Linear Polarization, Graphical Representation

Kamal L. Rajpal

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 paper explains it using a simple graphical approach.

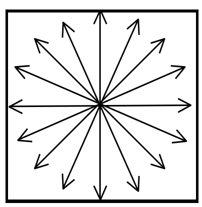


Figure 1

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 photon has a separate plane of vibration* and each double arrow represents the transverse vector direction of polarization of a photon.

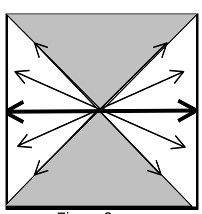


Figure 2

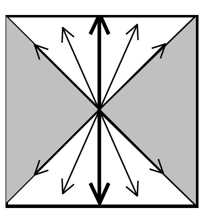


Figure 3

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. *Each photon has a separate plane of vibration.* 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. *As per conservation laws, each photon in Figures 2 and 3 continues to be in the same plane of vibration as in Figure 1.*

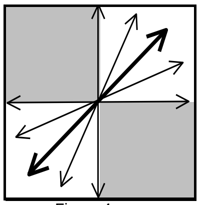


Figure 4

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.

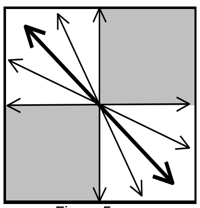


Figure 5

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.

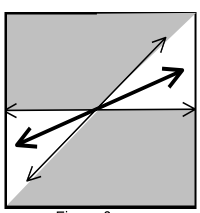


Figure 6

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.

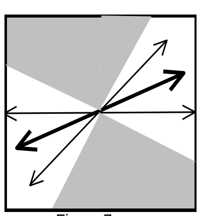


Figure 7

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 or electric 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.

Malus Law, Graphical Derivation

Malus law gives the transmitted intensity through two linear polarizers. It states that the intensity of a beam of un-polarized light, when passing through two polarizers placed in series varies as the square of the cosine of the angle between the transmission axes of the two linear polarizers.

A square (or a triangle or a hexagon) is a geometric figure that can fill up plane 2D space with no overlaps and with no gaps in space. A circle cannot.

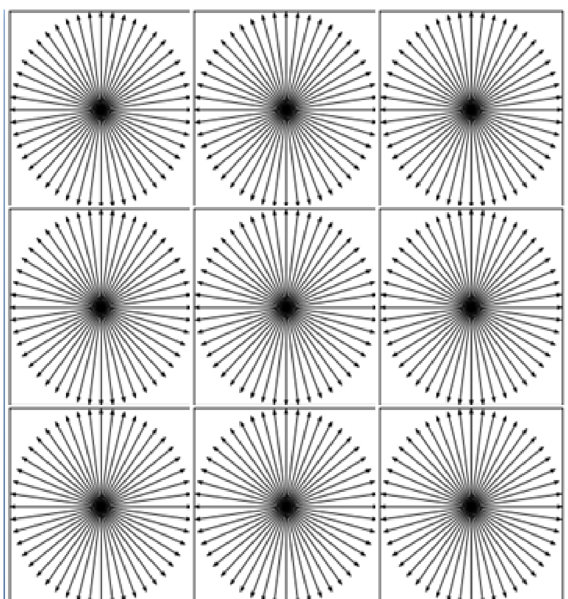


Figure 1

Figure 1 is a representation of a beam of un-polarized light consisting of 9 rays of un-polarized light. It can be viewed as 24 photons traveling along each ray of light, perpendicular to the plane of this paper. Each photon has a separate plane of vibration and each double arrow represents the transverse vector direction of polarization of a photon with wavelength equal to the length of a double arrow or the side of a square.

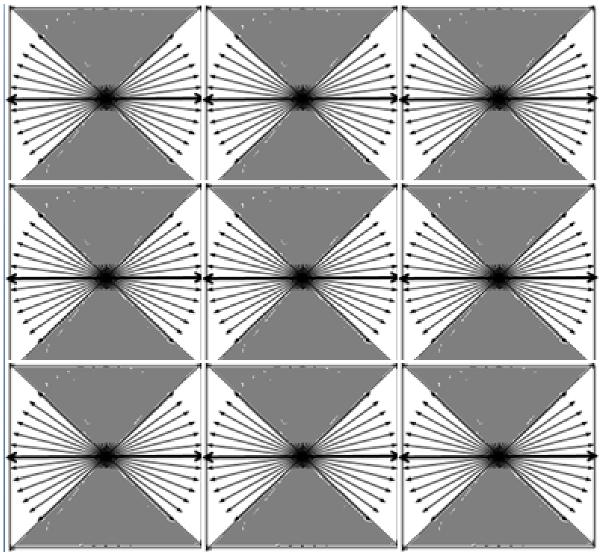


Figure 2

Figure 2 is a representation of a beam of linearly polarized light consisting of 9 rays of polarized light (H or horizontal). The 12 double arrows can be viewed as 12 photons traveling along each ray of linearly polarized light (H). Each **bold** double arrow along or parallel to the X-axis is the resultant direction obtained by the vector addition of the 12 double arrows. Each photon has a separate plane of vibration.

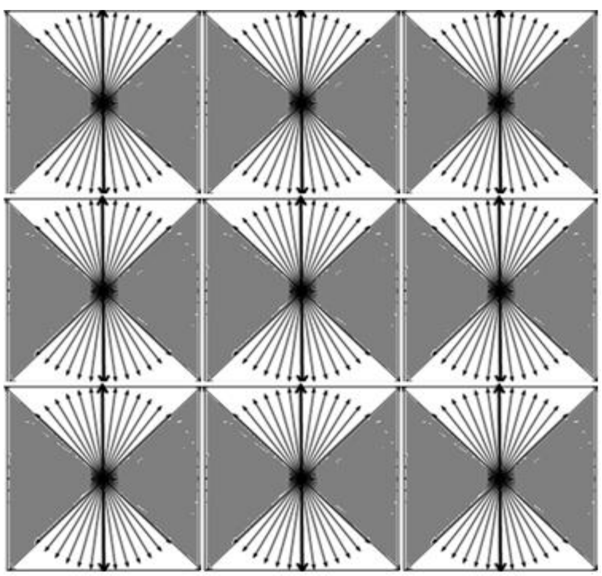


Figure 3

Figure 3 represents a beam of linearly polarized light consisting of 9 rays of polarized light (V or vertical). The 12 double arrows can be viewed as 12 photons traveling along each ray of linearly polarized light (V). Each **bold** double arrow along or parallel to the Y-axis is the resultant direction obtained by the vector addition of the 12 double arrows. Each photon has a separate plane of vibration.

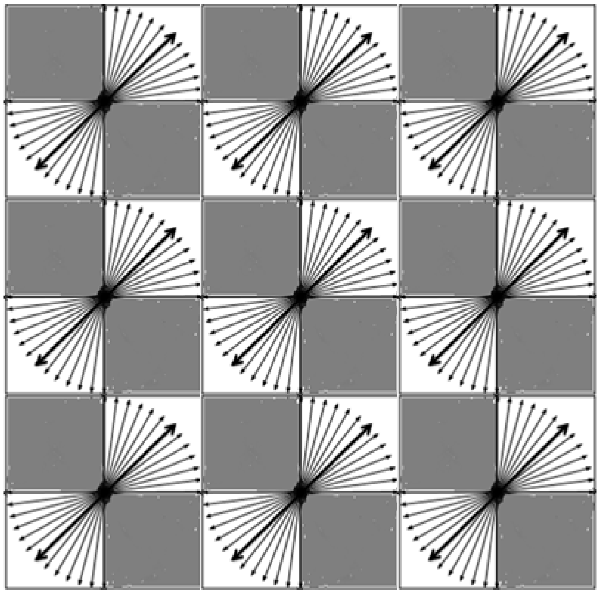


Figure 4

Figure 4 is a vector representation of a beam of linearly polarized light consisting of 9 rays of polarized light at $+45^0$. The 12 double arrows can be viewed as 12 photons traveling along each ray of linearly polarized light at $+45^0$. Each **bold** double arrow along or parallel to the $+45^0$ line is the resultant direction obtained by the vector addition of the 12 double arrows. Each photon has a separate plane of vibration.

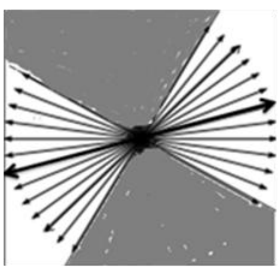


Figure 5

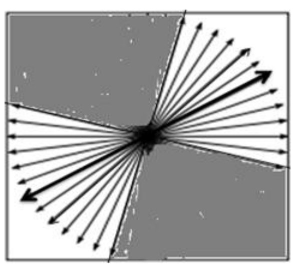


Figure 6

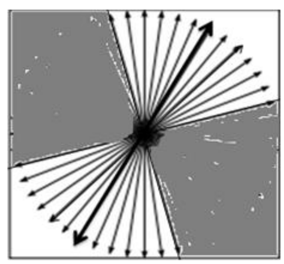


Figure 7

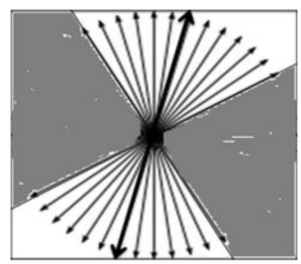


Figure 8

Figures 5, 6, 7, and 8 represent rays of polarized light with the transmission axis at $+15^0$, $+30^0$, $+60^0$ and $+75^0$ respectively.

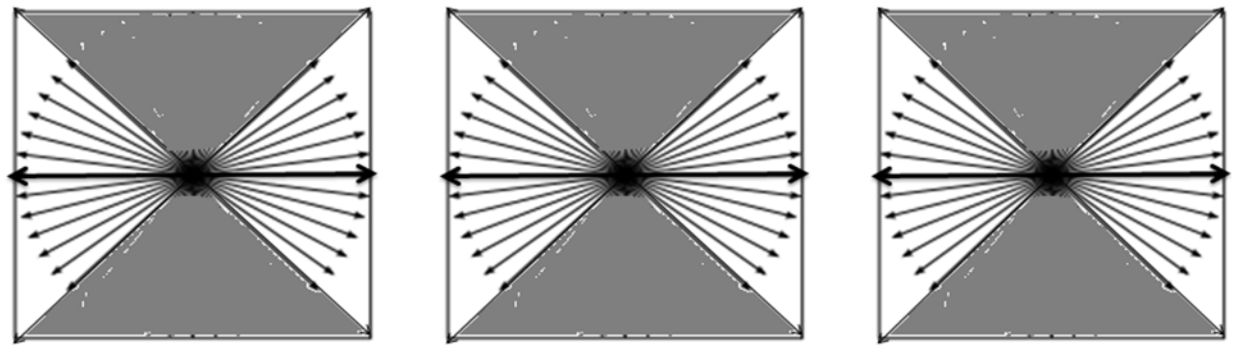


Figure 9a Figure 9b Figure 9c

Figures 9a and 9b represent linear polarizers both at 0^0 (X-axis). A ray of un-polarized light incident on 9a will pass through the common transparent non-opaque region of 9a and 9b placed in series and is given by Figure 9c. 100% transmission is observed.

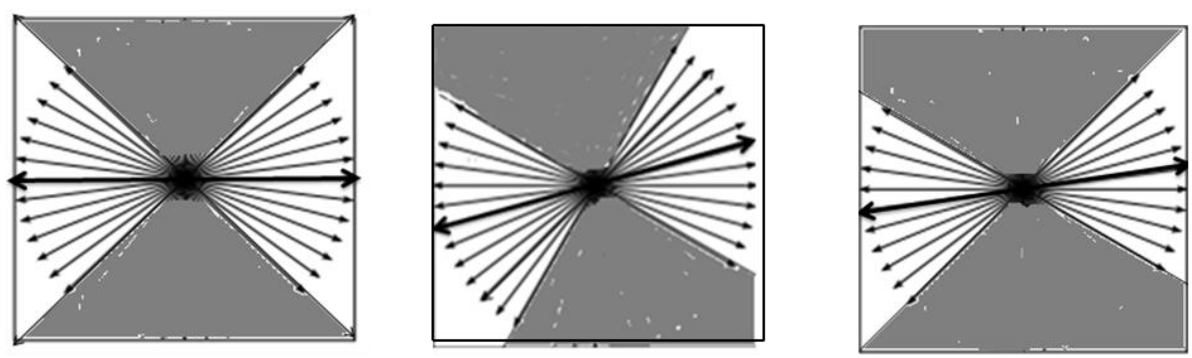


Figure 10a Figure 10b Figure 10c

Figures 10a and 10b represent linear polarizers at 0^0 (X-axis) and $+15^0$ respectively. A ray of un-polarized light incident on 10a will pass through the common transparent non-opaque region of 10a and 10b placed in series and is given by Figure 10c. 93% transmission is observed. The transmission axis is at $+7.5^0$.

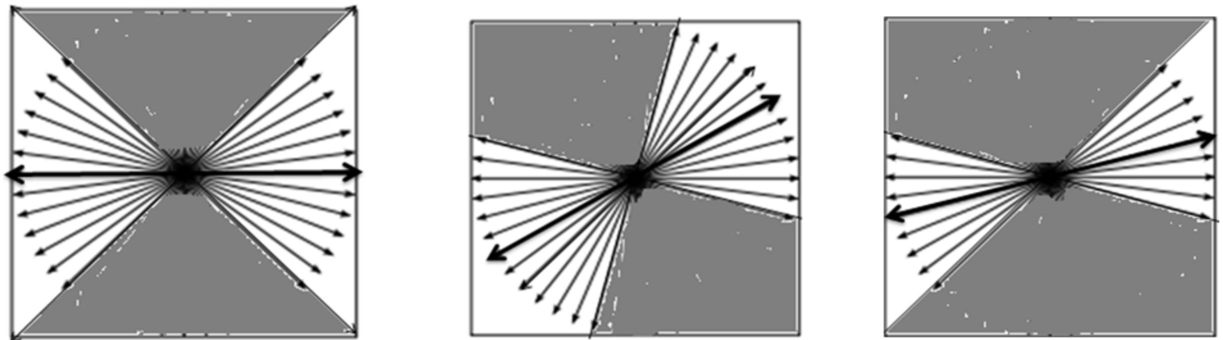


Figure 11a　Figure 11b　Figure 11c

Figures 11a and 11b represent linear polarizers at 0^0 (X-axis) and $+30^0$ respectively. A ray of un-polarized light incident on 11a will pass through the common transparent non-opaque region of 11a and 11b placed in series and is given by Figure 11c. 75% transmission is observed. The transmission axis is at $+15^0$.

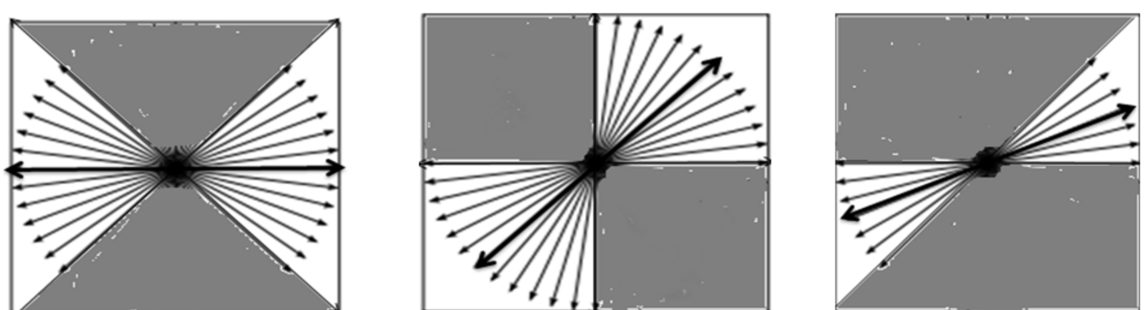


Figure 12a　Figure 12b　Figure 12c

Figures 12a and 12b represent linear polarizers at 0^0 (X-axis) and $+45^0$ respectively. A ray of un-polarized light incident on 12a will pass through the common transparent non-opaque region of 12a and 12b placed in series and is given by Figure 12c. 50% transmission is observed. The transmission axis is at $+22.5^0$.

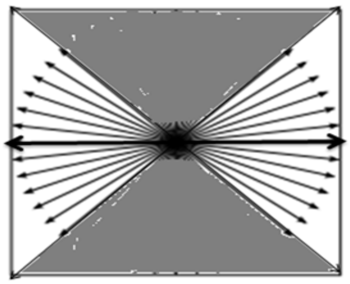


Figure 13a

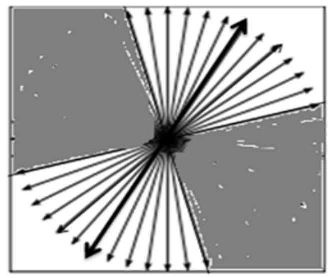


Figure 13b

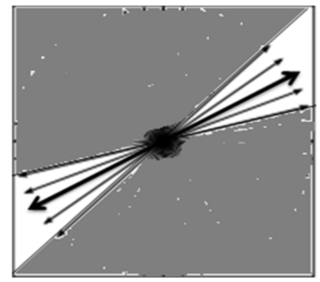


Figure 13c

Figures 13a and 13b represent linear polarizers at 0^0 (X-axis) and $+60^0$ respectively. A ray of un-polarized light incident on 13a will pass through the common transparent non-opaque region of 13a and 13b placed in series and is given by Figure 13c. 25% transmission is observed. The transmission axis is at $+30^0$.

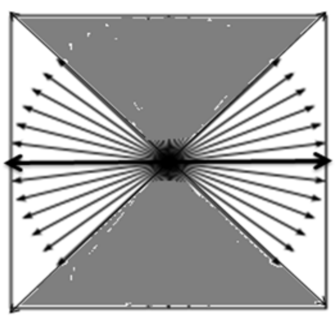


Figure 14a

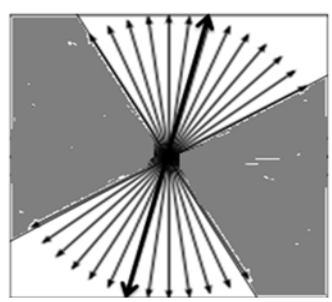


Figure 14b

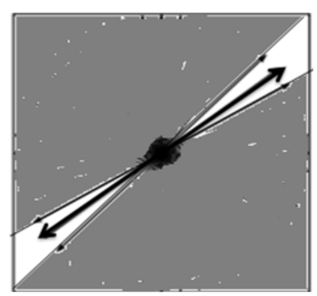


Figure 14c

Figures 14a and 14b represent linear polarizers at 0^0 (X-axis) and $+75^0$ respectively. A ray of un-polarized light incident on 14a will pass through the common transparent non-opaque region of 14a and 14b placed in series and is given by Figure 14c. 7% transmission is observed. The transmission axis is at $+37.5^0$.

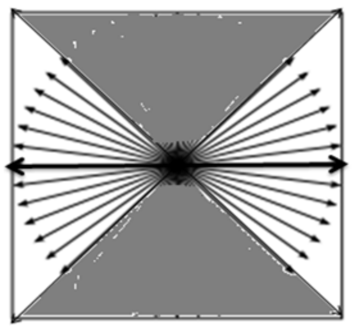


Figure 15a

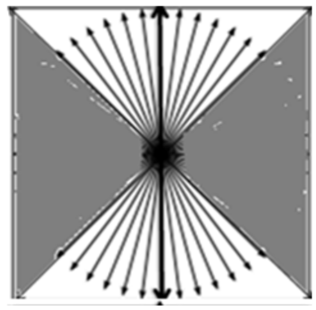


Figure 15b

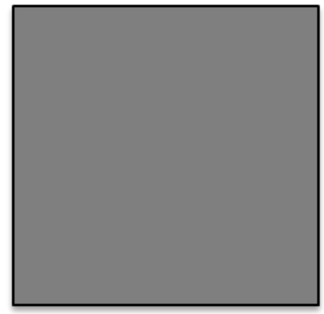


Figure 15c

Figures 15a and 15b represent linear polarizers at 0^0 (X-axis) and $+90^0$ (Y-axis) respectively. A ray of un-polarized light incident on 15a will pass through the common transparent non-opaque region of 15a and 15b placed in series and is given by Figure 15c. 0% transmission is observed.

The common transparent non-opaque regions in Figures 9c to 15c can be calculated using a millimeter graph paper and a 10cm wavelength ray of photon radiation. The observations are tabulated below and correspond to the cosine squared law of Malus.

Angle	0^0	15^0	30^0	45^0	60^0	75^0	90^0
Area%	100	93	75	50	25	7	0

The EINSTEIN-PODOLSKY-ROSEN (EPR) PAPER

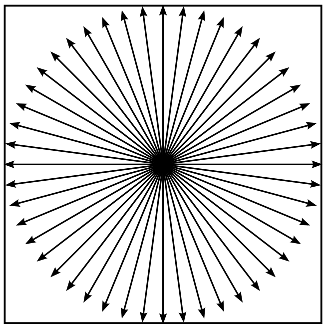
In a thought experiment published in a 1935 paper by Albert Einstein, Boris Podolsky and Nathan Rosen; the authors disagree with the Heisenberg uncertainty principle and concluded that Quantum Mechanics is not a complete theory of nature.

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.

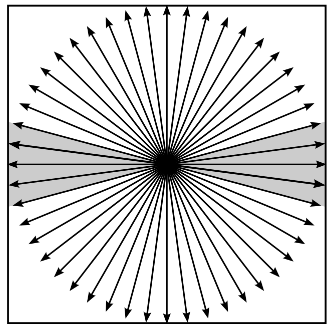
Polarization has been adopted as a convenient means of studying EPR correlations. Any two photons (or electrons) that originate from a common source will possess a total spin of zero.

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.

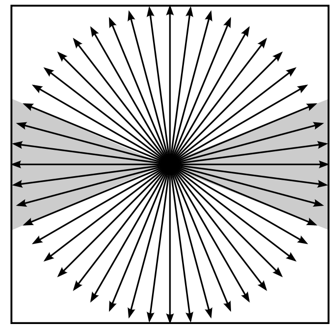
The crucial test comes when the polarization measuring devices are oriented obliquely to each other. However, the recorded observations are easy to explain if one realizes that: *the transverse magnetic or electric field vector direction of polarization of photons traveling along a ray of linearly polarized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



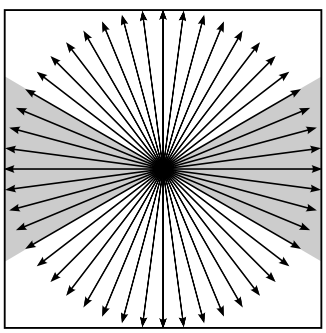
EPR 0.0 degrees



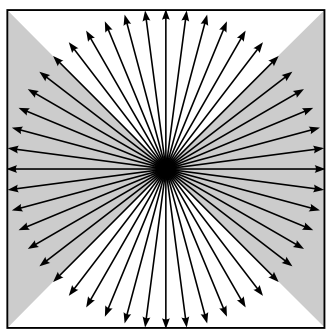
EPR 15.0 degrees



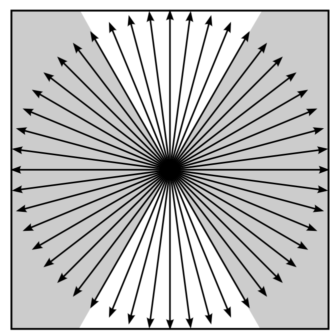
EPR 22.5 degrees



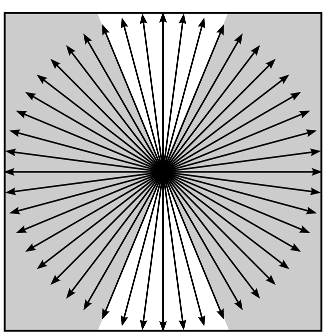
EPR 30.0 degrees



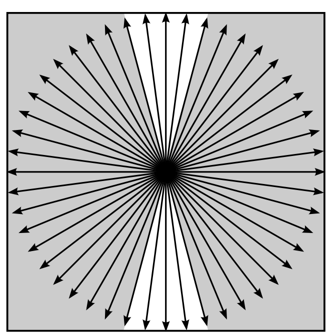
EPR 45.0 degrees



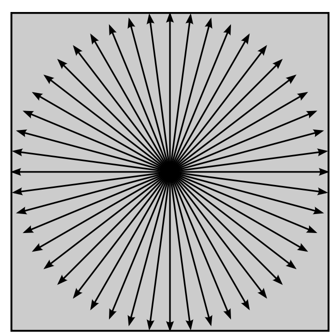
EPR 60.0 degrees



EPR 67.5 degrees



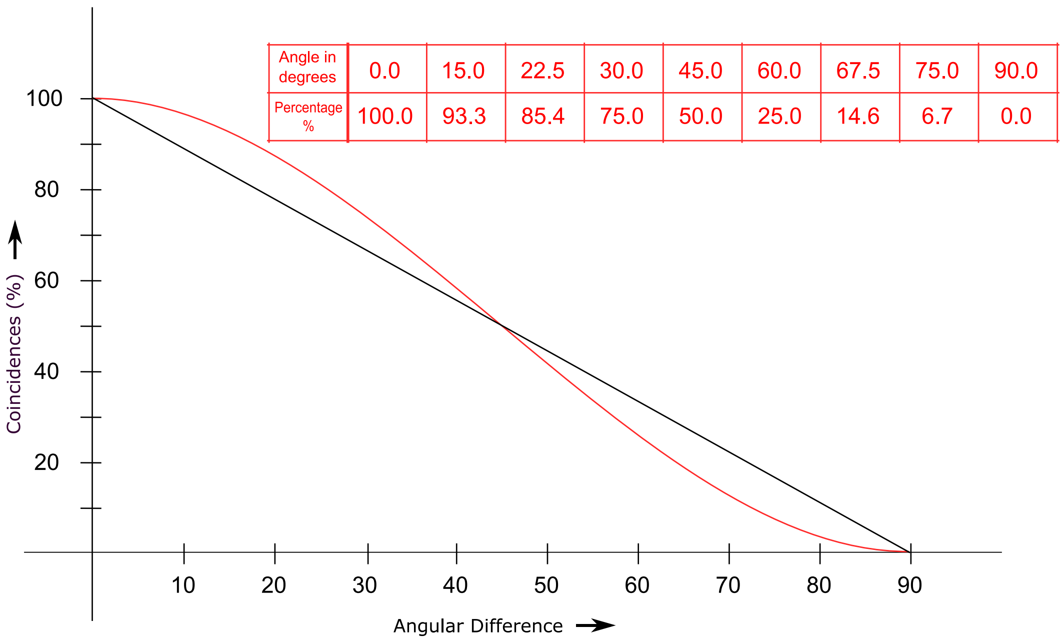
EPR 75.0 degrees



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 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 relation-ship predicted by EPR on the standard presumption that prevails even today in all physics text books that *the transverse magnetic or electric 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 paper 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”.

The above proposed Linear Polarization model can explain in a non-mathematical graphical manner all the experiments discussed in Chapters 2, 3 and 4 of the book [1] by Alastair Rae.

"If I can't picture it, I can't understand it." Albert Einstein.

REFERENCE

[1] Rae Alastair I M, Quantum Physics: Illusion or Reality? Cambridge University Press, Cambridge, UK, 1986.
Chapter 2 Which way are the photons pointing?
Chapter 3 What can be hidden in a pair of photons?
Chapter 4 Wonderful Copenhagen?

FURTHER READING

Conceptual Quantum & Photon Physics
http://vixra.org/author/kamal_l_rajpal

30 November 2002. Revised: 23 February 2014.

Email: webmaster@physicsphotons.org