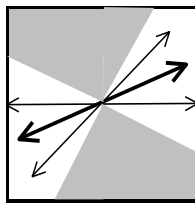


Figure 7

However, this light on coming out of the polarizer will spread out from minus 22.5 degrees to +67.5 degrees with the resultant vector remaining unchanged at +22.5 degrees (Figure 7).

*CONJECTURE: The transverse magnetic field vector direction of polarization of photons traveling along a ray of linearly polarized light are not all confined to a single plane of vibration. Each photon has a separate plane of vibration within an angular spread of 90 degrees.*

Text books in physics, the graphical representation of linear polarization is shown by the resultant bold double arrow only. The angular spread is assumed to be zero degrees. This is an incomplete translation of the mathematical model of linear polarization into a corresponding physical model.

If we place polarizer 4 in between the two crossed polarizers 2 and 3, it is now simple to visualize, as to why light will go through (and how much light will go through) the three polarizers in series but, no light will be transmitted if polarizer 4 is removed. By using trigonometry we can prove that the intensity of the transmitted light (as given by the overlapping transparent non-opaque areas) is as per the cosine squared law of Malus.

The graphical representation helps visualize, why no interference is observed with two orthogonal, linearly polarized, coherent point sources represented by Figures 2 and 3 or, by Figures 4 and 5. Physics text books give a mathematical explanation of this experimentally observed Fresnel-Arago law on the interference of polarized light.

This graphical approach also explains, the observations seen by Alain Aspect in his (Einstein-Podolsky-Rosen) EPR paradox experiment (1982), when the polarization measuring devices are oriented obliquely to each other.

## The EINSTEIN-PODOLSKY-ROSEN (EPR) PAPER

In a thought experiment published in a 1935 paper by Albert Einstein, Boris Podolsky and Nathan Rosen; the authors disagree with the Heisenberg uncertainty principle and concluded that Quantum Mechanics is not a complete theory of nature.

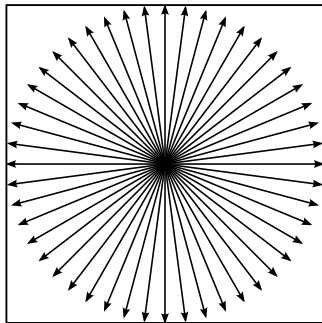
The experiment seeks to look at both the position and momentum of a quantum particle simultaneously. If a photon source placed at the origin in a given inertial frame of reference emits a pair of photons, simultaneously in the opposite direction, say, along the plus (+) X-axis and the minus (-) X-axis direction; then, a measurement of either the momentum or position of one photon reveals the momentum or position of the other.

Polarization has been adopted as a convenient means of studying EPR correlations. Any two photons (or electrons) that originate from a common source will possess a total spin of zero.

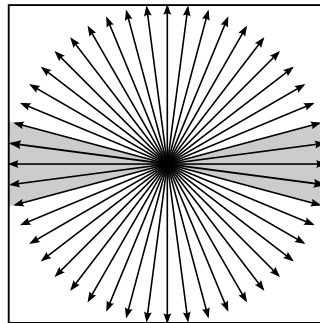
In an experiment (1982) by French physicist Alain Aspect, a radioactive calcium atom emits two correlated photons of random polarizations in the opposite directions. The photon polarizations are separately measured many meters apart. The left hand detector records random polarizations, correlated to the right hand detector's measurements.

The crucial test comes when the polarization measuring devices are oriented obliquely to each other. However, the recorded observations are easy to explain if we note that: *the transverse magnetic field vector direction of polarization of photons traveling along a ray of linearly*

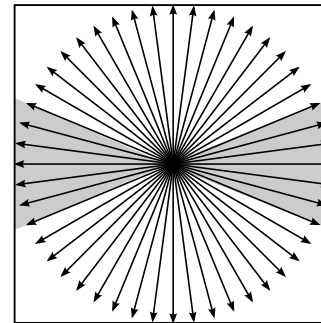
*polarized light are not all confined to a single plane of vibration. Each photon has a separate plane of vibration within an angular spread of 90 degrees.*



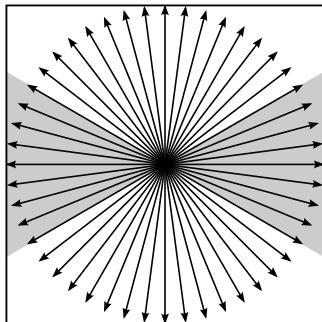
EPR 0.0 degrees



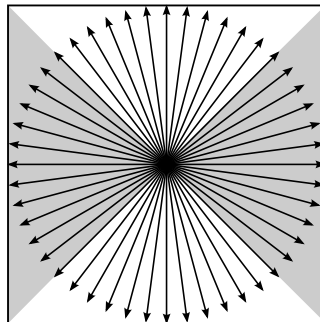
EPR 15.0 degrees



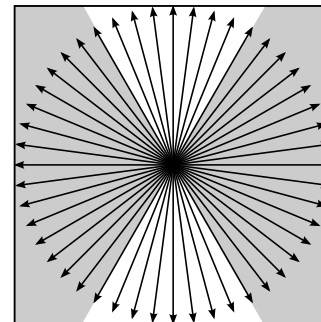
EPR 22.5 degrees



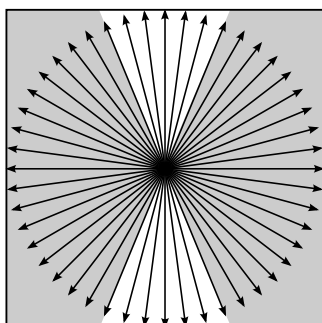
EPR 30.0 degrees



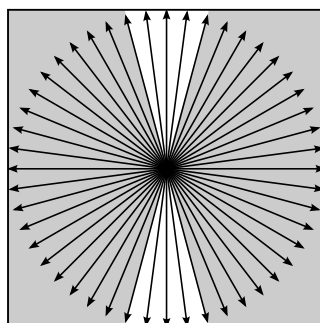
EPR 45.0 degrees



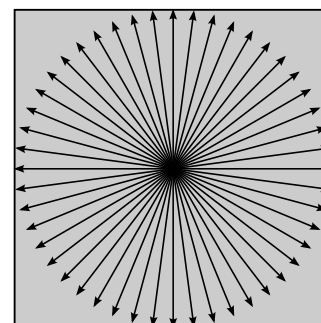
EPR 60.0 degrees



EPR 67.5 degrees



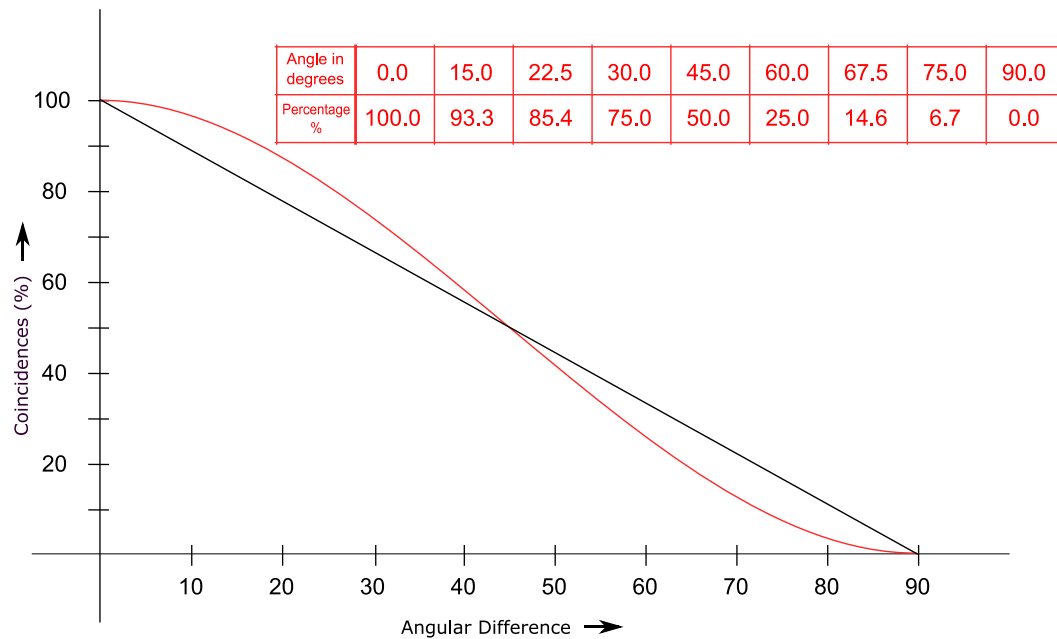
EPR 75.0 degrees



EPR 90.0 degrees

Angle in degrees	0.0	15.0	22.5	30.0	45.0	60.0	67.5	75.0	90.0
Percentage %	100.0	93.3	85.4	75.0	50.0	25.0	14.6	6.7	0.0

The red sine wave line (in the graph below is the plot of the data seen above) gives the relationship between the angular difference along the X-axis (between detector settings, from zero to 90 degrees) and the detected coincidences of photon pairs in percentage along the Y-axis.



The black linear line in the graph above is the relationship predicted by EPR on the standard presumption that prevails even today in all physics text books that *the transverse magnetic field vector direction of polarization of photons traveling along a ray of linearly polarized light are all confined to a single plane of vibration.*

This article proves that Einstein was right when he did not agree with the EPR experiment conclusions and had said, “spooky action at a distance” cannot occur and that, “God does not play dice”.

*“If I can’t picture it, I can’t understand it.”* Albert Einstein.

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[webmaster@physicsphotons.org](mailto:webmaster@physicsphotons.org)