

On the Relation between Bell's Inequalities and QM's Correlations in EPR-Bell Experiments

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Abstract

It is argued that Bell's inequalities do not give a complete representation of EPR-Bell experiments. A full account, corresponding to local-realism, is given for the quantum mechanic correlation in EPR-Bell experiments. The relation between Bell's inequalities and QM's correlation in EPR-Bell experiments is explained.

There is a problem in physics. The problem is that ideas are being accepted that are not being understood. In normal life this mostly is no problem but in physics it is. In physics it is important to understand what the used mathematics means. If the meaning of the mathematics of a theory is not well understood, ideas may loom up that do not correspond to the physical reality. Specifically, for quantum mechanics (QM), no one questions the correctness of the mathematics of that theory. The question is: what does it mean?

Concerning EPR-Bell experiments QM predicts results that also are being demonstrated by experiments. So nobody, rightly, doubts the correctness of the predictions. When Bell then asserts, for logical reasons, that these predictions and results are not possible in a local universe then there is a problem because Einstein asserted that the universe is local and the physics of a non-local universe is not understandable. Many physicists deal with this problem by accepting that the universe is non-local. They think that there is an instantaneous interaction between the distant particles of an entangled pair. They also think that Einstein was wrong.

But what if Bell's inequalities don't cover all aspects of the experiments? If he missed something? Then his calculations would not describe the experiments correctly and the conclusion that the results are not possible in a local universe doesn't hold. Einstein might have been right. This means that the QM results of the experiments still have to be explained.

Bell did miss an aspect of the experiments. There exists a local-real account for the QM results of the experiments that annul the necessity for a non-local universe. It seems to me that this account, described in this article, is important for a correct understanding of the mathematics in physics, for a correct understanding of the 'laws of physics', in order to make physics understandable again.

The aspect of experiments Bell missed is perspective. It is generally thought that perspective has nothing to do with Bell experiments. It is thought that these experiments are only about logical possible binary probabilities but that is a misconception. That is the reason why all examples given to explain Bell experiments fail. And it is also the reason why Bell's inequalities don't cover EPR-Bell experiments.

In Bell experiments a component of spin of particles from entangled pairs is being detected. In this article spin of a particle is considered in a classical physical way: a spinning movement. Spin is represented by an axial vector. Particles have this property from the moment they have been produced. When they are being measured they show the spin direction they already had. They don't choose at that moment a random spin direction. Spin of particles of an entangled pair is opposite. It

is in a random direction but the spin direction of one particle of an entangled pair is opposite in respect of the spin direction of the other particle of that pair. The spin directions don't change as long as the particles don't interact.

In case spin of particles is concerned, perspective is very important. Perspective is the direction in which the universe is being perceived. Observation, detection and projection (in this account) are all comparable processes. They are linear processes in one direction. In order to make different perspectives in agreement with each other a reference direction is needed. It will be explained that the universe perceived in one direction is very different from the universe perceived in two directions. First a Bell experiment is described in order to explain the importance of perspective.

A simple model of Bell experiments is described. It is Bell's own model, described by him in [1]. In Bell experiments pairs of entangled particles are being produced in order to detect a spin component of the particles in a certain direction. The particles of an entangled pair move in opposite directions and they have opposite spin directions. In this account there is no interaction between entangled particles after the moment of their production. One particle of a pair is supposed to move to the left and the other to the right along a line of motion. In one run of an experiment N pairs are being produced. For reasons of simplicity all pairs are being produced at the same time in this model. The spin of one particle of a pair is represented by a vector in a random direction. The spin of the other particle of that pair then is a vector in the opposite direction. At the moment of production the vectors of all the pairs point in random directions, making a sphere in which they are equally distributed, pair by pair.

The detection of the spin component of the particles is performed by Stern Gerlach (SG) devices. In order to be able to detect the particles the detectors are being placed perpendicular on the line of motion of the particles, one on the left hand side (detector A) and one on the right hand side (detector B). From each pair one particle is detected by A and the other by B. SG devices are composed of two different shaped magnets and a detector plate. Between the magnets an inhomogeneous magnetic field is being produced. The particles move through this field and experience a force. The force deviates the particles upwards or downwards in the field direction, depending on the spin component of the particle in that field direction. The field direction of a device can be adjusted at a certain angle by rotating the device around the line of motion. In this account A is adjusted along the vertical (at 0°) and B is adjusted at $+30^\circ$ so the angle between the field directions of A and B is 30° . This angle is called φ . In this account φ is chosen to be 30° but the account goes for all angles φ of course.

From all the particles detected by A, 50% will be deviated upwards and 50% downwards because the spin directions of the particles are random and equally distributed in space so one half of the particles detected by A will have a spin component in the field direction and one half of them in the opposite direction. This also goes for B, whether its field direction (= angle of adjustment) is 0° , 30° or any other angle. This is what the detectors 'see' and this is what they in fact represent.

The spin vectors of the pairs of particles produced in the source S, all at the same time, make a sphere with its centre in S. This sphere is called a vector space: all vectors start in S and end at the surface of the sphere. As the SG devices deviate the particles either upwards or downwards in respect of their field directions, we can imagine the devices as having a centre perpendicular plane: a particle will hit the detector either above or beneath that plane. The planes of both devices intersect the sphere dividing it in four sphere segments, two by two opposite of each other. The two opposite

segments between the centre perpendicular planes are named: vector spaces E and the remaining two opposite segments are named: vector spaces O. (See fig. 1)).

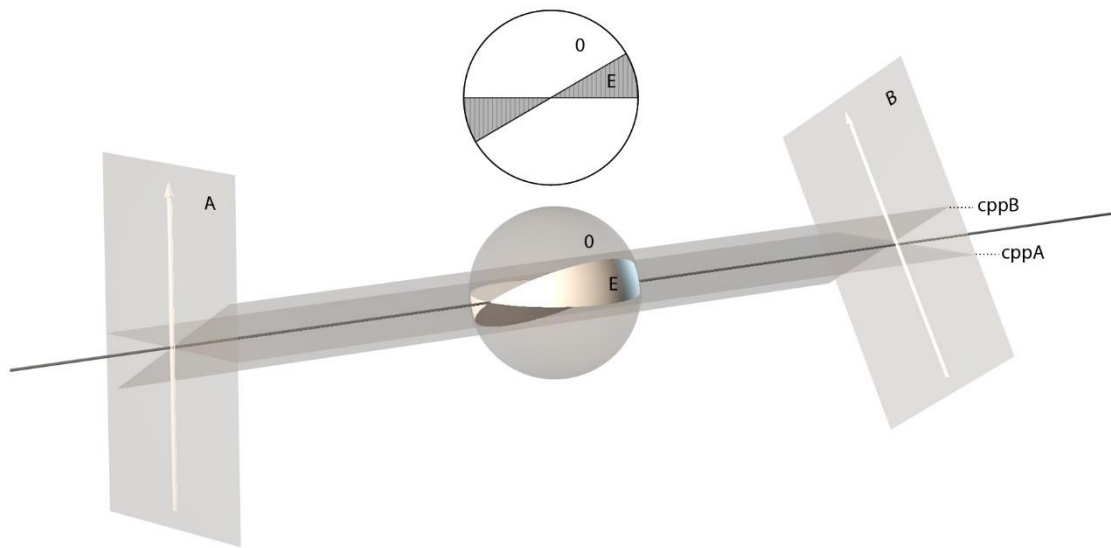


Fig.1) The spherical vector space of the spin directions of the particles divided by the centre perpendicular planes of A and B producing the spaces E and O from the perspective of A.

The opposite spin directions of an entangled pair (opposite vectors) are either both in E or they are both in O, otherwise the vectors are not opposite. Pairs, having their spin directions in E, will yield combinations of equal spin results, both + or both – (see fig. 2), left hand side). In the same way pairs, having their spin vectors in O, will yield combinations of opposite spin result (see fig. 2), right hand side). This however is only valid if perceived from one perspective.

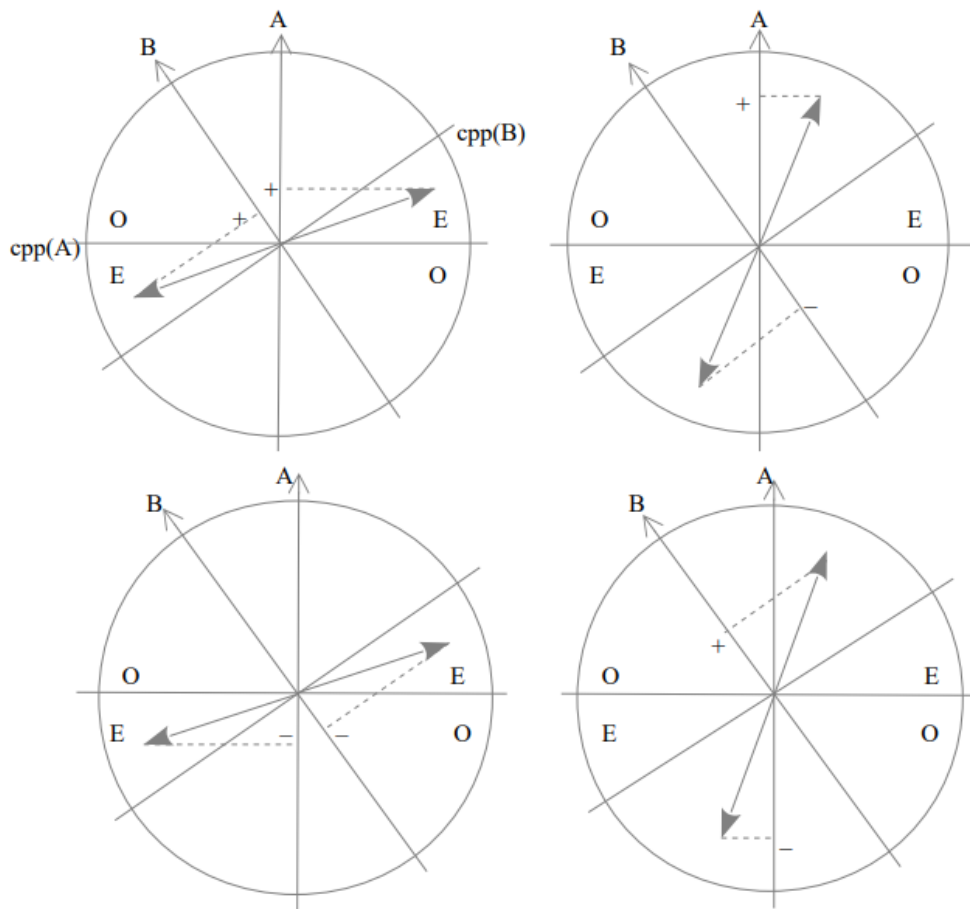


Fig. 2) A and B are the field directions of the SG devices A and B. In this case B is adjusted at -30° . If entangled particles both have their spin directions in vector space E, between the centre perpendicular planes of A and B, (left hand side of the figure), and one particle is detected by A and the other by B, then both detectors would show the same spin result if they would detect from one perspective. In the same way the detectors would show opposite spin result if the particles have their spin directions in vector space O (right hand side of the figure).

It has already been mentioned that an object perceived from different perspectives cannot be described in the same way as that same object perceived from one perspective. For example: if an observer is standing in front of a person he sees the right arm of that person at his left hand side and when he is standing behind the person he sees the right arm of the person at his right hand side. There is nothing strange about this. But describing a person from two perspectives, from the front and from the back, yields the contradictive result that the right arm of that person is on the left hand side as well as on the right hand side. Everybody will agree on the fact that this is not possible, so it is not allowed to describe an object from two perspectives. Yet it is exactly what the detectors do with respect to entangled pairs of particles according to Bell's description of the experiments. But when the lists of results are being compared with each other afterwards, they (indirectly) represent results as correctly described from one, correct perspective, as we will see. These results are the results as predicted by QM. Note that these results have not been measured by the detectors. They emerge in the comparison of the lists of results from the detectors afterwards.

A pair of entangled particles can be considered as one object composed of two particles moving and spinning in opposite directions. Imagine detectors A and B detect a pair of entangled particles from which the axis of spinning coincides with the line of motion of the particles. Then A and B get exactly the same picture of that entangled pair: a particle approaching them, spinning in a certain direction (left or right way around) and another particle flying away from them, spinning in the opposite direction. This is a picture from two opposite perspectives. A sees B's particle for example spinning right way around whereas B sees it spinning left way around and B sees A's particle spinning right way around whereas A sees it spinning left way around. So they either seem to disagree about the particles or about the spin directions. (The same goes for the movement directions of the particles).

From one perspective one perceives particle 2 behave opposite in respect of particle 1 and from two perspectives one perceives particle 2 behave exactly the same as particle 1. There is still nothing strange about this but it is confusing: what is the real behaviour of the particles? As the particles of an entangled pair behave oppositely they must be described from one perspective. But detectors detect from opposite perspectives so they must give an inadequate representation of pairs of entangled particles.

This problem becomes even more clear when it concerns vector spaces. Suppose the detectors detect from one perspective so detector B also is at the position of detector A for example. In this position B cannot detect anything because its particles never arrive there but that is not the point here. The point is that detector A is adjusted at 0° and detector B is adjusted at $+30^\circ$ so their centre perpendicular planes divide the vector space according to fig. 3).

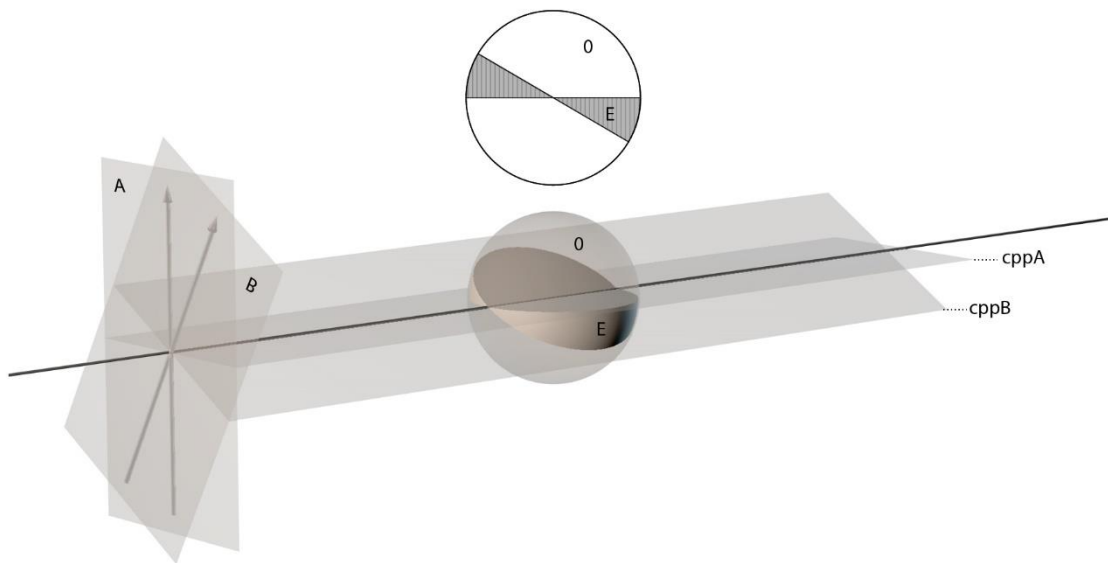


Fig.3) The spherical vector space divided in spaces E and O when both detectors detect from the position (perspective) of A

When detector B is then being moved to its own position, opposite of A, still adjusted at $+30^\circ$ according to B, then the centre perpendicular planes of A and B divide the vector space according to fig. 1). So the spaces E are now a different part of the vector space. There is no overlap between the first spaces E and the second spaces E because in respect of detector A, detector B is now adjusted at

-30° and that is exactly opposite (in respect of $+30^\circ$) and so the old and the new spaces E are each other's mirror image in the centre perpendicular plane of A. This means that the detectors A and B don't agree anymore about vector spaces E when they are being positioned opposite of each other and detect from opposite perspectives. One may argue that there is only one real set of vector spaces E between the centre perpendicular planes of A and B. Yes there is, but then A and B don't agree on their angle of adjustment: according to A, B is adjusted at -30° and according to B, he is adjusted at $+30^\circ$. So detecting from opposite perspectives, A and B disagree either on the vector spaces E or on their angle of adjustment. As opposite vectors both have to be in E in order to yield a combination of equal spin results, this is a serious problem: which spaces E does the pair of vectors have to be in, the old ones or the new ones? As the pair of vectors only yields a combination of equal spin results when being detected from one perspective, they must be in the old spaces E (when A and B were at the same place). But A and B detect from opposite positions so the pairs of vectors in the new spaces E will not necessarily yield combinations of equal spin result.

So it makes a difference if something is being perceived from one perspective or from two perspectives. Detectors in EPR-Bell experiments detect something from two perspectives so it is not to be expected that the results of these experiments correspond to results that would be obtained if the measured things would be measured from one perspective. The application of the idea of perspective can point out this difference precisely.

At this point an extra Observer is being introduced. He has nothing to do with Alice or Bob. Alice is detector A and Bob is detector B. The Observer however is someone standing in front of the vector space, looking at the vectors (the spin directions of the particles). He is looking from one, different, perspective to the (real) spaces E. Whereas the detectors have been placed perpendicularly on the line of motion and detect in the direction of the line of motion, the Observer observes in a direction perpendicular to the line of motion. (See fig. 4)).

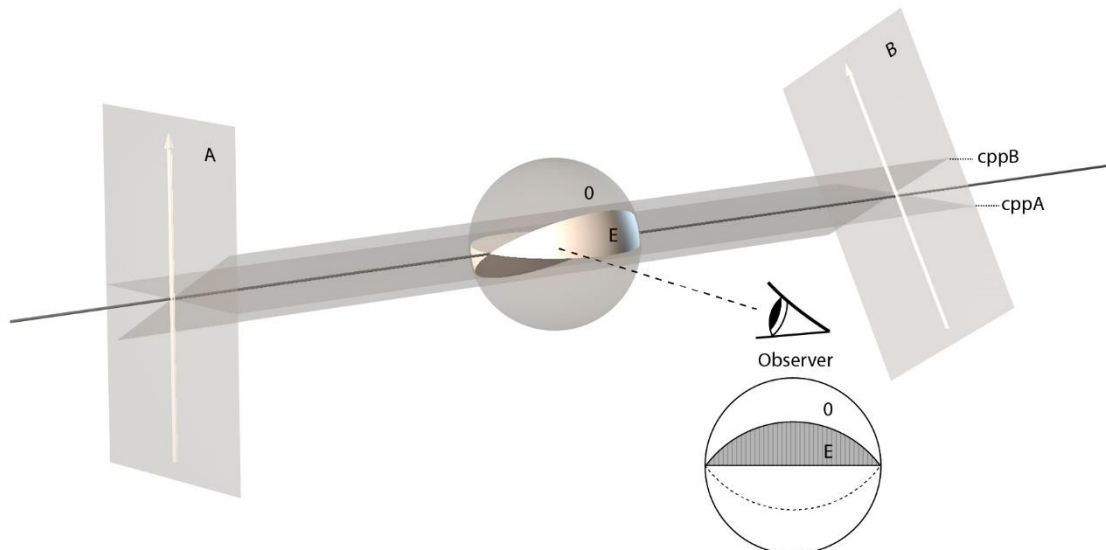


Fig.4) An Observer looking at the vector spaces from a position along the line of motion of the particles (black line in the figure). The perspective of the Observer is perpendicular in respect of the line of motion whereas the perspectives of the detectors are in the direction of the line of motion.

The number of vectors in one of the spaces E is of course equal to the number of pairs in both spaces E. Assuming that the vector pairs are equally distributed in the spherical vector space, the number in E can be calculated because it is proportional to the volume of E as part of the total volume of the vector space. So the number of vectors in E is $\frac{\varphi}{\pi} N$ (φ is 30° in this account and N is the total number of entangled pairs in one run of the experiment).

Imagine A and B detect from one perspective, B also standing at A's place but adjusted at 30° . (See fig. 3)). Imagine B's particles could fly backwards but keeping their spin axes in the same directions, so B is yet able to detect them. Then the number of combinations of equal spin result that A and B would find is indeed equal to the number of vectors in E. That number is $\frac{\varphi}{\pi} N$. $\frac{\varphi}{\pi}$ is Bell's calculated probability. It is proportional to φ as can be seen in the diagram at page 9. Of course in reality A and B don't detect from one perspective so it should be no surprise that this number is not found in real experiments.

From now on only the real vector spaces E (A and B detect from opposite perspectives, figs. 1) and 4)) will be described. The number of vectors in the real space E also is $\frac{\varphi}{\pi} N$. In this account observation, detection and projection are considered to be identical linear processes. Detection by the detectors is projecting the vectors on the detector plates in the detection direction. The detection direction is determined by the position of the detecting device in respect of the detected particle. The adjustment of the device is apart from this detection direction. The detection direction has the same direction as the line of motion. So the detector planes are situated perpendicular on the line of motion. The line of motion also is chosen as the reference direction. Observation by the Observer is projecting the vectors on a plane behind the vector space situated perpendicular to the observation direction (and parallel to the line of motion) and the observation direction is perpendicular to the line of motion (fig. 4)). So in this account the vectors in vector space E are being projected in two mutually perpendicular directions.

The number of vectors in E does of course not depend on the direction from which they are being observed or detected. The result of their projection however does depend on the direction the vectors are being projected in. The result of a projection is a projection density. It is a number (vectors in E) or a quantity (volume of space E) distributed on the area of the projection: the projection area (pa).

The fact that projection depends on direction can be demonstrated with a circle. The projection of a circle in a plane onto a parallel plane in the direction perpendicular to the planes has a an identical circle on the parallel plane as result. (See fig. 5)).

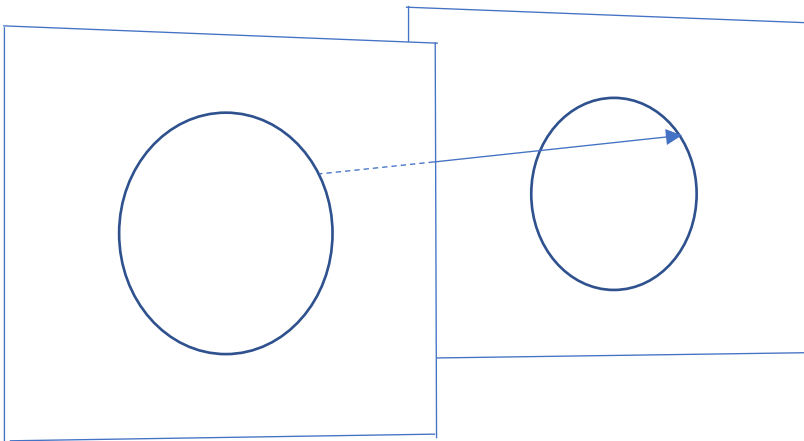


Fig. 5) Perpendicular projection of a circle onto a parallel plane.

Definition: The projection density distribution is the probability for a random point of the original circle to arrive at a certain part of the projection of the circle, per unit of length.

This probability is proportional to the size of that part.

However, a projection within the plane of the same circle on a line beside the circle in the same plane, in a direction perpendicular to the line, gives a line part as result. The projections of the, equally distributed, original points onto that line part are not equally distributed on that line part (see fig. 6)).

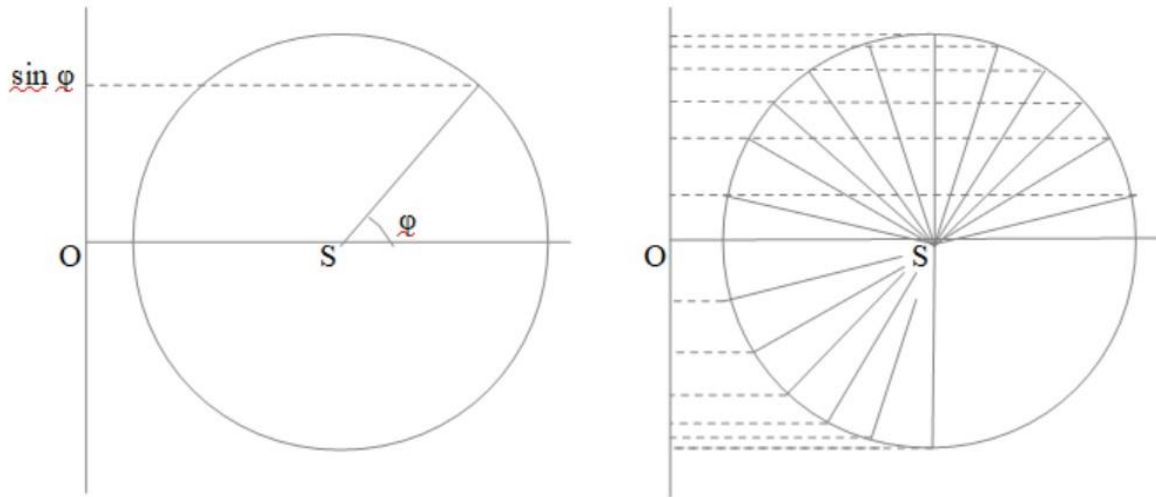


Fig. 6) Projection, within a plane, of equally distributed points of a circle onto a line. The projection density distribution is: $\sin^2(\frac{\varphi}{2})$.

Definition: The projection density distribution is the probability for a random point of the circle to arrive at a certain part of the line part, per unit of length.

It can mathematically be derived that this probability is $\sin^2(\frac{\varphi}{2})$.

These probabilities don't only go for the two dimensional situation but they are also valid in a three dimensional situation: projection of (parts of) a sphere on a plane behind it. Then 'per unit of length' becomes: 'per unit of area'. This is the situation in this model of a Bell experiment perceived from the perspective of the Observer and from the perspectives of the detectors.

The projection density distributions of the spin directions (vectors) in E, projected in two mutually perpendicular directions, have been defined as probabilities. These probabilities exactly correspond to the probabilities that occur in Bell experiments: Bell's probability and QM's probability (see the diagram at page 9). The diagram shows probabilities (upper half) and correlations (whole diagram).

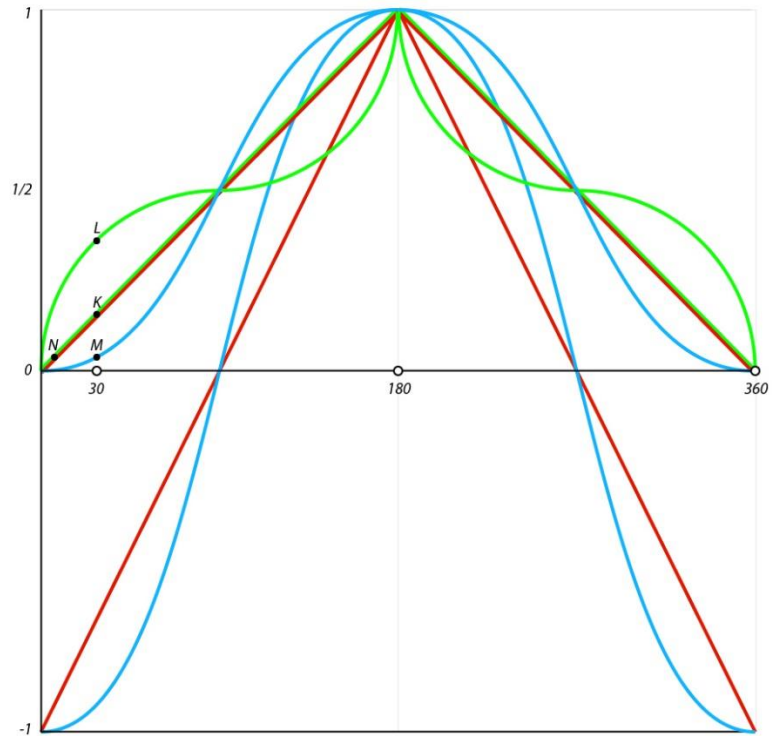


Diagram This diagram represents probabilities (upper half) and correlations (whole diagram) as a function of φ (the angle between the relative adjustments of the devices A and B). Bell's probabilities and correlations are the red lines. QM's probabilities and correlations are the blue lines. The dark looking line in the upper half is composed of a red and a green line. The straight green line represents the projection area as a function of φ from the perspective of A and the curved green line represents the projection area as a function of φ from the perspective of the Observer. At $\varphi = 30^\circ$ we find the point K on the red line. This point represents the number of vectors in E. This number projected onto the projection area of E from the Observer's perspective gives a projection density corresponding to the projection density distribution M. This projection density corresponds to the projection density N of the projection area of the detectors' perspectives at another angle φ . This is the projection density distribution that the lists of results of the detectors represent when they are being compared to one another. (See also figures 7) and 8)). These points (K, L, M and N) show the relation between Bell's probabilities and QM's probabilities and correlation.

Correlation is defined as the number of combinations of equal spin result minus the number of combinations of opposite spin result as parts of the total number of combinations. This is the same as: the probability for a combination of equal spin result minus the probability for a combination of opposite spin result. This can easily be seen in the diagram: for a particular angle the distance between 0 and the probability curve is the probability for equal spin result and the distance between the curve and 1 is the probability for a combination of opposite spin result. When the second is being subtracted from the first, the correlation is obtained. And together they are 1, of course.

Remember that, observed from one perspective, the pairs that have their spin directions in the spaces E, give combinations of equal spin result. Their number can be found by applying Bell's

probability and is: $\frac{\varphi}{\pi} N$. This number of vectors in E projected in the detection direction gives a projection density of $\frac{\varphi}{\pi} N$ distributed on a projection area of $\frac{\varphi}{\pi} \text{tpa}$ (tpa is the projection area of the total vector space). This is a projection density of $\frac{N}{\text{tpa}}$. The number of vectors in E is not represented by the results of the detectors because the detectors detect from two opposite perspectives and they cannot detect entangled pairs as having opposite spin directions, as explained at page 4.

The number of vectors in E projected in the observation direction gives a projection density of $\frac{\varphi}{\pi} N$ distributed on a different projection area, the Observer's projection area. For $\varphi = 30^\circ$ this projection area is much bigger than the projection area in the detection direction. The Observer's projection area is represented as a green, curved, line in the diagram. By definition the projection density in the Observer's direction is proportional to the projection density distribution which is $\sin^2(\frac{\varphi}{2})$ in this direction. This density calculated for a projection area of E in the detection direction ($\frac{\varphi}{\pi} \text{tpa}$) should yield and indeed yields a number of combinations of equal spin result exactly represented by the detectors and (of course) corresponding to QM's probability in the observation direction.

To calculate this the variables need to be named:

N = total number of pairs detected in one run of an experiment

C = correlation

P = probability

D = density of a projection

DD = density distribution of a projection (= probability)

pa = projection area

Subscript QM means: from the perspective of the Observer

Subscript Bell means: from the perspective of detector A

The number of pairs that have their spin directions in the spaces E, is the number of vectors in E, is:

$$N_{\text{Bell}} = P_{\text{Bell}} N = \frac{\varphi}{\pi} N \quad (1)$$

$$D_{\text{Bell}} = \frac{(\frac{\varphi}{\pi})N}{\text{pa}_{\text{Bell}}} \quad (2)$$

$$D_{\text{QM}} = \frac{(\frac{\varphi}{\pi})N}{\text{pa}_{\text{QM}}} \quad (3)$$

$$(2) \text{ divided by } (3) \text{ gives: } \frac{D_{\text{Bell}}}{D_{\text{QM}}} = \frac{\text{pa}_{\text{QM}}}{\text{pa}_{\text{Bell}}} \quad (4)$$

By definitions $D_{\text{Bell}} \approx DD_{\text{Bell}}$ and $D_{\text{QM}} \approx DD_{\text{QM}}$

As the same number of vectors ($\frac{\varphi}{\pi} N$) is being projected onto different projection areas

$$\frac{D_{\text{Bell}}}{D_{\text{QM}}} = \frac{DD_{\text{Bell}}}{DD_{\text{QM}}} \quad (5)$$

N_{QM} is the number obtained from the density in the observation direction (D_{QM}) calculated for the projection area in the detection direction (pa_{Bell}).

N_{QM} as part of N_{Bell} is equal to pa_{Bell} as part of pa_{QM} so

$$\frac{N_{QM}}{N_{Bell}} = \frac{pa_{Bell}}{pa_{QM}}$$

Together with (4) and (5) and the fact that $DD_{Bell} = P_{Bell}$ and $DD_{QM} = P_{QM}$ this gives:

$$\frac{N_{QM}}{N_{Bell}} = \frac{pa_{Bell}}{pa_{QM}} = \frac{D_{QM}}{D_{Bell}} = \frac{DD_{QM}}{DD_{Bell}} = \frac{P_{QM}}{P_{Bell}} \text{ SO}$$

$$N_{QM} = \frac{P_{QM}}{P_{Bell}} N_{Bell} = \frac{P_{QM}}{P_{Bell}} P_{Bell} N = P_{QM} N$$

This number N_{QM} is the part of N_{Bell} (= the number of vectors in E ($=\frac{\varphi}{\pi} N$)) that is proportional to pa_{Bell} (= the projection area of space E in the detection direction) as part of pa_{QM} (= the projection area of space E in the observation direction). As D_{Bell} (= the density of the vectors in space E projected on the projection area of space E in the detection direction) is: $D_{Bell} = \frac{(\frac{\varphi}{\pi})N}{(\frac{\varphi}{\pi})tpa} = \frac{N}{tpa}$, N_{QM} also is the part of the N pairs in the run of one experiment that give a combination of equal spin result. As is explained these pairs are random pairs and this calculation shows that their number is determined by P_{QM} (= QM's probability). So N_{QM} is the number of combinations of equal spin result that the detectors detect (indirectly) for random pairs as a consequence of the QM probability.

One question has remained: why is the observation direction, and not the detection direction, the correct direction to find the correct (QM) probability? Remember that the line of motion has been chosen as reference direction (page 5). Remember that the detectors have been placed perpendicular on the line of motion (page 2). This means that they have to rotate 90° from a position along the line of motion to arrive perpendicular on the line of motion. This position along the line of motion is for example the position of the Observer. As the line of motion is also the reference direction, the position of the Observer in respect of the line of motion is the correct position to find the correct QM probability. (The detectors have been rotated from that position, the Observer never has been rotated).

Any other direction than the line of motion could have been chosen as reference direction but then the rotations of all other participants must have been taken into account. In case of the line of motion is chosen as reference direction, the movement direction of the particles and their spin directions are already correctly described, as well as the position of the Observer. The line of motion as reference direction was the easiest choice.

Another answer to the question which perspective is the correct one to determine QM's probability, is that the particles establish a reference frame for themselves: the line of motion is one direction in space and the direction of the inhomogeneous field they experience is another (perpendicular) direction in space. Together these directions determine a plane. When the detector planes are placed in this reference plane (or parallel to it) then they would detect QM's probability directly. Of course they cannot detect any particles from this position so they cannot represent QM's probability directly. From this position the detectors have to be rotated 90° (in opposite directions in respect of each other) to arrive perpendicular on the line of motion, where they can detect the particles. But from these opposite positions they cannot 'see' the pairs of particles as being entangled (having opposite spin) so they cannot represent Bell's probability and they can represent QM's probability only indirectly.

It will be clear that the role of the Observer is not important at all. He has only been introduced to indicate the correct perspective.

Sometimes it is argued that Bell's theorem is valid even without experiments, experiments that confirm QM. Bell's theorem state that in a local universe Bell's probabilities must apply. Because the experiments show the results of QM it is generally thought that the universe is non-local. This is a

mistake because the experiments have not been properly analysed. This is because perspective has not been taken into account. In reality both QM's and Bell's probabilities occur in the experiments. The relation between the points K, L, M and N in the diagram shows how Bell's probability is related to QM's probability: Bell's probability is needed to calculate the number of pairs that have their spin directions in E, the number that leads to QM's probability when perceived from the correct perspective.

The detectors detect pairs of entangled particles from opposite perspectives. It has been demonstrated that in this way the detectors cannot represent the pairs as being entangled (having opposite spin). So the detectors cannot represent Bell's probabilities. Perceived from one perspective, the correct perspective in respect of the reference frame of the particles, QM's probabilities emerge. These are the probabilities represented by the detectors indirectly.

Summarizing

It has been argued that the pairs of particles that have their spin directions in the spaces E, between the centre perpendicular planes, can yield combinations of equal spin result if they are detected from one perspective. Their number would correspond to Bell's probability $\frac{\varphi}{\pi}$ because $\frac{\varphi}{\pi} N$ is the number of vectors in space E. As the detectors detect from two opposite perspectives they cannot represent this number and probability because from opposite perspectives the detectors cannot detect the particles of an entangled pair as having opposite spin directions, which they must have. The detectors do however represent a different number of combinations of equal spin result. This different number is caused by a probability that is different from Bell's probability but still only depending on φ . This different probability is correctly predicted by QM and is $\sin^2(\frac{\varphi}{2})$. (The probabilities can be found in the diagram, page 9).

How is it possible that the detectors represent this different number of combinations of equal spin result caused by QM's probability? If it are still the pairs, that have their spin directions in E, that yield combinations of equal spin result (when observed from one perspective), how can the detectors then represent this QM probability? The number of vectors in E still is $\frac{\varphi}{\pi} N$. When these are being observed by the Observer in a direction perpendicular to the line of motion and the vectors are being projected in that observation direction, then they arrive at a projection area that is much bigger (for $\varphi = 30^\circ$) than the projection area at which they would arrive when they were projected in the detection (line of motion) direction. (See fig. 7)).

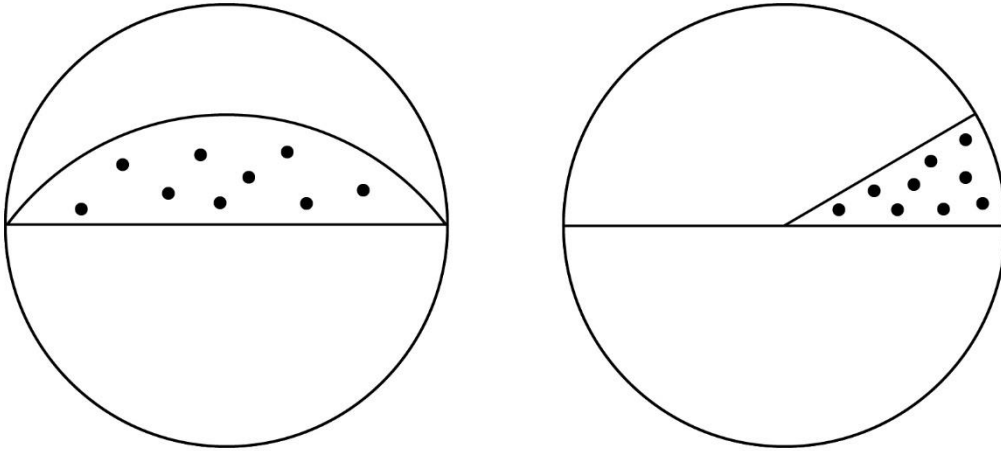


Fig.7) Left: projection density of the vectors in E from the Observer's perspective.
Right: projection density of the vectors in E from the perspective of A.

So the density of the projection in the observation direction is much less. When this density is calculated for the projection area of space E in the detection direction, then QM numbers emerge. (See fig. 8)).

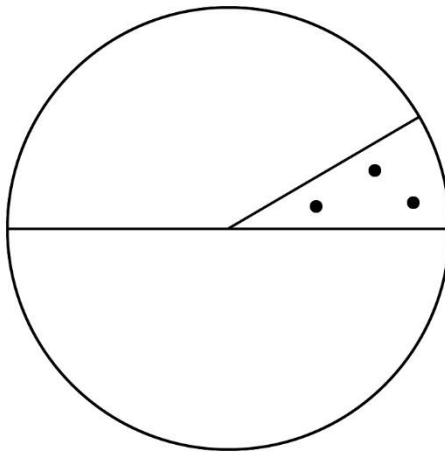


Fig.8) Projection density from the Observer's perspective calculated for the projection area of A.

Those numbers are represented, indirectly, by the detectors.

As has been argued the density of the projection in the observation direction corresponds to a projection density distribution of $\sin^2(\frac{\varphi}{2})$. This projection density distribution is a probability and this

probability corresponds exactly to QM's probability. It is this probability that causes the number of combinations of equal spin result. So it are the pairs that have their spin directions in E, observed from the Observer's direction (from one perspective), that yield QM's probability. These pairs cannot be detected, of course, because there are no detectors at the position of the Observer. But that probability, eventually, yields QM's numbers of combinations of equal and opposite spin result for random pairs, not necessarily pairs that have their spin directions in E, when the particles are being detected in the direction of the line of motion.

For every particle that a detector detects, he represents whether its spin direction is + or -. From the detected particles 50 % will have a positive spin direction and 50 % will have a negative spin direction in respect of the field direction of a detector. That is all that is being represented by detectors. Yet when their lists of results are being compared afterwards the QM probability emerges in the numbers of combinations of equal and opposite spin result.

As the detectors detect from two opposite perspectives, they cannot represent entangled pairs (particles with opposite spin directions). Detectors represent, indirectly, random combinations of equal or opposite spin result and the numbers of the combinations are determined by QM's probability.

When a die is thrown 600 times, one will immediately know that about 100 times a 'five' is thrown but not which throw will yield a 'five'. The same happens in Bell experiments. So the relation between Bell's probabilities and QM's probabilities in EPR-Bell experiments is determined by the pairs, that have their spin directions in the vector spaces (E) between the centre perpendicular planes of the detectors, and the directions from which they are being observed / detected / projected.

Conclusion

An EPR-Bell experiment is in fact a probability measurement. No pairs of particles with equal spin are measured because those pairs don't even exist in these experiments. Because opposite detectors cannot 'perceive' spin of particles as being opposite, they detect random combinations of spin results. The numbers of these combinations are defined by a probability. The measured probability is a projection density distribution of spin directions of entangled particles at certain relative adjustments of the detectors. The correct direction of projection follows from a reference frame determined by the particles. As QM describes the particles this direction of projection is needed to see QM's probability.

The probabilities in EPR-Bell experiments are fully understandable in terms of local-realism when the detection of the opposite spin directions of entangled particles is described from one perspective. It depends from that perspective which probability is found: in the direction of the line of motion Bell's probability is found and in a direction perpendicular to the line of motion QM's probability is found. The detectors however cannot represent Bell's probability because they detect from two opposite directions but they do, indirectly, represent the correct QM probability. Because the detectors detect from opposite perspectives they cannot detect the particles of an entangled pair as having opposite spin directions. So they represent from random pairs of particles numbers of combinations of equal and opposite spin result. For each particle a detector represents a 50 % probability to be 'up' or 'down'. The lists of the results from the detectors, being compared with each other afterwards, represent numbers of combinations of equal and opposite spin results. The numbers of the combinations represent a probability, depending on φ , predicted by QM. This probability can be 'observed' and explained by projecting the spin directions of the particles (vectors) in a direction perpendicular to the line of motion from one perspective. To find the QM probability the projection of the vectors must be done from this perspective because each of the detectors has been rotated 90°, in opposite directions, from this perspective to reach their individual position perpendicular on the line of motion. The detectors represent, indirectly and from opposite

perspectives, a probability that only can be understood from one perspective: the perspective of the Observer.

By recognizing the probabilities in Bell experiments as being projection density distributions from one object (vectors in a vector space) in two mutually perpendicular directions, the application of perspective makes the QM probability comprehensible in a way that corresponds to local-realism and it makes clear the relation between QM's probabilities and Bell's probabilities in EPR-Bell experiments. There is no interaction at a distance between particles or their detections involved except for the adjustments of the devices.

References:

- [1] J.S. Bell, Bertlmann's socks and the nature of reality. Archives ouverte HAL, 1981;
- [2] <https://www.youtube.com/watch?v=g1quDMTEIFE&t=1080s> (video).