Model and method to explain correlation in Bell-test experiments

Abstract

The correlation in Bell-test experiments in relation to elektronspin can be explained according to local-realism. A simple model shows that the position of the detectors respective of the direction of movement of the elektrons define vektorspaces in which the opposit spinvektors of entangled pairs of elektrons are which give equal spin result.

With this model the identification of those vektorspaces and the measuring and counting of the spinvektors can be described. In this way correlation, as it is calculated in quantum theory and found in experiments, is explained.

Introduction

The EPR paradox is a serious problem in physics. The paradox is about the properties of quanta. Einstein e.a. stated that quanta have well-defined properties while Bohr e.a. stated that quanta don't have well-defined properties. According to Bohr quanta show their properties only in interaction / measurement. These statements cannot both be true.

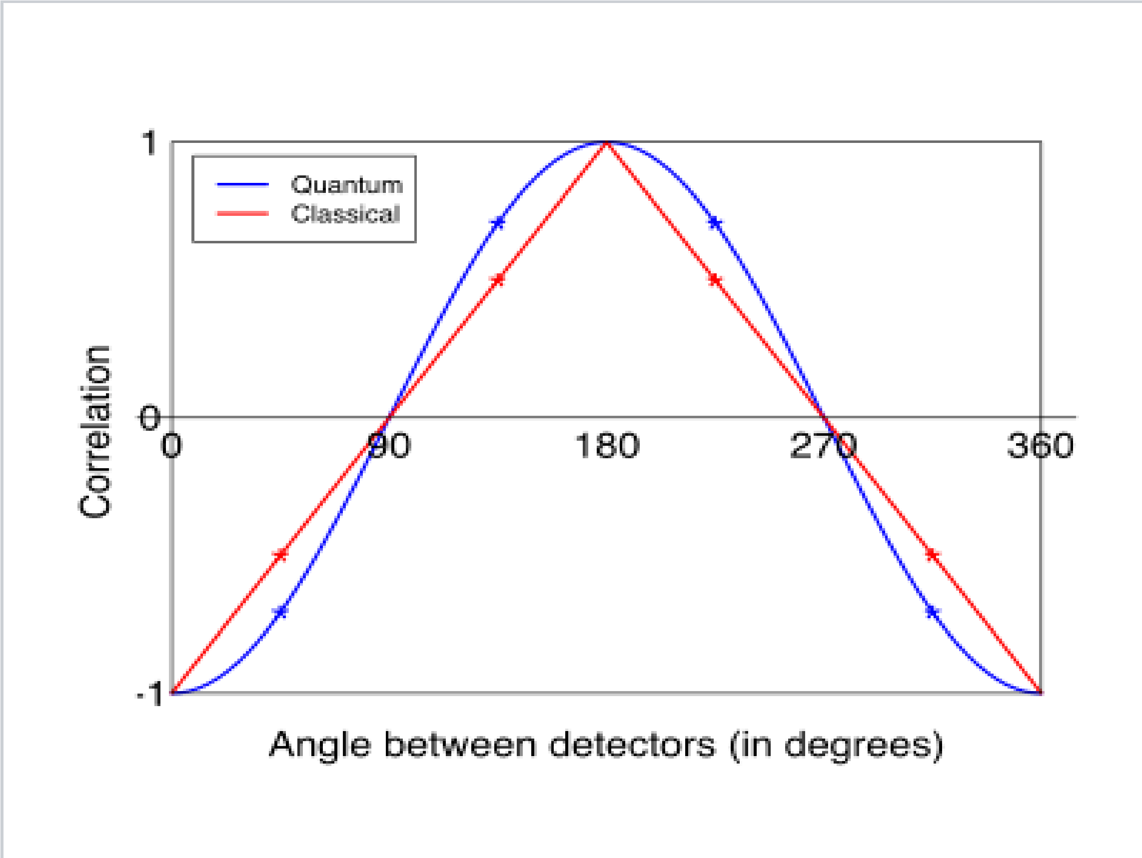
Bell did a magnificent job on this. He wanted to show that the views of Einstein were right. He calculated inequalities (and correlation) and stated that they must be valid in a local universe. Bell-test experiments showed, however, that his correlation was not found. The conclusion was that the universe can not be local. This conclusion is not necessarily right. It is very well possible that the theorem of Bell is not applicable to spin measurement of entangled elektrons. The model presented in this paper demonstrates this and gives also an explanation of correlation in Bell-test experiments.

Bell-test experiments

In Bell-test experiments spin of many entangled pairs of elektrons is detected and recorded as + or – . Although spin of entangled elektrons is always opposit, the result of the detection does not always show opposit spin. Sometimes the result is equal spin: + + or – – . The chance of equal spin result depends on the difference in angle (φ) at which the detectors are adjusted. This angle (φ) and the chance of equal spin result are correlated. The correlation (C) is defined as $C = (G - T) / (G+T)$ in which G is the number of equal spin results and T is the number of opposit spin results in a series of detections. Expressed as chances $(G+T) = 1$ and than $C = (G - T)$. (See also graphics next page).

The quest

The quest is to identify real spaces in which real opposit spinvektors are that give equal spin result at detection by two detectors adjusted at different angles. The results of the measurements must give the quantum mechanical correlation which is a function of φ.



The best possible local realist imitation (red) for the quantum correlation of two spins in the singlet state (blue), insisting on perfect anti-correlation at 0°, perfect correlation at 180°. Many other possibilities exist for the classical correlation subject to these side conditions, but all are characterized by sharp peaks (and valleys) at 0°, 180°, and 360°, and none has more extreme values (±0.5) at 45°, 135°, 225°, and 315°. These values are marked by stars in the graph, and are the values measured in a standard Bell-CHSH type experiment: QM allows $\pm 1/\sqrt{2} = \pm 0.7071\ldots$, local realism predicts ±0.5 or less.

Straight line = red. Wave line = blue.
Source: https//en.wikipedia.org/wiki/Bell%27s_theorem

Model and assumptions

It is possible to find these spaces starting from some assumptions. These assumptions are not necessarily according to reality, they are also not necessarily false. These assumptions are:

1) Elektrons have real (well-defined) spin;
2) Spin can be represented by a vektor with any fixed direction in space. Spinvektors of all elektrons have the same length (in one experiment). The direction of spinvektors of elektrons of an entangled pair is exactly opposit;
3) A detector exists of parallel detection lines in a plane. The detection lines have a common center perpendicular plane (cpp);
4) Detectors are positioned perpendicular to the direction of movement of the elektrons. Detectors can be adjusted by revolving around their center;
5) When spin of an elektron is measured, the tip of a spinvektor is projected on a detection line and the result is expressed as + or – . The direction of the projection is the direction of movement of the elektrons. When the projection of a vektortip arrives above the cpp of a detector then the result is + and when it arrives below the cpp of a detector then the result is – .
6) Spin detection in the direction of movement of an elektron is not possible.

Method and vektor spaces

In Bell-test experiments there are a number of participants:

- two detectors;
- a pair of elektrons;
- an observer.

To describe the experiment a coördinate system is chosen with a x-axis, a y-axis and a z-axis and with O (0,0,0) as center. The role of the observer is to choose this coördinate system and to observe the other participants in it. The position of the observer is somewhere at the – y-axis.

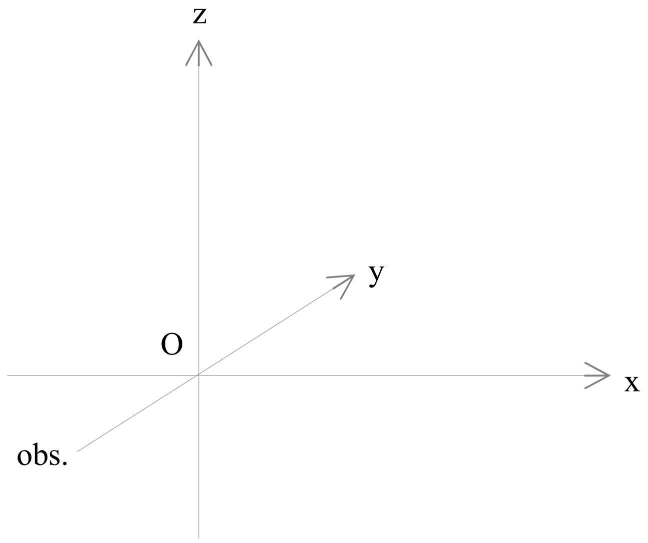
There are two different kinds of spaces: a real space and a space of directions. The real space is a fixed space repective of the coördinate system. The space of directions (also known as perspective) is the space that moves in the same way as the participants: front is always front, left is always left and above is always above.

There are two different ways of movement: translation and rotation. They have a different effect on the perspective of the universe to the participants. Translation doesn't change anything in the perspective of the participants: front stays front, left stays left and above stays above. The distance between the participant and the observer does change. Rotation doesn't change the perspective of the participants in one direction and in both other directions the perspective changes proportional to the rotation of the participants.

This applied to a Bell-test experiment gives an explanation for the correlation. In Bell-test experiments directions, planes and spaces play a role. Time doesn't play a role and also the sequense of the movements makes no difference. As translation doesn't change anything to the perspective of the participants, they can all be positioned in the center of the coördinate system (O) without any problem and from that situation can be observed which effect the various rotations have on the perspective of the participants. By placing all participants in one point (O), the perspectives (spaces of direction) of the participants can be well compared with each other. Note that the spinvektor space is the same space as the 'space of directions' of the elektrons.

The observer chooses a coördinate system as in fig.1).

Fig.1)



Coördinate system (obs. = observer)

When a coördinate system is choosen, space becomes absolute as it were. All movements of other participants take place respective of that absolute space.

The detectors have their center in O, both in the same position which means that their 'spaces of direction' are the same. (They face in the same direction). The direction of the detectors is free to choose and is chosen vertical (along the z-axis).

The entangled pair of elektrons is produced in O and they are about to move. The detectors must be perpendicular to the direction of movement of the elektrons so this direction of movement of the elektrons is free to choose in the x,y-plane. They are chosen to move along the y-axis: one elektron is ever to move in the direction of the – y-axis and the other in the direction of the +y-axis. The directions of the detectors and the directions of movement of the elektrons are now fixed in the y,z-plane. To get the detectors perpendicular to the direction of movement of the elektrons, they have to rotate around the z-axis, starting from that y,z-plane, until they reach the x,z-plane.

One has to realize that for the detector planes there is nothing to choose any more: after the directions of both detectors and the direction of movement of the elektrons are fixed in the y,z-plane, the detectors have to start from that y,z-plane to be positioned perpendicular to the direction of movement of the elektrons and they have to rotate 90° around the z-axis.

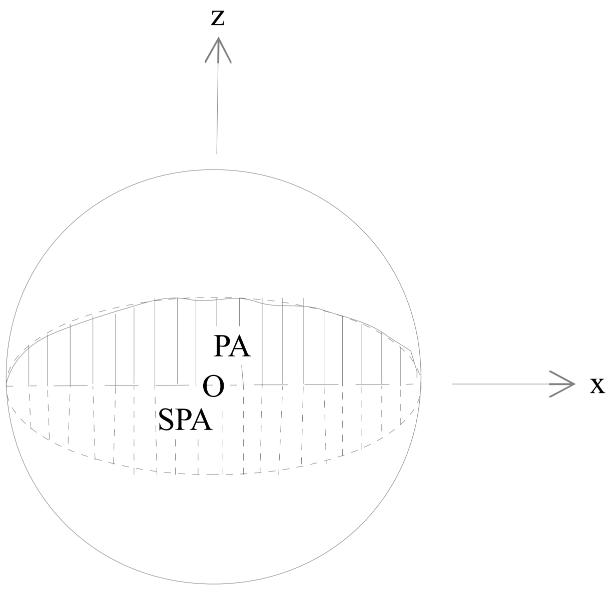
In a real experiment the detectors would have to be placed from this position to somewhere at the y-axis because of the direction of movement of the elektrons. Suppose detector A is being placed at the + y-axis and stays adjusted vertical during the whole experiment. Detector A has then just been translated and to this detector the perspective of the universe has not been changed. Detector B is being placed at the – y-axis and adjusted at φ° respective of the vertical. To get there detector B has to rotate not only φ° around the y-axis but also 180° around the z-axis.

For every rotation there is a choice to rotate the left way round or the right way round. The results of this choice are symmetrical situations and don't influence the results of the detections. That is also why it makes no difference if in the starting position both detectors face in the direction of the + x-axis or in the direction of the – x-axis.

To visualize the 'direction spaces' of the participants a sphere is used. The sphere is positioned with its center in O and its diameter is smaller than the width of a detector. At the surface of the sphere spaces can be drawn, for example the spaces between the cpp's of the detectors. By rotating the sphere the same way as the detectors, one can really see in what way the 'direction spaces' of the various participants move around.

In the starting position all participants are in O and also the detectors are in the same place facing in the same direction. It is chosen for the detectors to face in the direction of the – x-axis. Now detector B is being rotated left way 180° around the z-axis and φ° left way around the x-axis. Spaces arise between the cpp's of both detectors which can be presented, together with the sphere, as in fig.2).

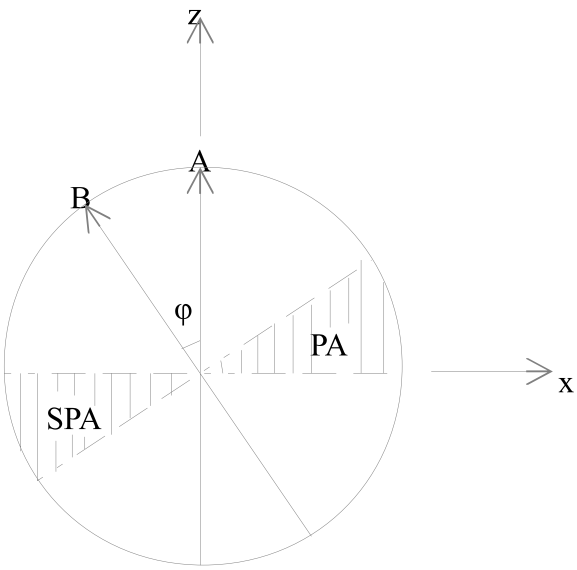
Fig.2)



The cpp of A is horizontal. The angle between the cpp of A and the cpp of B (ellips) is φ°. PA (perspective of A) is one of the 'direction spaces' between the cpp's to A. SPA is the other 'direction space' between the cpp's to A. Both spaces are symmetrical respective of O.

These are real spaces from the view of the elektrons (and the observer because they all look along the y-axis). Now the detectors are being positioned perpendicular to the direction of movement of the elektrons and by doing so, both detectors rotate 90° left way around the z-axis. Then the spaces between the cpp's look as in fig.3).

Fig.3)



Spaces between the cpp's after the detectors have been placed perpendicular to the direction of movement of the elektrons.

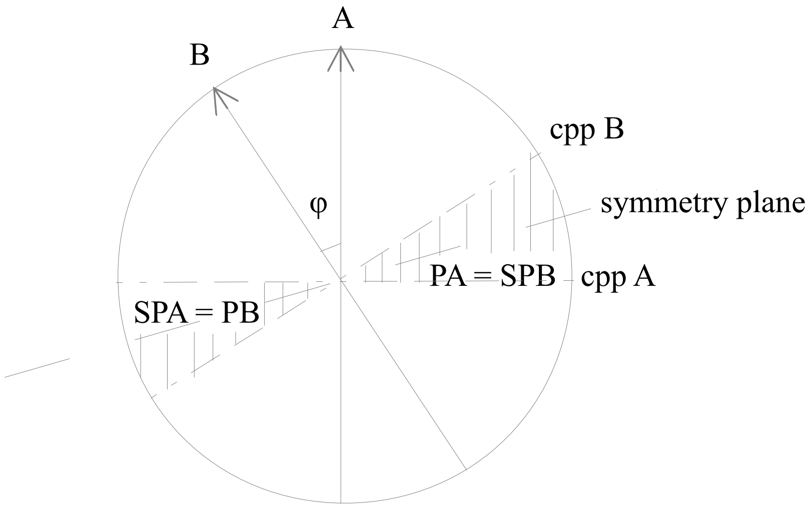
To the detectors the space PA in fig.3) (the 'direction space' of A) is still, after rotation of 90° around the z-axis, the space between the cpp's but respective of the coördinate system (and the elektrons) this space is totally different from the (real) space PA in fig.2).

From the moment that only just the directions of the detectors and the directions of movement of the elektrons are fixed (the start position) the detectors have to undergo two movements: the adjustment and the perpendicular positioning. At the adjustment only the perspective of detector B changes. It is this adjustment that defines the real vektorspaces. At the perpendicular positioning the perspectives of detectors A and B change in the same way. The sequence of the movements doesn't make a difference. During this whole proces the perspective of the elektrons doesn't change.

One could state that the space PA in fig.3) is real to the detectors as well as to the elektrons (and to the observer). This is true of course but it is not the space in which the spinvektors are that need to be detected. They are in the spaces between the cpp's in the situation of fig.2) because the 'direction spaces' of the elektrons don't change at the perpendicular positioning of the detectors. When the detectors are positioned perpendicular first and adjusted afterwards, then the perspective of the detectors has changed already and that still has to be taken into account. It is not allowed to ignore the rotation of 90° around z-axis (the perpendicular positioning).

The spaces between cpp's of A and B in fig.3) seem to be the same to A as to B but they are certainly not. To 'direction space' PA of detector A belongs a 'direction space' SPA which is symmetrical respective of O. This space SPA is to detector B the 'direction space' PB but mirrored in the plane which is exactly between the cpp's of A and B. And to detector B the 'direction space' SPB is the same as 'direction space' PA but also mirrored in that same plane. (See fig.4)). This is easy to show by rotating the sphere, with the spaces drawn on it, the same way as detector B.

Fig.4)



'Direction spaces' between the cpp's as they look to detector A and detector B.

The wanted real vektorspaces, in which the opposit spinvektors are which give equal spin result, are the spaces between the cpp's of both detectors after adjustment of detector B (rotation 180° around the z-axis and φ° left way), as seen by the elektrons and the observer. This is as in fig.2).

Changing the adjustment of the detectors changes the spaces between the cpp's as well as the vektorspaces. The changes of both spaces are one and the same effect of the change of adjustment of the detectors. The effect is instantanuous and nothing is transmitted: no force, no energy and no information. Because of the fact that the perpendicular positioning must be taken into account, the change of the vektorspaces as a result of the changed adjustment of the detectors is the same as the change of the spaces between the cpp's. What a real space is to the spinvektors (elektrons), is a 'direction space' to the detectors and what real space is to the detectors, is a 'direction space' to the spinvektors (elektrons).

Detecting and counting.

In Bell-test experiments spin of many entangled pairs of elektrons is detected. Spin of an elektron is represented by a vektor. The direction of the spinvektor is completely arbitrary but fixed in space. The direction of the spinvektors of the elektrons of an entangled pair is exactly opposit. It is assumed that the spinvektors of all elektrons (in one experiment) have the same length.

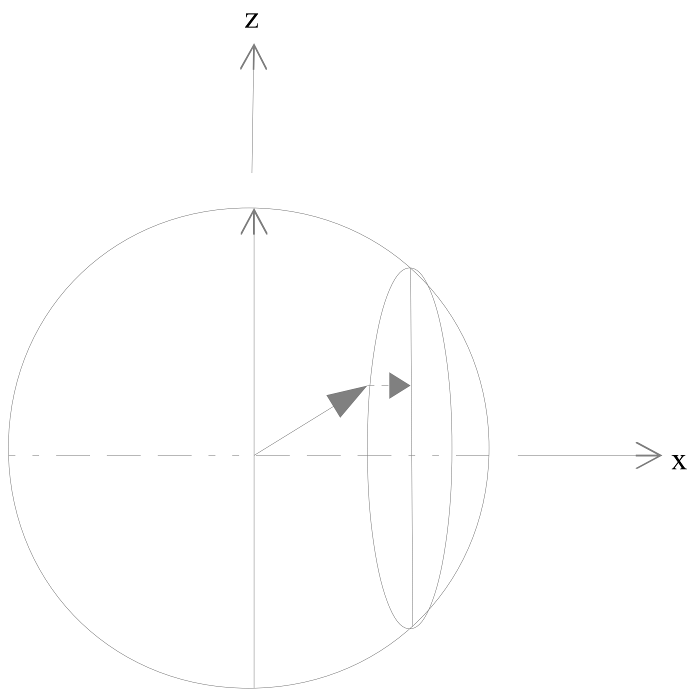
All pairs of elektrons are produced in O. The elektrons don't start moving yet so after a while there are many pairs of elektrons in O. The spinvektors of all these pairs point in any direction but the spinvektors of one pair point in opposit directions. As the spinvektors all start in O and all have the same length, their vektortips will be at the surface of a sphere. This sphere is chosen to be the same as the one described before.

The spinvektors of elektrons of an entangled pair are in the sphere symmetrical respective of O as do the spaces between the cpp's of the detectors in the starting position (fig.2)). Opposit spinvektors are both in these spaces or are both not in these spaces. When they are both in these spaces and one of the spinvektors is 'above' the cpp of A then the other one is 'above' the cpp of B and when one of them is 'beneath' the cpp of A then the other one is 'beneath' the cpp of B. The result of the detection is in the first case: + + and in the second case: – – . When both spinvektors are not in the spaces between the cpp's and one of the vektors is 'above' the cpp of A then the other one is 'beneath' the cpp of B and when one of the vektors is 'beneath' the cpp of A then the other one is 'above' the cpp of B. Now the result of the detection is in the first case: + – and in the second case: – +.

For detection of spin the vektors are projected perpendicular at the detector. The direction of the projection is parallel to the direction of movement of the elektrons (y-axis). The detectors are perpendicular to this direction in the x,z-plane.

A detector exists of detection lines in the plane of the detector parallel to the direction of the detector. Each detection line can be considered as the diameter of a parallel cirkel perpendicular to the detector plane. Considered this way, each vektortip is on a parallel cirkel of the sphere that belongs to a particular detection line of the detector. (See fig.5)).

Fig.5)



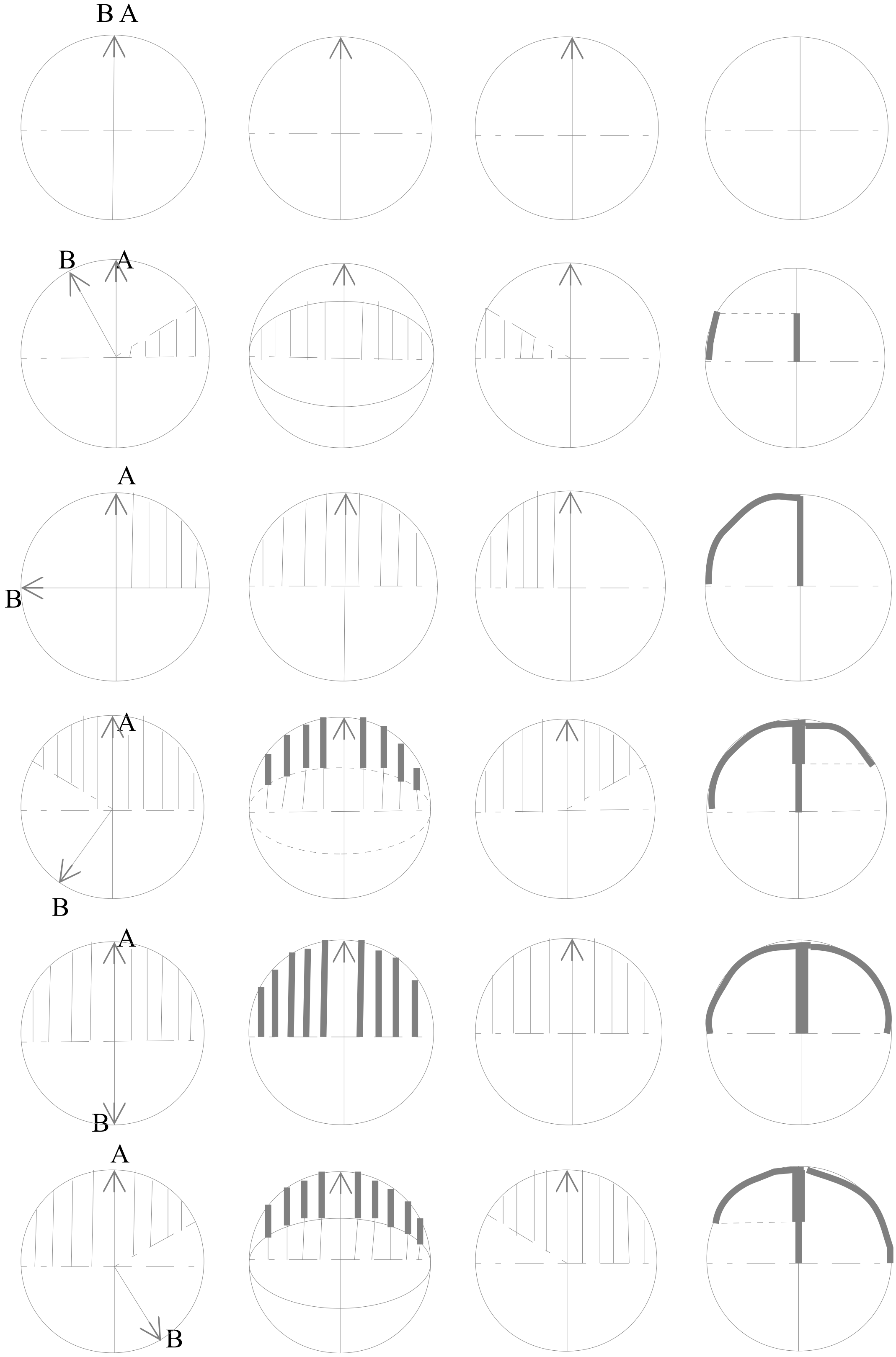
Projection of a vektortip from a parallel cirkel to a detection line.

From the perspective of the elektrons the real vektorspaces are between the cpp's of the detectors while these detectors are in the y,z-plane (as in fig.2)). From these spaces the spinvektors are detected by projection at the detectors while these detectors are in the x,z-plane (to the elektrons the vektorspaces haven't been moved with the perpendicular positioning of the detectors). Each vektortip is being projected from its own parallel cirkel to the accompanying detection line.

Of course one spinvektor is in one half of the sphere: either it is above the cpp or it is beneath the cpp. As the assessment of the chance of equal or opposit spin result for both halves of the detection line is the same, this proces need to be described for only one half of the detection line. Than this counting is valid for the whole detection line because the chance for the projection of a vektortip on a parallel cirkel to arrive at the accompanying detection line, is 1.

In fig.6) (next page) various spaces are drawn for a number of angles φ. The detectors are represented in the detecting situation which means: after adjustment and perpendicular positioning. In the left column of fig.6) the observer is looking at the front of detector A and at the back of detector B.

Fig.6)



φ = 0°

φ = 30°

φ = 90°

φ = 150°

φ = 180°

φ = 210°

Spaces between cpp's from the observer's view.

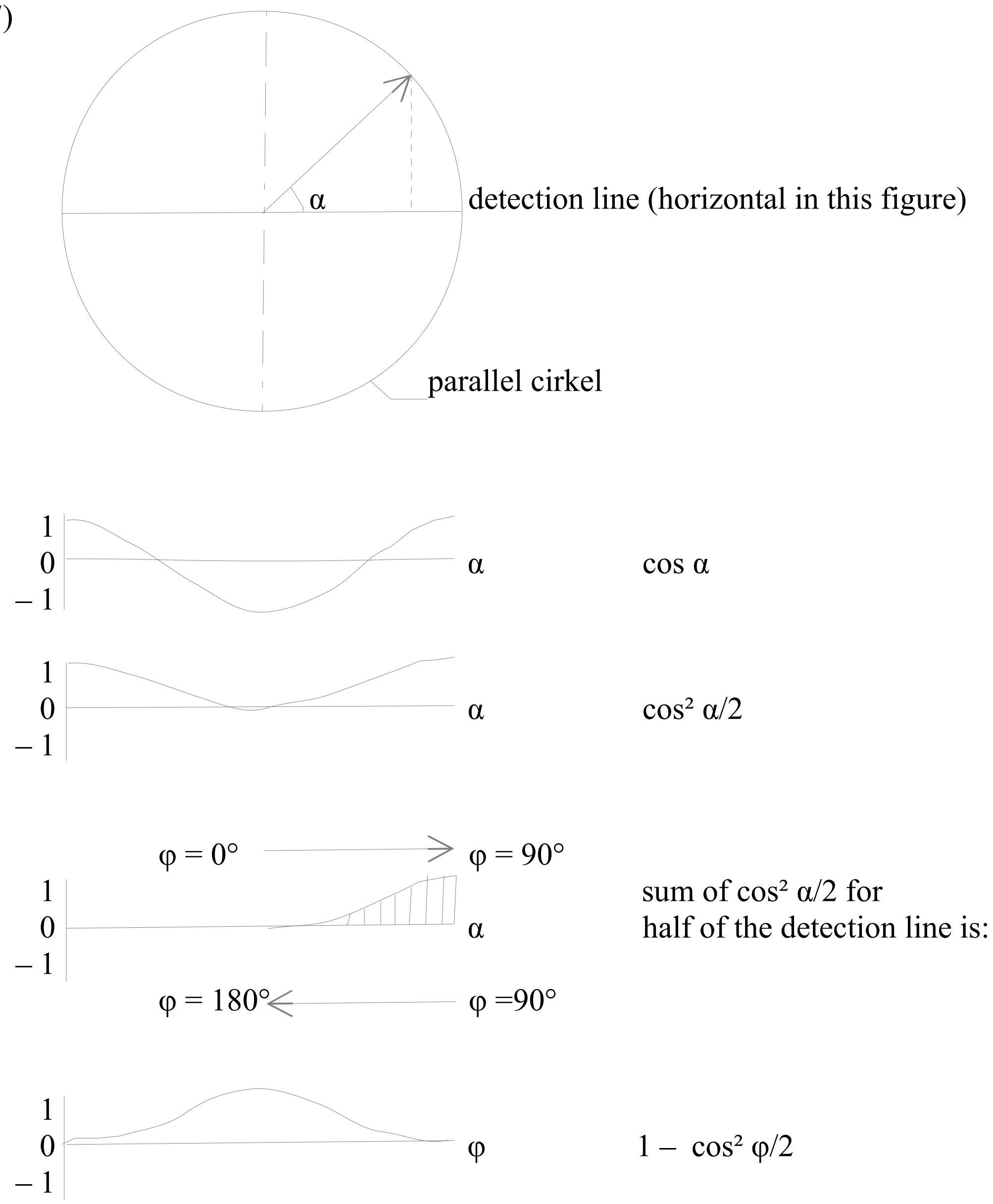
Real vektorspaces from the observer's view.

Real vektorspaces seen from a point at the + x-axis.

Detection lines with part of the parallel cirkels that cover the vektorspaces, projected on them (view: + x-axis).

The projection of points from a cirkel to its diameter is given by cos α. The chance for the projection of a point of the cirkel to arrive at a certain place at the diameter is given by $\cos^2 \alpha/2$. The real vektorspace, corresponding to φ, defines the part of the parallel cirkel that, projected at the detection line, indicates the chance (G) for a certain vektor to belong to a pair which give equal spin reult. That chance (G) is the sum of $\cos^2 \alpha/2$ over the part of the detection line at which that part of the parallel cirkel is projected. That chance is $1 - \cos^2 \varphi/2$. (See also fig.7)).
At φ = 0° the cpp's are in the same place and the vektorspace between them is 0.
At φ = 90° the real vektorspace fills halve of the halve sphere. At this point the increase of G is the fastest.
At φ = 180° the real vektorspace fills the whole of the halve sphere and then G = 1. (See also fig.6)).
At φ > 180° emerges in the halve sphere the space again in which no spinvektors are that give equal spin result. In this way the halve sphere is emptied in the same way as it was filled.

Fig.7)



So $G = 1 - \cos^2 \varphi/2$
$T = 1 - G = \cos^2 \varphi/2$
Correlation $C = G - T = 1 - 2\cos^2 \varphi/2 = -\cos \varphi$.

This procedure is the same for:

- all detection lines of the detectors;
- all spinvektors;
- both detectors.

The same (symmetrical) situation is valid to the spinvektor of the other elektron of an entangled pair. If the spinvektor of one of the two elektrons of an entangled pair is in PA than the spinvektor of the other elektron is in SPA. As SPA = PB both detectors give the same result. If both spinvektors are outside of these spaces than both detectors give an opposit result. The angle φ between both detectors define the space PA. That causes the correlation between φ and the chance of equal spin result.

Correlation from quantum mechanics is $C = -\cos \varphi$ and this is also demonstrated by the experiments. This means that correlation depends only of the angle between the detectors which is shown by this model. This also means that Bell's correlation is not applicable to spin measuring of entangled elektrons because Bell's correlation is not a cosine. The cosine shape of correlation is caused by the projection of the spinvektors on the detector as a result of the movement of the elektrons through the detector.

The theorem of Bell requires that the adjustment of detector A has no influence on the results of detector B and vice versa. That may be so but it doesn't alter the fact that it is the combination of angle adjustments of the detectors that defines the combination of measurements results. This is also why the theorem of Bell is not applicable to the detection of elektronspin.

Conclusion

The positioning and adjustment of the detectors respective of the direction of the movement of the elektrons define the real spaces in which the opposit spinvektors are which give measurement results of equal spin. With the identification of these real vektorspaces and the model described here, correlation in Bell-test experiments can be explained.

Because of the assumption of well-defined spin and the fact that no information transfer is needed between elektrons of an entangled pair, this explanation is entirely according to local-realism.

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