On the EPR Paradox and Quantum Mechanics
(A layman's explanation of Quantum Mechanics)

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Abstract

Could it be possible that quanta, described by a superposition of waves, yet have definite properties, like water surfaces disturbed by many sources and described by many wave equations, yet have definite shapes at any moment? Could it be that quanta have statistical definite properties, wave- and particle properties at the same time? These questions need an answer to reach some consensus in physics and to solve some of the most urgent problems in physics. These questions will be answered in this paper.

Also the probabilities in Bell experiments, predicted by quantum mechanics, are made visible and their explanation is accounted for mathematically.

Contents

Terminology

In this paper appear terms like: 'vector', 'vector space' and 'projection area'. These words may or may not correspond to the mathematical meaning of the terms.

A 'vector' in this paper is meant to be an axial vector: an arrow with a certain length and a fixed direction in space. A 'vector space' in this paper is a sphere divided in four parts by two planes going through the centre of the sphere. The sphere and the four parts are the vector spaces. Each vector starts in the centre of the sphere and ends at the surface of the sphere, so a vector can be considered as a radius of the sphere. A 'projection area' is the area of the projection of one of the vector spaces in an indicated direction.

Quantum Mechanics

Quantum Mechanics (QM) is a theory in physics on quanta. A quantum is a small quantity of energy. Quanta are the smallest building blocks of the universe. They appear in the shape of particles or radiation. Quanta have particle properties and wave properties.

During the past centuries light alternately has been considered as a wave or as a beam of particles. Since James Clerk Maxwell we know that light is electro-magnetic radiation. Because of the photo-electric effect Albert Einstein recognized that light also must have particle properties. For particles it was the other way round. Particles were considered to be particles of course but double slit experiments showed that particles yet produced an interference pattern. This was unexpected and inexplicable. Then it was Louis de Broglie who came up with the idea that particles also have wave properties.

In this situation quantum mechanics was developed. In 1925 Werner Heisenberg developed a theory using matrices. In 1926 Erwin Schrödinger developed a theory based on a general wave equation. The theories turned out to be identical, so there was no problem.

Schrödinger derived the Schrödinger equation from a general wave equation. In wave equations there is an amplitude and also in the Schrödinger equation there is an amplitude. The amplitude in waves is the distance between the top of the wave and the trough of the wave. In the Schrödinger equation the amplitude is called a wave function and can consist of a superposition of waves. The square of the amplitude represents a probability. This probability can be the outcome for any property of a quantum being studied. This means that QM can at most give a probability for a property of a quantum and not an exact value.

This is where the problems start to arise. Niels Bohr and Einstein quarrelled about the completeness of QM. There is no need to worry about the completeness of a theory. There is no theory in physics that can describe the state of an atom of the air in your room. All theories use statistical quantities, like pressure and temperature, to describe the atoms in the room. So not a single theory is complete.

Then there is the idea that theories on physics should be deterministic. Theories are expected to describe nature and with that description they are expected to be able to predict future developments. It may be required that a theory on physics is deterministic but the universe isn't. If the universe were purely deterministic then creation wouldn't be possible in nature and everywhere I look I see creation. According to John Steward Bell Einstein wasn't very concerned about determinism (J.S. Bell: Bertlmann's socks and the nature of reality [1]).

Some properties of quanta, for example position and momentum, are related to each other. They are related in a way that the better the position of a quantum is known, the less its momentum is known and vice versa. This relation is called the uncertainty relation of Heisenberg because he discovered in 1927 the exact mathematical relation: the product of the spreading of position and the spreading of momentum is a constant. This means that we cannot measure, or even know, at the same time both the position and the momentum of a quantum.

This uncertainty relation is often explained using a wave. A wave is defined by its wavelength and its frequency. Because waves have a constant velocity the wavelength and the frequency are inversely proportional. Waves with long wavelengths have low frequencies and waves with short wavelengths have high frequencies The wavelength is related to the position of the wave and the frequency is related to its energy and momentum. The longer the wavelength is, the more its position is spread out in space and the better its frequency can be defined. The shorter the wavelength is the better its position is defined and the less its frequency is defined.

Considering that the general wave equation is derived from a constant circular movement, a movement with a constant angular velocity and a constant rotational velocity, it is not surprising that the uncertainty relation is a constant. The wave equation is constructed that way.

In his book: 'Einstein's Unfinished Revolution' [2] Lee Smolin says: “we can only know half of what we would need to know to precisely predict the future”. This is concerning the uncertainty relation of Heisenberg. In that respect QM is doing very well: half is 100% more than nothing at all. In the previous explanation of the uncertainty relation one wave was used. We can also give an explanation using a superposition of one or many waves. For one wave the position is spread out but the momentum is well defined. Superpositions of many waves show peaks and the highest peak can be considered as the definite position of a quantum but the momentum is then indefinite. It is like waves on the surface of water. Disturbed by one source the surface shows a wave spreading out on the surface with a definite hight and velocity. Disturbed by many sources the surface shows a chaotic, unpredictable shape with peaks and valleys. The highest peak can be considered as the position but there is nothing to say about the hight of this peak or where the next highest peak is. According to Smolin [2] we can visualize a quantum with a definite position but without a definite momentum as a particle that is jumping around. One moment it is somewhere at a definite position and the next moment it is somewhere else, like the peaks on the water surface. This is because its momentum (velocity) is unknown because of the uncertainty relation. A particle with a definite momentum but a completely indefinite position can then be visualized as a pure wave. It is spread out but it has a definite momentum (velocity). From this picture (Bohr's picture) we can see that particles don't follow a trajectory.

Because of the uncertainty relation we can only measure either the position of a quantum or its momentum but never both at the same time. This means that we can see the quantum as a particle or as a wave but not at the same time. Considerations like these made Bohr to assert that quanta behave like particles or like waves but not together. This was his idea of complementarity. He also asserted that quanta don't even exist until they are being measured, probably because there is nothing to say about quanta: they don't follow trajectories, QM gives only probabilities for their properties and because of the uncertainty relation their position and momentum cannot both be measured or even be known exactly at the same time.

The fact that there is not much to say about quanta before measurement is not enough reason to assert that quanta have no definite properties or to assert that they don't even exist. The view represented by these assertions Einstein couldn´t accept. He said: “it is like the moon doesn't exist when I don't look at it”. I think he believed that quanta have definite properties, particle properties as well as wave properties together at the same time. This was what the debate was about. It is again like the water surface but now the surface itself represents the position of the quantum: at any time it is somewhere and it moves continuously (quanta follow trajectories). The shape of the surface represents its momentum: disturbed by one source the quantum is like a pure wave and has a definite momentum and disturbed by many sources (a chaotic surface) the quantum is like a particle with a undefinable momentum (the wave function of a quantum is a superposition of many waves) but surely definite momentum (the water surface has a definite shape at any moment). So in this picture (Einstein's picture) quanta follow trajectories and they have definite properties.

The view of Bohr, and he was not the only one with this view, brought many problems in theoretical physics with it. Problems like:

- The measurement problem; how does a quantum know what property it has to show while being measured when it has no properties before measurement?
- The collapse of the wave function; the quantum 'chooses', while being measured, a definite value for the property that is being measured and by doing so it changes the probability, described by the wave function, in a certainty, a fixed value, and by doing so the wave function 'collapses'. And it collapses everywhere at the same time because if a quantum is somewhere with certainty, the probability that it is somewhere else lapses.
- The problem of Schrödinger's cat (and Wigner's friend).

This was the situation in 1935 when Einstein, together with Boris Podolsky and Nathan Rosen, published an article in order to show that QM did not correspond with Bohr´s view. The article was about a logical irrefutable argument. An irrefutable argument unless one accepts a very extreme assumption. The assumption is about non-locality. Locality is the principle that when two objects interact with each other they have to be in contact with each other and if not it takes time to transmit the action. Forces cannot be transmitted faster than the speed of light according to the Relativity Theory. So if there is instantaneous interaction between entangled particles at a great distance of each other, the principle of locality is violated and that is called non-locality. To my opinion nonlocality destroys everything physics is build on and no one knows the laws of non-local physics. It even puts causality at risk.

The EPR paradox

The EPR article from 1935 was based on a phenomenon in physics called entanglement. Entanglement is the phenomenon that two particles can be created together, having opposite properties in a way that the sum of their properties is zero. For example: two particles move in opposite directions having the same momentum. Then the sum of their momenta is zero. (Momentum is the velocity of the particle multiplied by its mass).

In wave theory entanglement would be the same as resonance. When in music a tuning fork is touched to produce a certain tone then the legs of the fork start to tremble in opposite directions. (In fact entanglement can appear with more than two particles).

It is generally believed that there exist interaction between the particles of an entangled pair. For how can one particle know its property at the moment the other particle is being measured? Einstein called this: 'spooky action at a distance'. The interaction between particles is not necessary, the fact that particles have opposite properties is enough. In an attempt to explain the interaction between entangled particles the idea of 'hidden variables' was introduced. Hidden variables are not needed either, they are only definite opposite properties, as we shall discover.

EPR thought of an experiment in which a pair of entangled particles was used to measure both position and momentum. According to Bohr this wasn't possible. Let us call the particles of the pair: A and B. The properties of A and B are opposite. So for example they move in opposite directions with the same velocity. According to EPR we can measure the position of A and then we also know the position of B without having disturbed B. So the position of B must be an element of reality. The same goes for momentum (velocity). Measuring the momentum of A we also know the momentum of B without having disturbed B. So the momentum of B also must be an element of reality. So both the position of B and the momentum of B are elements of reality (meaning that they exist at the same time), which is not possible according to QM because of the uncertainty relation. Because of this argument Einstein asserted that QM is incomplete. Bohr didn't agree with Einstein on this conclusion. I don´t know Bohr´s answer to the EPR article but according to Klaas

Landsman [3] it was aimed at tackling the definition of elements of reality. The debate between Bohr and Einstein lasted all their lives and even went on between their successors.

I think particles do have definite properties but it is not possible to measure the position and the momentum of one particle at the same time.

What can we do to find out which of the two views (Einstein's or Bohr's) is the correct one? Fortunately everything that is needed to find that out has already been done by the masters of physics themselves: Einstein, Bohm, Bell and by the experimentalists: Aspect and others. We only have to understand theory and experiments correctly.

But imagine what it would mean if quanta, correctly described by QM, yet have definite properties contrary to Bohr's view. No more measurement problem, no more collapse of the wave function. All problems solved. Schrödinger's cat finally behaving normal again.

Spin

Around 1935 there was a quantum theory perfectly describing almost all phenomena at the atomic level. There is no doubt about it. There were some difficulties which seemed to be of an interpretational nature. The most confusing ideas coming from the theory were the ideas of superposition and entanglement. And there were the two conflicting explanations of the theory: Bohr's view and Einstein's view. Bohr cried down Einstein's view by maintaining that the position and the momentum of a particle cannot be measured at the same time and so not both can be known. He was right about that but it didn't mean that a particle could not have both a definite position and a definite momentum.

It would be nice if there were an experiment that could decide which of the two views was the correct one. David Bohm found out that it should be possible to prove the EPR idea experimentally. Not by measuring the position and momentum of entangled particles but by measuring their spin in three directions.

Spin is the intrinsic angular momentum associated with quantum particles (Julian Barbour: The End of Time [4]). It is believed that in QM spin is a quantized property, meaning that the particle cannot choose its spin axis in a random direction. Some directions are allowed, others are not. Maybe it is the same for the particle's angular velocity but that makes no difference in this paper. In classical physics spin is the spinning of a particle around a random axis. Classically spin can be represented by an axial vector. The direction of the vector represents the direction of the spin axis and the length of the vector represents the angular velocity of the particle (its spinning energy). In this paper I shall use the classical representation (the axial vector) which, I think, is in agreement with Einstein's view.

Spin cannot be measured directly but when a spinning particle is electrically charged then it acts like a little magnet and by manipulating particles by their magnetic properties there is something to tell about their spin.

In 1922 Otto Stern and Walter Gerlach (SG) already had developed a device with which the particles could be manipulated. It was a device composed of two magnets and a detector plate. The magnets were oblong and had different shapes. Because of the different shapes of the magnets, Stern and Gerlach were able to produce an inhomogeneous magnetic field in the space between the north pole of one magnet and the south pole of the other magnet. When a particle was sent through that field, it experienced a force, deviating it in the direction of one of the poles, depending on its spin direction. At the end of the magnets a detector plate was placed which detected the particles and so the deviation of the particles, indicating a spin direction component of the particles relative to the field direction of the SG device.

Bell

In the sixties Bell [1] calculated probabilities for the outcomes of the experiments that Bohm had invented. These calculations became known as Bell's inequalities. Remarkably the outcome of Bell's calculations didn't agree with the outcome of QM probabilities. This fact is called the violation of Bell's inequalities.

At that time the experiment couldn't be performed technically. Around 1980 Alain Aspect was able to perform the experiment. After him many others performed the experiment and the results were always the same: the outcomes were in agreement with QM. This was unexpected because the experiments were meant to show that Einstein's view was the correct one and now it seems that Bohr's view was the correct one.

This was a kind of a problem because the results of the experiments could only be explained if one accepted non-locality. And non-locality was exactly what Einstein not could accept and what not could exist. Anyway, that is what he tried to prove with the EPR paradox.

There was however no other explanation for the outcome of the experiments so most physicists accepted non-locality and with that they accepted the strange effects of entanglement and superposition. It seemed that Bohr was right and that Einstein was wrong.

The model

But is there really no other explanation possible for the outcomes of the experiments? From now on our goal is to account for QM probabilities in Bell experiments and to establish what is needed to reach that goal.

To calculate his probabilities Bell used a model of an experiment as described in [1]. We shall follow exactly that same model. The model consists of pairs of entangled particles, being measured by SG devices. That is all. The pairs of particles are being produced in a source S. The particles of the pairs move in opposite directions along the line of motion. In the spirit of Einstein the particles of a pair possess opposite spin from the moment they are created. The opposite spin can be represented by two opposite axial vectors in a random direction. The length of the vectors depends on the rotation energy of the particles and is supposed to be the same for all particles.

The SG devices are placed at either side of the source on the line of motion in such a way that the particles go through the inhomogeneous field and are detected at the detector plates which are placed perpendicular on the line of motion. The devices can be adjusted at certain angles by rotating them around the line of motion. This means that the direction of the magnetic field can be adjusted in directions in a plane perpendicular to the line of motion.

So far this model is described by Bell himself in [1]. Note that this model is only about directions: the direction of the motion of the particles, the direction of their spin, the direction of the adjustment of the devices and the positioning of the detectors perpendicular on the line of motion. Time doesn't play a role at all. And as Smolin rightly says ([2], page 55): distance makes no difference. The fact that the experiments only are about directions can also be deduced from the results of the experiments: the correlations, calculated from the probabilities, simply and solely depend on φ. And φ is the angle between the adjustment directions (the field directions) of the devices.

At this point something goes wrong. Terribly wrong. All popular science writers use in their books an example to explain Bell experiments and to calculate or deduce Bell's inequalities: Landsman [3] uses twins, separated in different rooms, answering three different questions about music preferences. Smolin [2] uses two persons in different rooms or places, answering questions about different preferences. Brian Greene [5] uses two persons in different countries, opening boxes with three lids and having lights inside that can choose between two colours. Even Bell [1] himself leaves his model and changes to two examples being: 'the long box' and Bertlmann's socks that keep their colours or lose their colours being washed at three different temperatures.

What is wrong with these examples is that they only reflect binary logical possibilities. They totally neglect the directional nature of the experiments. The adjustments of the devices (the field directions) in the experiments define vector spaces. Vector spaces can be looked at or projected in different directions. That is not possible with questions or lids. We shall get to this later.

Rovelli (Carlo Rovelli: Helgoland [6]) tries to explain the experiments in a relational way by observations of the colour of light in two far away cities. He doesn't succeed at all. The only conclusion is that when the results of the observations are being compared with each other afterwards, then the QM correlation appears. We know that by now but why the QM correlation? It still is as if the particles obey the laws of QM whereas it should be that QM describes and predicts the behaviour of the particles. It cannot be like this that the particles only obey the laws of QM. Smolin rightly asks ([2], page 62): 'Is a successful prediction always the same as an explanation?'. Richard David Gill once wrote to me that Bell experiments are experiments with a binary input and a binary output. This is not true. The output may be binary but the input certainly isn't. The input is a pair of particles with opposite spin in a random direction and the pair of the particles can 'choose' its spin direction from a spherical continuum of directions (as long as both spin directions are opposite) and the fact that the 'chosen' spin direction is 'up' or 'down' in respect of the field direction of the SG device does not belong to the input but is represented by the output.

Opposite spin

It is rather difficult to demonstrate opposite spin. The best way is to feel it in your body. It may seem a little bit ridiculous but I strongly advise you to perform the following movement a few times. Hold your fists in front of you, close to your chest, knuckles against each other, backs upwards. Then pull your right fist to the right and at the same time your left fist to the left while rotating them a little bit in opposite directions. The directions of rotation are not important as long as they are opposite.

Now put your imaginary self at the position of your right elbow and imagine what you see. You will see a fist coming towards you with a clockwise (or anti-clockwise) rotation. Then put yourself at the position of your left elbow and imagine what you see. You will see a fist coming towards you with a clockwise (or anti-clockwise) rotation. These are identical pictures and that should not be possible because your fists rotated in opposite directions. So it is not possible to look at the universe in opposite directions at the same time and insist that you see the universe as it is. Your fists represent entangled particles with opposite spin.

Note that detectors perceive and detect exactly in the same way as you do, looking from the position of your elbows. So in this case detectors see entangled particles with opposite spin as exactly equal. This was a special case because the spin axis and the direction of motion coincided. There is one other special case. That is when the spin axis of an entangled pair has a perfect vertical direction. Observed from either left or right or behind or from the front, the spin is always opposite, as it should be. For all directions of spin axes other than the vertical direction, opposite spin directions will not correctly be perceived by detectors detecting in opposite horizontal directions.

The model again

And that is what happens in Bell experiments. Let us return to the model. As time plays no role in the model, we can as well produce all pairs from the run of an experiment at the same time. As distance plays no role either, we can keep all those pairs in the source S where they have been produced. This results in a sphere of opposite spin vectors pointing in random directions (but opposite for each pair). This sphere is a vector space. We now place the SG devices alongside the vector space on the line of motion. Device A is adjusted in the vertical direction and device B is adjusted at an angle φ in respect of A. As each particle, detected by a device, is being deviated either upwards or downwards in respect of the field direction, we can consider the devices as possessing a central plane perpendicular to the field direction. These central perpendicular planes of the devices divide the spherical vector space in two pairs of opposite spaces, called E and O (E from equal and O from opposite).

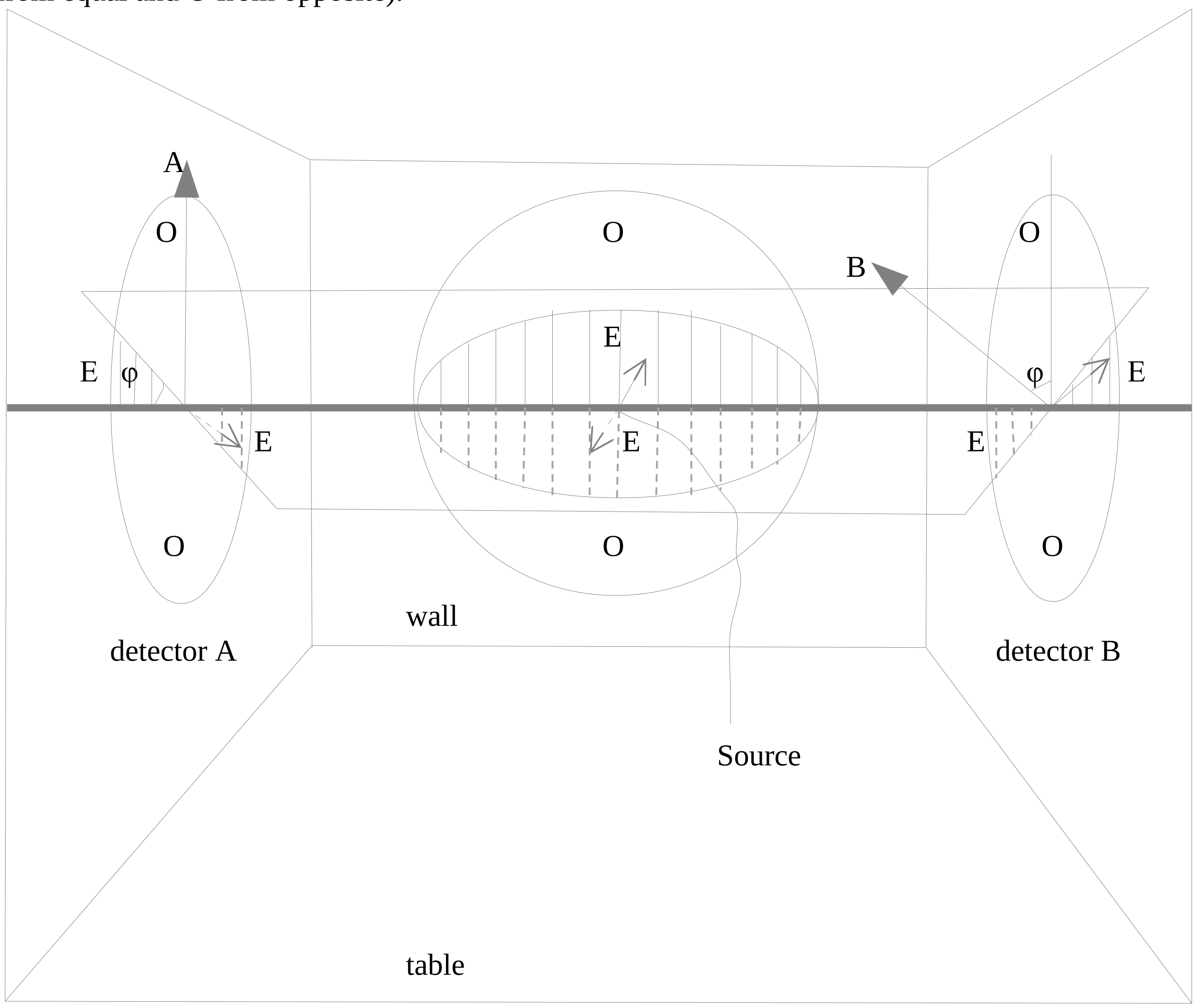


Fig. 1) Realistic model of a Bell-test experiment

The fat horizontal line is the line of motion of the particles and it also represents the perfect horizontal central perpendicular plane of detector A. The central perpendicular plane of B makes an angle φ with this horizontal plane. A and B indicate the field directions of the detectors.

Around the source in the middle is the spherical vector space, divided in the four vector spaces E and O (like the parts of an orange). The spaces E and O are being projected to the left and the right onto the detector plates and to the back onto the wall. The picture of the projection on the wall is of course the same as the picture in the middle. The projections of the vector spaces E onto the wall and onto the detector plates produce projection areas. They are the striped surfaces in the figure. The projection areas onto the wall behind the vector space are called pa_{QM} and the projection areas onto the detector plates at the right and at the left are called pa_{Bell}. We shall meet them before long.

If a pair of entangled particles has its spin directions in space E then the particles are expected to be deviated both upwards or both downwards in respect of the devices (see fig. 2)). So one would expect the detectors to show a combination of equal spin results. If a pair has its spin directions in space O then the particles are expected to be deviated in opposite directions in respect of the devices (see fig. 2)). So in this case one would expect the detectors to show combinations of opposite spin results.

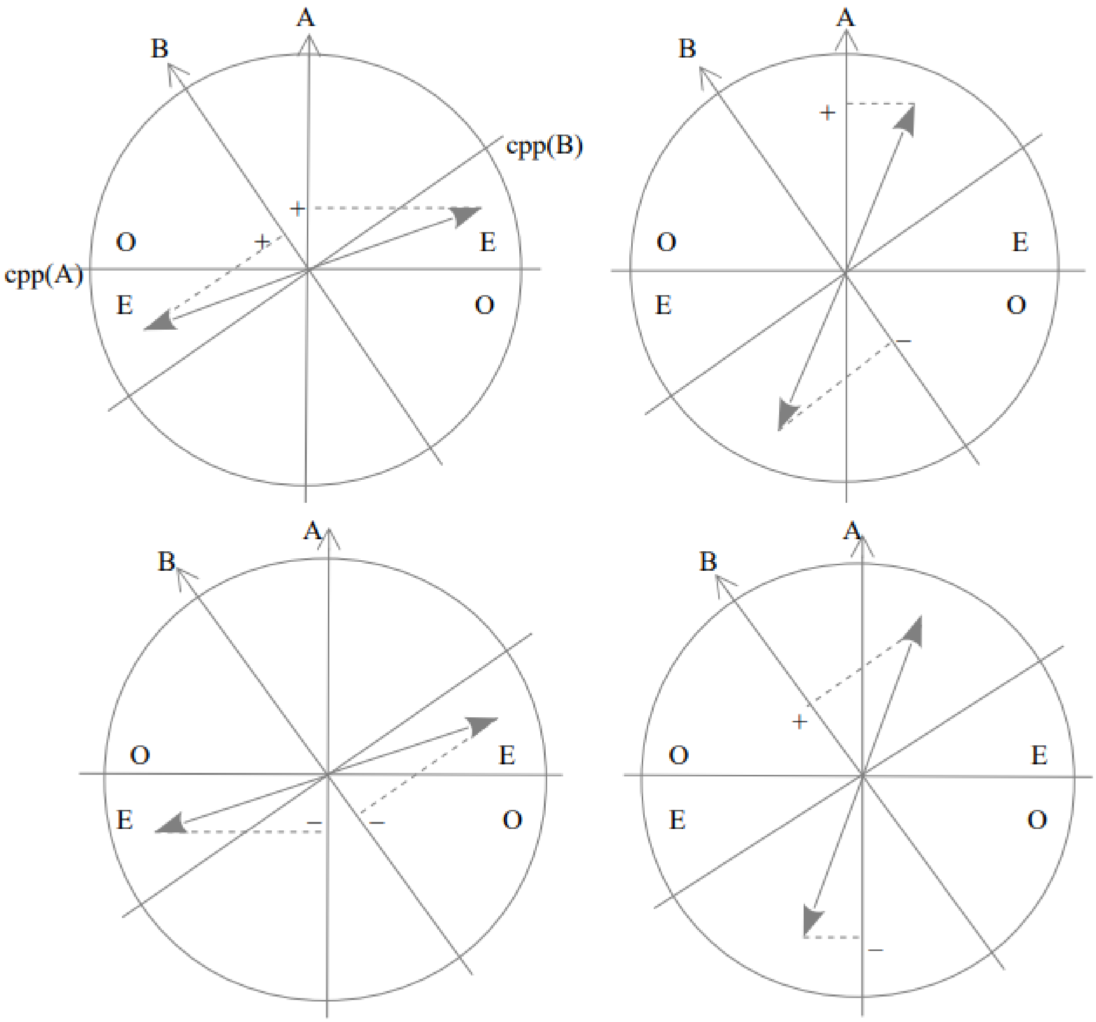


Fig. 2)

Vector spaces with the central perpendicular planes of A and B in it and the field directions of A and B. When the spin directions of a pair of particles find themselves in E then the components of the spin directions in respect of the field directions are both positive or negative (left hand side of the figure) and when the spin directions of a pair are in O they have opposite signs (right hand side of the figure).

But remember that from the viewpoint of the detectors the pairs do not have opposite spin at all. In fact the situation is much worse. If the devices A and B would be at the same position and A is adjusted in the vertical direction and B is adjusted at an angle φ in respect of A then they both agree on the spaces E and O. But when B, keeping its adjusted direction, then moves to its own position, opposite of A, thereby turning around to look at A, then they don't agree at all on the spaces E and O. So A and B not only disagree on the spin direction of a pair of particles, they also disagree on the vector spaces. They can, each for themselves, only report from each particle they detect whether its spin component is upward or downward in respect of their own field direction. That is all they can do and that is what they do.

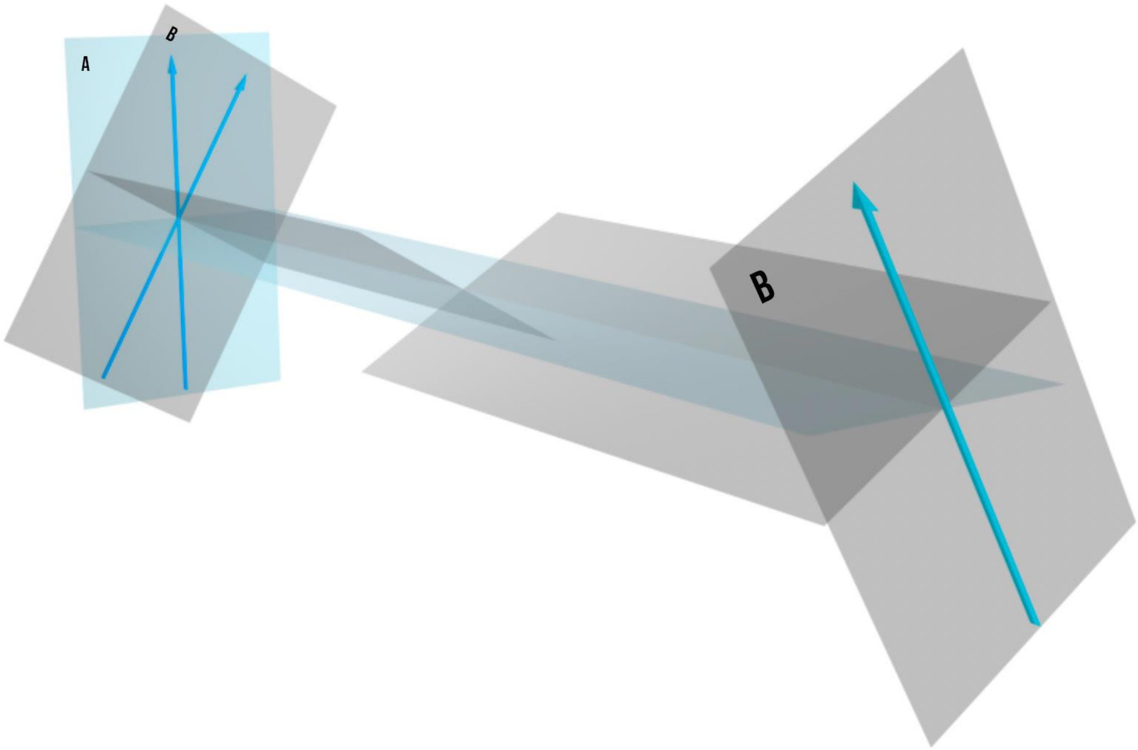


Fig. 3)

Disagreement between A and B on the vector spaces between the central perpendicular planes of A and B. At the left hand side in the figure when B is at the position of A then they agree on the vector spaces and at the right hand side in the figure, when B has been moved to its own (real) position, B experiences completely different vector spaces.

This is also the reason why the pairs that yield combinations of equal spin result, are completely random pairs. It are not necessarily pairs that have their spin directions in E. If a pair from which one particle is detected by A and that particle has its spin direction in E, then the other particle of that pair has its opposite spin direction in the other part of E in respect of A but definitely not in respect of B because B experiences vector space E as completely different from the vector space E experienced by A and there is no overlap.

To an experimenter/observer who set up the experiment, it is all clear. He can see that the vectors of each pair point in opposite directions and for him there is no confusion about the vector spaces E and O. But he is perceiving the experiment from one direction, not from two directions at the same time. Note that the observation direction of the experimenter is perpendicular to the line of motion, perpendicular to the detection direction of the devices. So the observation direction is important.

If you find it difficult to imagine the vector spaces with the vectors in it and projections of them in different directions, you can imagine an orange. An orange has an axis and around the axis are the parts of the orange. Our orange has 10 parts and there are 7 seeds in each part. If you look at one part of the orange while the axis of the orange is pointing at your nose, you see this:

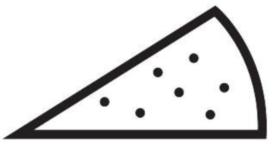


Fig. 4)

The number of seeds per square meter represents Bell's numbers (density) , corresponding to Bell's probabilities. If you now look at the same part while the axis of the orange is horizontal parallel to your front, then you see this:

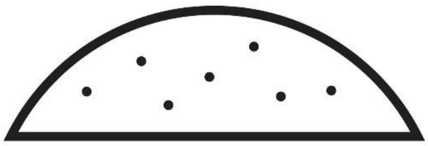


Fig. 5)

Now the number of seeds per square meter represents QM's numbers (density), corresponding to QM's probabilities.

The part of the orange represents one halve of vector space E. The other halve of E is represented by the part directly opposite of the part you have been looking at. Please, keep this image in mind.

Probabilities

Probabilities are ratio of numbers that need to be correctly defined. In Bell experiments ratio of numbers appear that are equal to the ratio as calculated by QM. Now we can try to explain those ratio of numbers in order to find an explanation for the QM probabilities but maybe we have to do it the other way round: try to explain the QM probabilities in order to find an explanation for the results in Bell experiments.

Let me explain the probabilities in the run of a Bell experiment by comparing the run of the experiment with a number of throws of a die. The number of measured pairs is equal to the number of throws of the die, for example the number is 600. When we count the times a six is thrown we shall find about 100 times. To explain the number of about 100 we only have to know the probability of throwing a six by a die and the number of throws and we can calculate the result of about 100 times. We cannot tell which throw will yield a six. That is completely random, meaning that each time you throw a die 600 times, the sequence of the six's will be different.

The probability of throwing a six depends on the die: it has six equal surfaces each with a number of dots on it. And with every throw one of the surfaces will end up upside with equal probabilities: 1 out of 6. It is useless to ask how the die knows to show about 100 times a six when it is thrown 600 times: it doesn't know. We can calculate the number.

The same goes for Bell experiments. We don't need to explain the numbers of combinations of equal and opposite spin results in the run of an experiment: we can calculate them if we know the probability. We cannot tell which pair will end up in a combination of equal or opposite results: that is completely random as it is with the die. In Bell experiments it is also useless to ask how the detectors know how many times they have to show certain combinations of results: they don't know. We can calculate them if we know the probability. There is no information exchange between the detectors (or between the particles of a pair).

In our model the probability is defined by the opposite spin of a pair of entangled particles and the angle φ between the adjustments of the SG devices. The probability is given by QM and is perfectly represented by experiments. The probability differs from Bell's probability so we have to account for the QM probability, not for Bell's probability.

The vectors in E do not represent cases of equal spin (pairs with equal spin) because there are no pairs with equal spin. All entangled pairs have opposite spin. The vectors in E represent the probability for combinations of equal spin results (not the numbers of combinations of equal spin results). The vectors represent this probability by way of a projection density distribution, the vectors being projected in a direction perpendicular to the line of motion. (Remember the seeds of the orange when its axis is parallel to your front).

Definition: The projection density distribution is the probability for a random vector to arrive by projection in a certain direction at the projection area of a certain vector space.

The projection density distribution in the detecting direction (which is the direction of the line of motion) turns out to correspond to Bell's probability and in the observation direction of the experimenter (perpendicular to the detection direction) it turns out to correspond to the QM probability.

Thesis

If a paper needs a thesis, the thesis of this paper would be: 'The probabilities in Bell experiments are projection density distributions of projections in two relative perpendicular directions of vectors in certain vector spaces. The vector spaces are defined by φ. The vectors represent spin directions of entangled particles. Projection in the detecting direction of vectors in a vector space yields projection density distributions that correspond to Bell's probabilities and projection of the same vectors in the same vector space in a direction perpendicular to the detecting direction yields projection density distributions that correspond to QM probabilities'.
This needs an explanation / demonstration.

Projection

Consider a circle with radius 1. Through the centre of the circle is a horizontal line. At the left side of the circle is a vertical line. They are all in the same plane. The intersecting point of the vertical and the horizontal line is O.

More or less equally distributed points of the circumference of the circle are being projected onto the vertical line, starting with the most remote point of the circle in respect of the line. The angle between the radius of the projected point and the horizontal line is φ. Then the distance between O and the projection of a point from the circle onto the vertical line is given by sin φ. We can see in the figure that the projection density is not equally distributed on the vertical line.

Definition: The projection density distribution is the probability for a random point of the circumference of the circle to arrive, by projection, at a certain point of the vertical line.

As probabilities are always positive and the sinus is not, the sinus is squared and to adjust for the period, the angle is halved. This function matches the projection density distribution on the vertical line exactly. So the projection density distribution is $\sin^2(\frac{\varphi}{2})$.

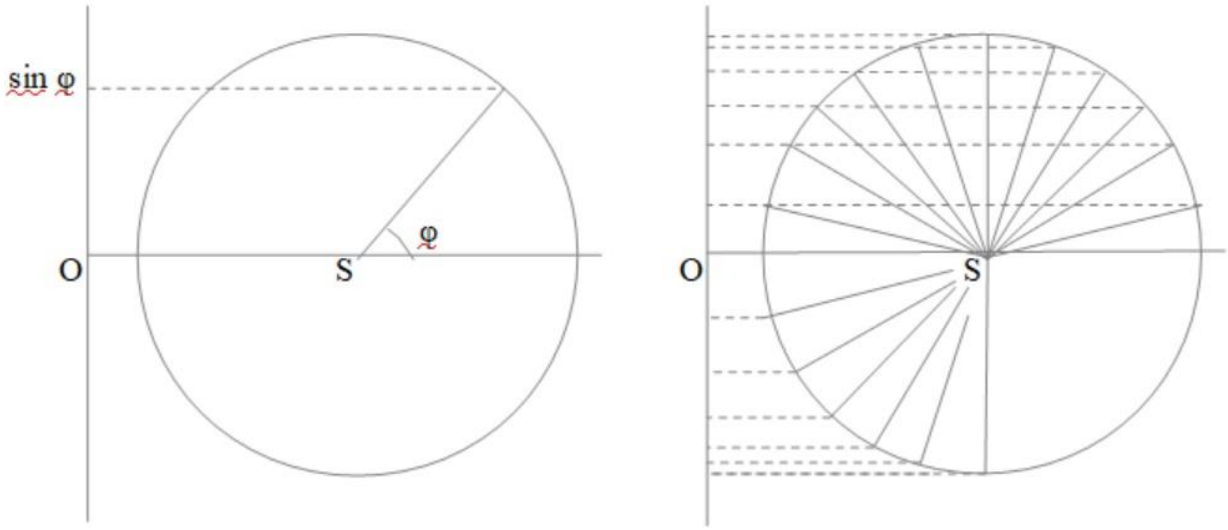


Fig. 6) Projection of equally distributed points of a circle onto a line, yielding a projection density distribution of $\sin^2(\frac{\varphi}{2})$.

If we now replace the circle by a sphere with the same centre and we replace the vertical line by a vertical plane also perpendicular to the horizontal line, we can project the points of the sphere onto the plane in the same direction. The sphere can be filled exactly, without overlap, with circles with different radii, circles like the one described above. Now every point of the sphere can be projected onto the plane, points of the surface as well as points inside the sphere, with the same projection density distribution as that of the points from the circle in the plane. So the projection density distribution goes for every point of the sphere and so it also goes for every vector starting at the centre and ending at the surface, and for every vector space within the sphere, build up by those vectors. The condition is that the points are being projected in the same direction as the points of the circle described above.

The projection density distribution for a projection in this direction ($\sin^2(\frac{\varphi}{2})$) is equal to the probability in QM for the combination of equal spin result in Bell experiments. In case the probabilities in QM for Bell experiments have been deduced in the same way as above, this paper seems to show nothing. This however is not true because in this paper it is assumed that real quantities exist (spin directions) that can be observed, detected and projected from different directions. Without these quantities QM probabilities would be meaningless. QM probabilities are projection density distributions of really existing quantities. That is what this paper wants to show.

Correlation

List of symbols:

C = correlation
N = total number of pairs in a run of an experiment
NE = number of pairs having their spin directions in E
Ne = number of combinations of equal spin result
No = number of combinations of opposite spin result
P = probability
Pe = probability for a combination of equal spin result
Po = probability for a combination of opposite spin result
pd = projection density
pdd = projection density distribution
pa = projection area
tpa = total projection area
The indication '$_{\text{Bell}}$' means: projection in the detecting direction.
The indication '$_{\text{QM}}$' means: projection in the observation direction.

Correlation in Bell experiments is defined as the number of combinations of equal spin result minus the number of combinations of opposite spin result and this difference divided by the total number of pairs: $C = \frac{\text{Ne}-\text{No}}{\text{N}}$. By dividing the numbers individually the correlation can be expressed as probabilities: $C = \frac{\text{Ne}}{\text{N}} - \frac{\text{No}}{\text{N}}$ gives C = Pe – Po.

QM and Bell give us different probabilities for the various combinations, so there are two different correlations. Both correlations are shown in the diagram.

QM probabilities are given by QM as well as produced in experiments and also deduced from projection. They are:

$Pe_{QM} = \sin^2(\frac{\varphi}{2})$ and

$Po_{QM} = \cos^2(\frac{\varphi}{2})$ $(= 1 - \sin^2(\frac{\varphi}{2}))$.

According to the definition of correlation QM's correlation is:

$C_{QM} = \sin^2(\frac{\varphi}{2}) - (1 - \sin^2(\frac{\varphi}{2})) = -\cos\varphi$

Bell's probabilities are based on the assumption that spin directions of the entangled pairs are equally distributed over all directions [1]. So Bell's probabilities are equally proportional to the size of the vector spaces and so they are equally proportional to φ. They are:

$Pe_{Bell} = \frac{\varphi}{\pi}$

$Po_{Bell} = \frac{\pi-\varphi}{\pi}$

According to the definition of correlation Bell's correlation is:

$C_{Bell} = (\frac{\varphi}{\pi}) - (\frac{\pi-\varphi}{\pi}) = \frac{2\varphi-\pi}{\pi}$

Bell's probabilities go for $0 \leq \varphi \leq \pi$ because while varying φ, the central perpendicular planes of the devices rotate and at $\varphi = \pi$ they move 'through' each other. They switch the sides of their planes as it were. This can mathematically be solved by using modulus symbols [1]. This is the reason why Bell's correlation has a sharp peak in the diagram.

Bell's probabilities don't turn up in the results of the experiments because they cannot be perceived and detected by the detectors for reasons that are being explained before.

Calculation

To prove the thesis of this paper we have to show that the probabilities in Bell experiments can be described as projection density distributions. This means that we have to show that for every angle φ (= angle between field directions) the projection in two different directions of one and the same vector space with one and the same number of vectors in it, produce both Bell's numbers (NE) and QM's numbers (Ne). In that way we show that there is a relation between Bell's probabilities and QM probabilities in Bell experiments. The goal of all this is to show that it are real vectors, real spin directions, who cause the (QM) results in the experiments.

We shall now examine the possibility for the probabilities to be projection density distributions. We shall only consider the entangled pairs of particles that have their spin directions in vector space E. Vector space E is defined by the position and adjustment (φ) of the SG devices because it is the space in the sphere between the central perpendicular planes of the devices.

We found already that the QM probability is equal to the projection density distribution in the 'projection' section.

Bell's calculated probability is the number of pairs that have their spin direction in E (= NE) as part of the total number of pairs (= N). The probability for a random vector to find itself in E is equal to the size of E in respect of the total sphere. So Bell's probability is: $\frac{2\varphi}{2\pi} = \frac{\varphi}{\pi}$. The number of vectors in E is $(\frac{\varphi}{\pi})$ N and so $(\frac{\varphi}{\pi})$ is the projection density distribution in the detecting direction (= pdd_{Bell}) and it is Bell's probability (=Pe_{Bell}). So Bell's probability is a projection density distribution in the detecting direction.

Pe_{Bell} is the projection density distribution in the detecting direction, as we have seen. Bell's projection density (= pd_{Bell}) is the number of pairs that have their spin directions in E (= NE) projected onto the projection area (= pa_{Bell}) of E in the direction of the line of motion (the detecting direction).

This is: $pd_{Bell} = \frac{NE}{pa_{Bell}} = \frac{(\frac{\varphi}{\pi})N}{(\frac{\varphi}{\pi})tpa} = \frac{N}{tpa}$ so $\frac{NE}{pa_{Bell}} = \frac{N}{tpa}$.

So Bell's projection density is equal to the average total projection density.

QM's detected probability (and given by QM) is the number of combinations of equal spin results (= Ne) as part of the total numbers of combinations (pairs) (= N). So: $Pe_{QM} = \frac{Ne}{N}$.
Pe_{QM} is the projection density distribution in the observation direction (= $\sin^2(\frac{\varphi}{2})$) as is deduced. We now have to show the relation between Bell's probability and QM's probability by showing that the numbers NE (Bell's calculated numbers) and Ne (QM numbers and the results of the experiments) are being produced by the projection densities from projections of one vector space (E) with one number (NE) of vectors in it, projected in two directions. Bell's numbers (NE) have already been calculated (= $(\frac{\varphi}{\pi})$N).

When we look at the vectors in E being projected in the detecting direction, we find the number of vectors (= NE = Pe_{Bell} N) on the projection area of E (= pa_{Bell}), so the projection density in the detecting direction is: $pd_{Bell} = \frac{Pe_{Bell}N}{pa_{Bell}}$

When we now look in the observation direction we see that the projection area of E changes from pa_{Bell} to pa_{QM}. The number of vectors (= Pe_{Bell} N) doesn't change so the projection density changes inversely (to the projection area) from pd_{Bell} to pd_{QM}. While changing the projection

direction the only condition is that the number of vectors in E (= NE = Pe_{Bell} N) doesn't change, so $pd_{QM}\, pa_{QM} = pd_{Bell}\, pa_{Bell}$ (= NE = Pe_{Bell} N).
While changing the projection direction from the detecting direction to the observation direction, the projection area of vector space E changes from pa_{Bell} to pa_{QM}.
$pa_{Bell} = (\frac{\varphi}{\pi})$ tpa and $pa_{QM} = \sin^2(\frac{\varphi}{2})$ tpa.
If we want to compare the projection densities (pd_{Bell} and pd_{QM}), we have to express them in numbers per square meter for example because $(\frac{\varphi}{\pi})$ tpa and $\sin^2(\frac{\varphi}{2})$ tpa are different areas that cannot be compared with each other. To accomplish this we have to use the reciprocal of the projection areas because if an area is x m^2, a square meter is $\frac{1}{x}$ area. That is why we have to use the reciprocal of the projection areas (pa).

If one prefers to take the total projection area (tpa) as a unit of area the outcome is the same.

This also goes for pa_{QM} of course. So:
pa_{Bell} becomes $\frac{1}{\left(\frac{\varphi}{\pi}\right)\mathrm{tpa}}$ [m^2]
pa_{QM} becomes $\frac{1}{\sin^2\left(\frac{\varphi}{2}\right)\mathrm{tpa}}$ [m^2]
Then $\frac{pa_{Bell}}{pa_{QM}} = \frac{\sin^2\left(\frac{\varphi}{2}\right)\mathrm{tpa}}{\left(\frac{\varphi}{\pi}\right)\mathrm{tpa}} = \frac{Pe_{QM}}{Pe_{Bell}}$

So $pa_{QM} = \left(\frac{Pe_{Bell}}{Pe_{QM}}\right) pa_{Bell}$ [m^2].
Now pd(Bell) = $\frac{Pe_{Bell}N}{pa_{Bell}}$ [m^{-2}]
and pd(QM) = $\frac{Pe_{Bell}N}{pa_{QM}}$ [m^{-2}]

$$= \frac{Pe_{Bell}N}{\left(\frac{Pe_{Bell}}{Pe_{QM}}\right)pa_{Bell}} [m^{-2}]$$
$$= \frac{\left(\frac{Pe_{QM}}{Pe_{Bell}}\right)Pe_{Bell}N}{pa_{Bell}} [m^{-2}]$$
$$= \frac{Pe_{QM}N}{pa_{Bell}} [m^{-2}]$$
$$= \frac{Ne}{pa_{Bell}} [m^{-2}]$$

So pd(QM) = $\frac{NE}{pa_{QM}}$ [m^{-2}] = $\frac{Ne}{pa_{Bell}}$ [m^{-2}].

This double equation means that Bell's numbers of vectors, projected in the observation direction, yield a projection density belonging to a projection density distribution that produce QM numbers of vectors. This QM number of vectors, projected in the detection direction, show that projection density distribution (Pe_{QM}) by the detectors when the lists of results of both detectors are being compared afterwards.

The situation in Bell experiments described by vectors and vector spaces is:

$$\frac{Pe_{Bell}}{Pe_{QM}} = \frac{pdd_{Bell}}{pdd_{QM}} = \frac{NE}{Ne} = \frac{pd_{Bell}}{pd_{QM}} = \frac{pa_{QM}}{pa_{Bell}} [m^2] = \frac{\frac{\varphi}{\pi}}{\sin^2\left(\frac{\varphi}{2}\right)} .$$

So this is the relation between Bell's probabilities and QM probabilities: their ratio is equal to the ratio of the projection densities in two different directions of one vector space with one number of vectors in it for every φ.

This means that Pe(QM) = pdd(QM) (this is the projection density distribution ($\sin^2(\frac{\varphi}{2})$) from the observation direction). The observation direction is the direction from which the spin directions of the particles have to be watched to see them as they really are and the same goes for the vector space E. It means that P(QM) is not inexplicable at all: it is the projection density distribution of a projection in the correct direction.

Considered this way the situation in Bell experiments is as follows: the angle φ between the field directions of the SG devices defines the vector spaces E between the central perpendicular planes and with that it defines Bell's probability. With Bell's probability the number of pairs with opposite spin directions in these vector spaces (E) can be calculated. This number of vectors projected in the observation direction, the direction in which there is no doubt about opposite spin directions and vector spaces, gives a projection density corresponding a projection density distribution that is equal to QM's probability. This QM probability yields the QM numbers of pairs detected by the detectors, by comparing the measurement results of the detectors afterwards. These QM numbers come from completely random pairs yielding combinations of equal spin result. They are not necessarily pairs having their spin directions in E. These pairs projected in the detection direction yield a same projection density as Bell's numbers projected in the observation direction. If Bell's numbers of vectors could be detected in the observation direction then they would produce Bell's probabilities naturally. This goes for every φ.

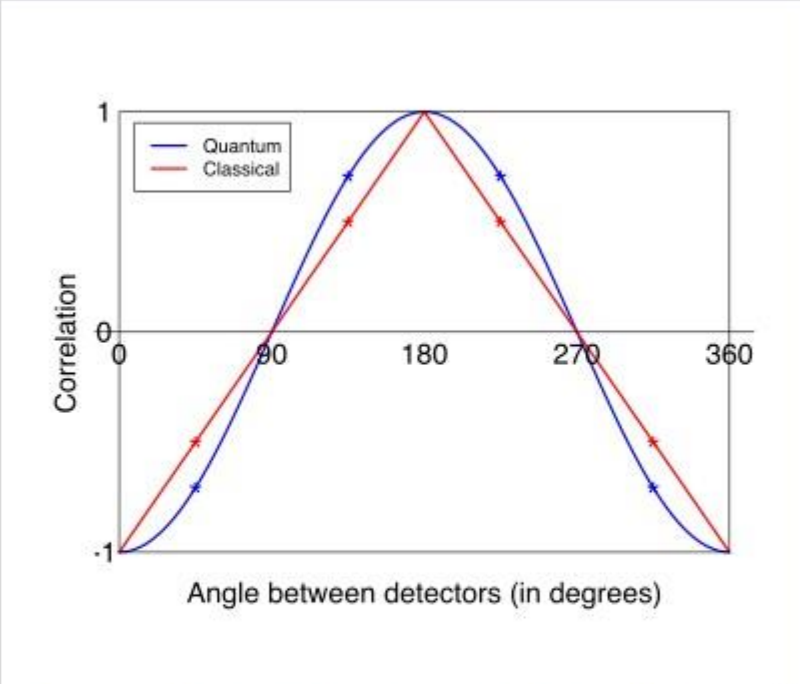
In this way the number of combinations of equal spin results is explained by the explanation of the QM probability.

For vector space O and the vectors in it, it is the same story. To get Bell's results one has to project O in the detection direction. To get QM's results one can project O in the observation direction, which gives the same results as projecting space E from above. Then pdd(QM) is $\cos^2(\frac{\varphi}{2})$. But it is easier to remind that this story is redundant because probabilities add up to 1.

Bell's model was designed to show that certain pairs of entangled particles (the particles that have their spin directions in E) yield equal spin results. It appeared that this didn't happen. It appeared that the detectors couldn't detect the pairs as they really are. This is because they detect in two opposite directions. Is the model completely wrong then? No, it isn't. The same pairs of particles that were supposed to yield equal spin results yield the probabilities of QM for the combinations of equal spin results if the particles are being looked at from the direction of the experimenter. So instead of explaining Bell's numbers the model explains QM numbers by explaining the QM probabilities that are also represented by the experiments. Bell's model is perfectly correct, it only needs to be understood correctly.

I think it has been proven with this that it can be the same set of entangled pairs of particles that yield Bell's probabilities as well as QM probabilities and so Bell's numbers as well as QM numbers. The two detectors cannot perceive the pairs as one observer can. They cannot detect a pair as having opposite spin. So they cannot produce Bell's numbers and probabilities in the results of the experiments but they can and do produce QM's numbers and probabilities. This account for QM probabilities shows that they are not incomprehensible at all. QM probabilities are logically explicable and they are the reason why QM's numbers appear in the experiments. So there is no need for information exchange between particles of a pair. The only condition is that spin direction is a real property of particles.

Diagram



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.

Source: Wikipedia

The diagram shows Bell's correlation (straight lines) and QM's correlation (negative cosine). As the correlation is a difference between probabilities, the diagram can also be considered as a diagram of probabilities. As probabilities have a range between 0 and 1, we then have to adjust the y- scale: 0 at the bottom, ½ in the middle and 1 at the top. Now the areas beneath the lines in the diagram all represent probabilities for combinations of equal spin result and the areas above the lines all represent probabilities for combinations of opposite spin results. For every φ the distance between 0 and a line represents the probability for a combination of equal spin result and the distance between a line and 1 represents a probability for a combination of opposite spin result. This even goes for the horizontal line at y = ½ : this line represents the probability for a particle to yield spin 'up' or spin 'down' when being measured by a detector. For each detector this probability is 50% at every angle it is adjusted in.

The area between QM's line and Bell's line represents probability distributions of projections (or observations) of the vector space with its vectors in it from directions in between the observation direction and the detecting direction. If one moves from the observers viewpoint to the detectors viewpoint, down the road projecting the vector space and vectors, it is like tightening QM's line until it takes the shape of Bell's line. (If one could do that for every φ at the same time).

Bell's theorem

Bell stated that correlations could not exceed certain limits in a local universe. And QM correlations do exceed the limits, in theory as well as in the real experiments. So Bell stated that the universe is non-local, meaning that there must exist interaction at a distance between entangled particles.

This would be the case if Bell experiments solely were about logical possibilities. They are not. They are about directions and for directions these upper limits don't count. So Bell's upper limits are not valid and that makes his theorem invalid. The universe is local yet.

Conclusion

In Bell experiments is being detected in two opposite directions at the same time. One cannot maintain that observing the universe from two directions at the same time is the same as observing the universe from one direction. This also goes for all objects in the universe, like entangled pairs of particles. The fact that in Bell experiments is being detected in two directions is ultimately the reason why the detectors cannot represent Bell’s probabilities and why they can represent QM’s probabilities, as is explained in this paper.

In this paper it has been assumed and demonstrated that in Bell experiments real quantities are being detected. These quantities are the spin directions (vectors) of pairs of entangled particles. It has been shown that the probabilities in Bell experiments are projection density distributions of these real properties of quanta. The real quantities must be taken into account otherwise it is not possible to account for the correlation in Bell experiments as all the stories about the violation of Bell's inequalities prove and as is suggested by the fact that it hasn't been managed for almost half a century.

A model proves nothing but it can explain a lot. The explanation of Bell's model solves many problems in physics. It shows that entanglement is like resonance: particles can have opposite properties but there is no interaction as soon as they are separated. Interaction between entangled particles at great distance of each other is not needed anymore to explain the correlation in Bell experiments. Superposition is like interference: quanta do have definite properties and they are not in different states at the same time, 'choosing' their states while being measured.

In this paper we demonstrated, using Bell's own model, that the probabilities appearing in Bell experiments can be considered as projection density distributions of projections, in two relative perpendicular directions, of vectors representing the real spin direction of entangled particles. The vectors find themselves in vector spaces defined by the position and adjustment of the SG devices. Bell's calculated probabilities are related to QM probabilities. The facts that QM probabilities are very well explicable and that they determine the results in Bell experiments mean that information transmission between particles of entangled pairs is not needed and that means that the universe is normally local, as Einstein insisted.

Smolin says ([1], page 172):”What I want from realism is a detailed explanation for how the probabilities arise as relative frequencies, averaging over a set of repeated runs of the experiment”. This sounds to me as if he meant Bell experiments. Well, I think this condition has been fulfilled in this paper.

Appendix A Explanation for the QM results in Bell experiments

(This might be a resource for a better understanding of the paper)

Reasoning of the explanation:

1) Realize that the experiment is all about directions.
2) An experiment must be described from a correct direction (point of view).
3) Choose a reference direction, for example: the line of motion of the particles.
4) To find the correct direction to describe the experiment all rotations of the elements of an experiment (the detectors in this case) must be taken into account.
5) Realize that the detectors are placed perpendicular on the line of motion. This takes a rotation of 90º from a starting point that is in agreement with the reference direction.
6) Choose for example the viewpoint of the observer/ experimenter as starting point (see fig.1).
7) The direction in which the observer looks at the experiment is a correct direction in agreement with the reference direction.
8) The pairs that have their spin directions in vector spaces E yield combinations of equal spin result (see fig.2) provided observed/ detected from the correct direction.
9) Realize that the detectors don't detect in this direction.
10) The detectors (having been rotated) cannot represent these pairs (and of course also cannot represent their number).
11) The number of the pairs that have their spin directions in E can be calculated by Bell's probability and is: NE.
12) These pairs, observed in the correct direction, yield a projection density which is NE per projection area (the projection of vector space E in the correct direction) ($pd_{QM} = \frac{NE}{pa_{QM}}$).
13) This projection density (pd_{QM}) corresponds to a projection density distribution (pdd_{QM}) which is: $\sin^2(\frac{\varphi}{2})$.
14) Pdd_{QM} is QM's probability ($= \sin^2(\frac{\varphi}{2})$) for combinations of equal spin result.
15) This probability is reflected by the number of combinations of equal spin result (= Ne) represented by the detectors when their lists of results are being compared afterwards.
16) These combinations of equal spin result come from totally random pairs because the detectors cannot 'see' opposite spin and they totally disagree on vector spaces. This is because they 'look' and detect in different (opposite) directions.
17) This reasoning also goes for combinations of opposite spin result.

Appendix B Perspective

The idea of perspective is not easy to grasp. It seems so obvious that perspective doesn't matter but it makes all the difference. One cannot correctly perceive / describe / detect the universe (or an object in it like an entangled pair of particles) from two perspectives at the same time. The SG devices (detectors) in Bell experiments detect from two opposite perspectives at the same time so they cannot 'see' an entangled pair (and also not the vector spaces) as one observer does.

The difference between observers (people) and SG devices is that people calculate (very fast and unaware) and SG devices are like cameras. When a person moves from the position of A to the position of B he immediately knows that what he saw at the right hand side when he was at the position of A, he will see at the left hand side when he is at the position of B. An SG device at the position of A, taking a picture and bringing that picture with it when it moves to the position of B, still 'sees' at B's position at the right hand side what he saw at the right hand side when he was at the position of A.

To device B the vector space he saw at the right hand side when he was at the position of A, really is at its right hand side when it arrives at its own position (B) because B has to turn around to face A and its central perpendicular plane turns along with the device. But the vectors in the vector space don't move along.

In whatever way, when B moves from the position of A (A and B having the same perspectives) to its own position at B (A and B having different perspectives) something changes. Either A 'remembers' B as it was when it was at the position of A and then they don't agree on the position of the vector spaces or A 'see' B in its new position and then φ changes to − φ according to A.

One may even consider device B not to rotate but to translate to its own position in order to maintain φ. In that case the detector plate of device B turns out to be at the wrong side of B's magnetic field so B cannot detect anything anymore. So detecting from opposite directions is possible but (compared) results are not the same as one would expect from a detection from one perspective (if that would be possible). Compared detection results from one perspective would yield Bell's correlation as expected. Compared detection results from opposite perspectives yield QM's correlation. This result is not expected but in agreement with an observation from one (correct in respect of the reference direction) perspective.

This is what happens in Bell experiments.

Acknowledgement

I would like to express my gratitude to Anneli who showed the ability to keep my feet on the ground, but more importantly she kept faith in me and the process.

I thank David Spier for his computer assistance. And I thank all those who tried to really understand this paper and comment on it. Thank you.

References:

[1] J.S. Bell, Bertlmann's socks and the nature of reality. Archives ouverte HAL, 1981;
[2] L. Smolin, Einstein's Unfinished Revolution;
[3] N. Landsman, Naar alle Onwaarschijnlijkheid;
[4] J. Barbour, The End of Time;
[5] B. Greene, De Ontrafeling van de Kosmos;
[6] C. Rovelli, Helgoland;-
[7] https://www.youtube.com/watch?v=g1quDMTEIFE (video).

Addendum

Calculating in ratio is as counter intuitive as perceiving in different directions at the same time is.

Bell and Einstein

There is an inside and there is an outside
There is a small and there is a big
Inside we find the small
Outside we find the big

A line has two directions

From outside to the inner we see the small
From inside to the outer we see the big

Time has one direction

In spacetime we find the universe
In the universe we find spacetime
In space and time we see the universe
In the universe we see God

God is no point
In a point is nothing
There is nothing in a point

A line has no beginning
A line has no end
God is a line

Space has no centre
Space has no outside
God is space

Spacetime is no matter
Spacetime is no wave
Spacetime is the universe
The universe is God

Time has no beginning
Time has no end

God is everything we can’t describe
God is in itself in its Self

Gerard van der Ham