(This is a part of the book The Concept of Reality.pdf)

Contents:

1. Local Solution of the EPR-Paradox

1.1. Preliminary Notes

The EPR Paradox will be cleared up in two rounds. The first one is dedicated exclusively to the refutation of the conviction that it is impossible to reproduce the quantum mechanical predictions for measurements on entangled systems by a strictly local theory. To this effect it is sufficient to present such a theory – the physical implications resulting from it can be ignored for the moment. However after the interpretation of special relativity, the alternative description of the Photoelectric and the Compton Effect and the explanation of the reduction of the wave function, we will return to EPR. The local solution of the paradox will then be part of the new local and objective interpretation of quantum mechanics.

To understand what the paradox is about, only a few facts are needed:

1. Generally, the quantum mechanical description of an object determines for some attributes not a definite value but only the probability distribution of possible measurement values.

2. This applies also to the case of two spatially separated objects which interacted in the past or which originate from the decay of an object.

3. Between the outcomes of certain measurements on these two objects there will then be a connection that is called "entanglement". E.g. in the case of two identical particles A and B which come from the decay of an object at rest and depart into opposite directions, the measurement values of the two momentums are interconnected in the same way as in classical physics, which means that in any case $p_A = -p_B$. Another example: If a spin 0 system decays into two photons, then the measured polarization directions of the photons are rectangular to each other.

That's all there is to it! What is paradoxical about it? This is quickly explained, too:

Let us assume as yet no measurement has been performed. Thus only the probability distribution of the measurement values is known. But if now the momentum of particle A is measured, then, because of (3), *at the same moment* also the momentum of B is known, and the same applies to the case of the photon polarizations.

Now one can argue with Einstein, Podolsky and Rosen in the following way:

B is at an arbitrarily great distance from A. Therefore, the measurement on A cannot have influenced B. Thus we can state: if B has a definite momentum *after* the measurement on A, then it must have had this momentum also already *before* the measurement on A – otherwise the measurement on A would have caused a change of the state of B. However, since the quantum mechanical description does not contain this momentum, it must be considered incomplete. (In this case, the momentum would be a so-called *hidden parameter.*)

That sounds like a reasonable argument! Indeed the alternative would be to assume a *non-local* connection between the two measurements, that is a connection which requires either a faster-than-light transmission or which exists without any mediating process at all and must simply be accepted as such.[1]

But now follows the paradox: Exactly this plausible EPR assunption – that the result of the measurement on B is already determined *before* the measurement on A, because it corresponds to an *objectively existing* attribute of a single system – is a necessary and sufficient condition for the derivation of Bell's Inequality, from which then follows that a local description of the world, which conforms to the experimentally verified predictions of quantum theory, is impossible. Hence, in the end, exactly the argument by which EPR meant to proof the incompleteness of quantum theory serves to reduce their own intention to absurdity, to describe the world in an objective and local way.

Thus the entanglement must in fact be understood as *non-local connection.* We seem to be compelled to resign ourselves to the non-locality of the world. At least this is the current state of affairs.

1.2. The 2-Photon Scenario; Derivation of Bell's Inequality

Let us now turn to the experimentally best tested case of entangled systems: a 2-photon system with total spin 0.

Let Z be a spin 0 system that decays into two photons:

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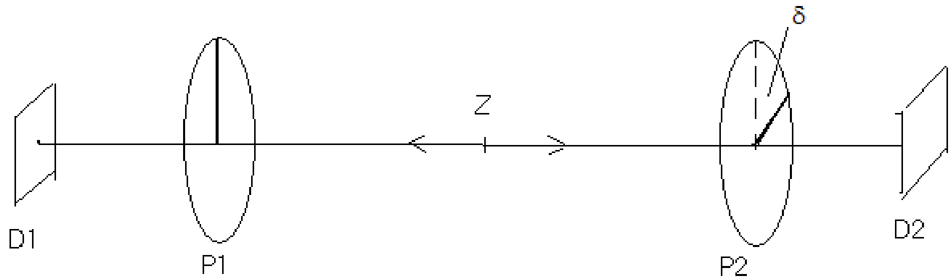
[1] The quantum mechanical formalism informs only about the measurement values which are to be expected, but it does not inform about *how* these values are realized or from which moment on the measurement value of B exists. However the possibility of a transmission the speed of which is not greater than that of light has been ruled out by experiment.



(S1)

P_1 and P_2 are polarizers; D_1 and D_2 are photon detectors. The plane of the right polarizer P_2 is turned by the angle δ against the plane of the left polarizer P_1.

At first in short the Quantum mechanical description (however just for the sake of completeness; all which is in fact necessary for the following considerations is the value of the probability W(δ) in (2)).

The state vector of the two photons is

$$\psi = \sqrt{\frac{1}{2}}\left(x_1\, y_2 - x_2\, y_1\right), \tag{1}$$

where x_1, y_1 and x_2, y_2 are the polarization states of the two photons with respect to any x- and y-axes. Expressed by trigonometric functions:

$$\psi = \sqrt{\frac{1}{2}}\,(\cos\alpha \sin(\alpha-\delta) - \cos(\alpha-\delta)\sin\alpha) \tag{1'}$$

For the probability W(δ) of the simultaneous reaction of both detectors holds

$$W(\delta) = \psi^2 = \frac{1}{2}\sin^2\delta\ . \tag{2}$$

Let us now look at an experiment performed with a series of such photon pairs.

There are two series of events: {EL} (events left side) and {ER} (events right side), both in any case with two possible values: 1 (photon) or −1 (no photon). The events are *polarization measurements*.

Before measurement – in the state described by (1) – the photons do *not* have a definite polarization, which is expressed by the fact that (1) is independent of the directions of the x- and y-axes, i.e. it is rotationally symmetric with respect to the propagation direction of the photons.

If now the polarization of a photon, say: the left one, is measured, then also the polarization of the right one is given. (E.g. if the left photon appears in the detector, its polarization must be parallel to the direction of the left polarizer; then it is known also without measurement that the polarization of the right one is orthogonal to this direction. Thus the probability of its appearance in the right detector will be $\sin^2\delta$.)

This is the starting point of the ***EPR argument***: In the quantum mechanical description, the right photon is – after the measurement of the left one – in a different state than before this measurement. However as it can be ruled out that the measurement of the left photon could *in fact* have changed the state of the – arbitrarily far away – right one, it must be assumed that the polarization of the right photon has already existed before this measurement. According to (1), however, there is no definite polarization before the measurement, therefore quantum mechanics is incomplete.

The ***EPR assumption*** that the attributes to be measured exist already before – which means: independent of – the measurement, is a necessary and sufficient condition for the derivation of ***Bell's Inequality****,* for the following reason:

Any derivation of Bell's Inequality is based on statements about how the measurement objects of a certain experiment *would behave at other measurements* – in fact without such a statement the inequality couldn't even be noted down. For *entangled objects,* however, statements of this kind are not permitted, because these objects and their respective counterparts must be understood as *one single system*, and statements about their behavior at further measurements are thus impossible.

However, due to the EPR assumption it becomes possible to make such statements: If the objects are *separated* from each other and possess their attributes independently of measurement, then it is evidently also known which results other measurements on these objects would lead to.

This shall now be demonstrated by a variant of the inequality[2] (originally introduced by Bernard d'Espagnat in 1979), adapted for our example:

[2] I chose this variant because it can be understood without physical knowledge and because, with respect to my conclusions, it doesn’t make any difference which variant of the inequality is used. The step which my argument refers to is *in any case* necessary for establishing the inequality. More to that follows in the text.

Let the hidden parameter be the polarization direction of the photons. Accordingly, each of the two photons possesses – independently of any measurement – a component 1 or 0 (that is: goes through the polarizer or does not go through) in every possible direction.

Let α be the angle of the left polarizer, γ the angle of the right one. Let $R(\alpha|\gamma)$ be the number of the cases in which at R measurements both detectors respond.

If both polarizers are adjusted at the same angle, then, because of (2), never both photons of a pair pass through but in any case either the left or the right one. Therefore $R(\alpha|\gamma)$ can be divided into $R(\alpha,\beta|\gamma)$ (this is the number of photons in $R(\alpha|\gamma)$ which *would* go through at a third angle β on the *left* side), and $R(\alpha|\beta,\gamma)$ (the number of photons in $R(\alpha|\gamma)$ which *would* go through at the same angle β on the *right* side):

$$R(\alpha|\gamma) \;=\; R(\alpha,\beta|\gamma) + R(\alpha|\beta,\gamma) \tag{3}$$

This is the point where the EPR assumption comes into effect: The objects which were measured at the angles α and γ could not be measured additionally at the angle β, and in case of their entanglement the above conclusions would be prohibited. However, due to the EPR assumption it becomes possible to make statements about what would be the case if both polarizers were adjusted at the angle β and ***the same photon pairs*** *as in the actually executed series were underway.*

Certainly is $R(\alpha,\beta|\gamma) \leq R(\beta|\gamma)$, since the number of photons which go through at the angle β cannot be smaller than the number of photons which would go through at β *and* at α. In the same way it is evident that $R(\alpha|\beta,\gamma) \leq R(\alpha|\beta)$. *(Also for this step the EPR assumption is needed.)*

With this, from (3) follows Bell's inequality:

$$R(\alpha|\gamma) \;\leq\; R(\alpha|\beta) + R(\beta|\gamma) \tag{4}$$

According to (2) is $\quad R(\alpha|\beta) \;=\; \frac{R}{2}\sin^2(\beta-\alpha) \;=\; \frac{R}{2}\sin^2\delta$

Let be $\alpha = 0°$, $\beta = 22{,}5°$, $\gamma = 45°$. Then (4) turns into

$$0{,}5 \;\leq\; 0{,}1464 + 0{,}1464 \qquad\qquad 0{,}5 \;\leq\; 0{,}293.$$

Thus Bell's inequality contradicts quantum mechanics. Experiments confirm quantum mechanics. This means: as regards the actual measurements, Bell's inequality does not hold true.

As seen above, however, apart from logic and mathematics (whose validity is presupposed), for the derivation of the inequality only two assumptions are needed: the entanglement condition (that is: with the same angle on both sides, exactly *one* photon at a time will appear) and the EPR assumption. The validity of the entanglement condition is proven experimentally. Hence from the falseness of the inequality follows the falseness of the EPR assumption, which means:

Prior to the measurement of the one photon, the other photon does indeed ***not*** *have a definite polarization. After this measurement, it* ***does*** *have a polarization. Therefore, the measurement of the one photon causes a change of the state of the other photon. There is in actual fact a non-local connection.*

So much for the chain of evidence that is considered safe and inevitable by almost all physicists

1.3. The Local Alternative, demonstrated by a Simple Example

If – as EPR assumed – the objects are *separated* from each other and possess their attributes independently of measurement, then it seems completely self-evident that the behavior of these objects at further measurements is known.

However, exactly this ostensible obviousness shall now be challenged. We will investigate, whether it is true that the assumption of separateness or locality (the EPR assumption) permits statements about further measurements on the same objects and, in this way, enables the derivation of Bell's Inequality.

To begin with, let us once again formulate the locality-assumption. It reads as follows:

A1: *The measurement on one side is independent of whether a measurement on the other side has been carried out or not. It is not influenced by this measurement.*

As discussed above, for the derivation of Bell's inequality (not only for the variant presented here but for all possible variants) the following assumption is required:

A2: *Statements about further measurements on the same objects are permitted.*

(The necessity of this assumption is obvious: As follows from the substantiation of equation (3), establishing the inequality involves statements about results of *various measurements on the same objects*. Therefore, without assumption **A2** the inequality could not be established.)

But I will now show: ***A2** does **not** follow from **A1***.

This means:

***A1** is necessary, but not sufficient for **A2**. There must be a condition which is required for deducing the inequality but <u>not</u> for maintaining locality.*

The following simple example will be sufficient to prove this assertion and to show at the same time what condition that is. In spite of its simplicity, it possesses all attributes needed for clearing up the issue.

Imagine a square room in the center of which is a bunch of balls that weigh 1, 2, 3 or 4 grams. Along the left and the right wall empty containers are positioned, 10 on each side. Under each container, there is a scale which emits a short tone, if, during a loading process, a limit of 5 grams or a multiple of 5 grams is reached or exceeded.

In the room is a person who performs *moves.* A move is defined as follows: To each of the two series of containers, balls with a total weight of 4 grams are distributed, i.e. 4 grams to the left and 4 grams to the right. (The symmetry of the weight distribution represents the entanglement condition.) The choice of the balls and of the containers is random. (With due regard to the 4g rule: e.g. after a 3g ball, only a 1g ball is possible.)

Each move entails a pair of *events* (event to the left and event to the right); each event has two possible values: *tone* or *no tone.* (The value *tone* can also consist of more than one tone.)

Evidently, here the connection between the objects and the measurement values is not as simple as in the EPR scenario: it is not the *object-attributes* themselves (the weights of the balls) which are measured, but the *effect of their accumulation.*

This circumstance is of decisive importance for the question of whether statements about further measurements on the same objects are possible, because in this case the events that follow from a move do not only depend on <u>that</u> move but also on the <u>preceding</u> moves.

E.g. let E1 und E2 be two measurement series with 50 moves each. Let us assume, the 38^{th} move of E1 causes the event pair (*tone*|*no tone*).

Now, if any of the moves of E2 (except the first one) is replaced by this move, is then anything known about the event pair that will be caused by this move in E2?

The answer is no.[3] Whether the replaced move will cause a tone or not does not only depend on this move but also on how much weight has been in the containers already before this move. However that depends on the specific course of E2 which is most likely different from the course of E1 and completely unknown.

Therefore we can state: *The connection between a move and the following event pair is inseparably bound to the course of the respective measurement series.*

Every event pair does not only depend on the directly preceding move but also on all other previous moves. Therefore it is not possible to predict anything about what would be the case if a move was transferred from one experiment into another experiment.

With this, it is proven that the assumption A2 does not follow from the assumption A1. Though it is evident that, in our example, the event on one side is not influenced by the event on the other side, it is still impossible to predict anything about the events that would follow from a move of a certain experiment if it were transferred into another experiment.

In other words: *Statements about further measurements on the same objects are not permitted.*

So what is the condition which is necessary for deducing the inequality but <u>not</u> for ruling out non-locality? It is the assumption made by EPR that the measurement value is determined already before the measurement *because it corresponds to an objectively existing attribute of the measured object which this object possessed already before the measurement.*

But evidently, this assumption is not necessary for maintaining locality: Also in our simple example, every measurement value is determined already before the measurement, however not because it corresponds to an attribute of the measured object but *because it is generated by the measuring process – by the adding up of the weights of the balls and the acoustic signal caused by it – in a definite manner.*

Thus here the measurements are not performed on "objects" in the usual sense, which means: on "things" that persist "as themselves" or "identical with themselves" and which are therefore available for further measurements, but on varying aggregates of always new composition, and, moreover, the measurement result depends in any case also on the preceding course of the experiment.

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[3] Of course with the exception of the general probability statement that follows from the consideration of all possible series. However this is irrelevant here.

Generally spoken: *The concepts "object" and "measurement process" are fundamentally changed.*

With this, we have shown that besides quantum mechanical standard interpretation and the interpretation of Einstein, Podolsky and Rosen, there is indeed another, *local* interpretation of the 2-photon scenario – provided it is possible to apply the scheme of the example to this scenario.

So if we succeed in transferring this scheme to the 2-photon scenario, then the consequence is that the condition which is necessary for the derivation of Bell's inequality is no longer met. The inequality is then suspended, and the path to local descriptions is open.

1.4. The 2-Photon Scenario – Local Reconstruction of the QM-Predictions

What does that mean:"Local reconstruction of the QM predictions for measurements on entangled photons"?

It means expressing – in a consistent way – the measurement values predicted by QM as functions of variables located directly at the position of the measurement – i.e. in one of the detectors –, and, additionally, adopting the structure of the whole scenario, which in turn means that the objects that are the carriers of these variables must originate from the decay at the position Z, then pass through the polarizers (or not) and ultimately arrive at the detectors (or not).

The first step is transferring the scheme of the ball-example to the 2-photon scenario. For that only one single condition has to be met:

The measuring result must not correspond to the attribute of an object. Instead only the accumulation of objects should trigger an event.

In the case of photons, the way to meet this condition is actually very simple and obvious. The dualistic model of radiation does indeed contain besides the concept "particle" also the concept "wave". Thus all that is needed is to assume that not the particle but the accumulation of waves triggers the event. [4]

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[4] Remember that, in this first round of EPR, the only objective is to refute the general conviction that equation (2) cannot be substantiated by a local model. The power of Bell's proof lies indeed in its claim to hold independently of any kind of physics. Thus at first it must be shown that this claim is actually not justified. For now, the physical implications can be ignored. Of course they will be discussed later.

Concretely, this assumption reads as follows: *The discontinuous transitions between different states where "photons" are generated or detected are the consequence of continuous emission or accumulation of light waves. As a result of this assumption, "photons" are* ***defined*** *as such transitions.*

In the case of entangled photons, these waves are emitted as pairs. Their polarization directions are at random. (Equally distributed between 0 and 2π*.)*

This assumption forbids – exactly in the same way as in the example of the previous section – to transfer any event of one experiment into another experiment; Statements about what would be the result if a specific pair of objects (that is: all the waves that have been emitted into both directions since the previous event-pair) which have already been measured, were measured again, are then no longer possible. This means: Bell's inequality cannot be derived; the proof of non-locality disappears. (Later I will go more extensively into this issue.)

With this, the scheme of the example has already been transferred to the photon scenario.

However now, in addition, a rule is needed which – in connection with the function for calculating the measurement values, which will be presented in the following – guarantees that equation (2) holds for all event pairs of a series, e.g. that for $\delta = 0°$ (both polarizers are adjusted at the same angle) *never* simultaneous transitions on both sides occur, or that for $\delta = 90°$ the transitions are *always* simultaneous.

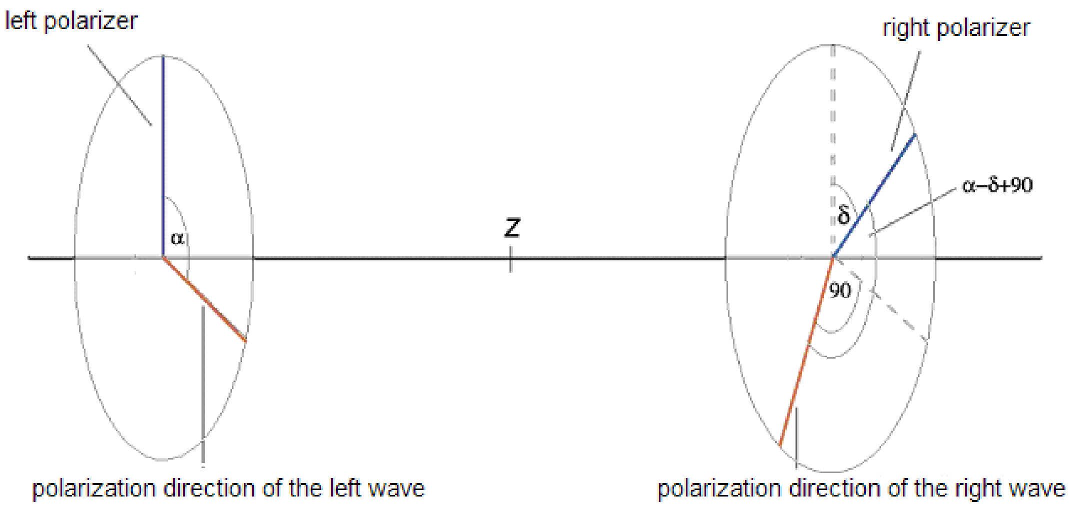
The rule that meets this requirement is "borrowed" from quantum mechanics:

The angle between the polarization directions of the waves that are emitted as pairs into opposite directions is equal to the angle between the polarizations of the measured photons. (90° in our case.)

Regarding all other parameters, we assume the waves to be completely symmetrical.

It must be cleared up yet what it means, in this model, that *a photon with a certain polarization direction* is measured. It has the following meaning: waves that have passed through a polarizer adjusted at this angle cause a transition. To this transition – i.e. to the "photon" – can then be assigned the attribute *polarization at this direction.* Here, only in this sense we can speak of the attribute *polarization of a measured photon.*

Therefore, the whole scenario can be outlined in the following way: (S2 differs from S1 because of the assumption of the hidden parameter *polarization of the light waves.* Please note however that this hidden parameter *is not identical* with the hidden parameter *polarization of the photons,* which is part of the EPR interpretation of the scenario!)



(S2)

Let the left polarizer be adjusted at the angle 0°, the right one at the angle δ. Let α_i be the random polarization angles of the waves on the left side, accordingly (α_i+90) those of the waves on the right side. As regards the amplitudes of the waves, no specific assumptions are needed. Therefore they can be set to 1. Then $\cos\alpha_i$ are the amplitudes of the waves which have passed through the left polarizer, $\cos(\alpha_i+90-\delta)$ the corresponding amplitudes to the right.

With this, all resources needed for the local reconstruction of the quantum mechanical results of experiments with polarization measurements on entangled photons are prepared.

At first we define random variables X and Y as follows:

$$X_i = \cos^2 \alpha_i \qquad (1 \le i \le n) \qquad (5)$$

$$Y_i = \cos^2(\alpha_i + 90 - \delta) \qquad (1 \le i \le n) \qquad (5')$$

Thus in this model the random variables are the squares of those wave amplitudes which *actually* arrive at the detectors. So they are without any doubt *local variables.* [5]

Assertion:

Let $I = \{ i \mid 1 \leq i \leq n \}$ be the set of the numbers of random variables in the case of a total number of n pairs.

Let $I_L = \{ i_L \}$ be the subset of I, where $X_{i_L} > 1/2$, $I_R = \{ i_R \}$ the subset of I, where $Y_{i_R} > 1/2$, and $I_{LR} = \{ i_{LR} \}$ the subset of I, where $X_{i_{LR}} > 1/2$ and $Y_{i_{LR}} > 1/2$. ($I_{LR} = I_L \cap I_R$)

Let w_L be the probability of the appearance of a photon on the left side, w_R the according probability on the right side, w_{LR} the probability of the simultaneous appearance of photons on both sides.

Then applies (with $n \rightarrow \infty$)

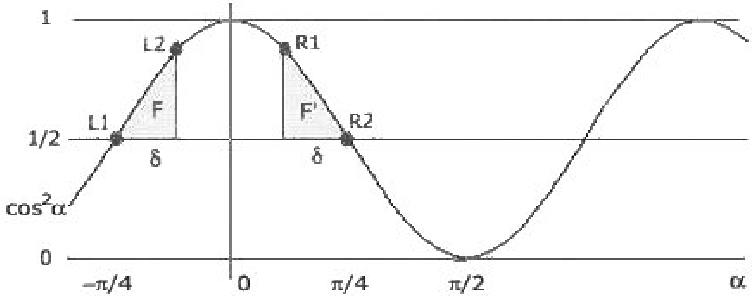
$$w_L = \frac{\pi}{n} \sum_{i \in I_L} (X_i - 1/2) = 1/2 \qquad w_R = \frac{\pi}{n} \sum_{i \in I_R} (Y_i - 1/2) = 1/2 \tag{6}$$

$$w_{LR} = \frac{\pi}{n} \sum_{i \in I_{LR}} (X_i - 1/2) = 1/2 \sin^2\delta \qquad \left[= \frac{\pi}{n} \sum_{i \in I_{LR}} (Y_i - 1/2) \right] \tag{7}$$

Proof:

We look at the $\cos^2$-curve. (δ is the angle between the two polarizer planes.

[5] As can be seen, in the following formulas for calculating the probability of photon detections, only amplitude squares greater than ½ are taken into account. Obviously, this is the easiest way to assure that there are no common events if δ = 0, because in this case only on one side the amplitude square is greater than ½. Remarkably, this condition alone is also sufficient for any other δ. I think, already the simplicity of formula (7) is a strong indication that the specific kind of entanglement in this scenario – and therefore also the statistics of the resulting measurements – is somehow contained in the experimental setup. However I abstain from presenting the associated physical processes because, in my eyes, some additional assumptions make them unattractive.



(S3)

If α (the angle between the oscillation direction of the wave and the polarizer plane on the left side) lies between L1 and L2, then α+90–δ (the according angle on the right side) lies between R1 and R2. It can be seen that only for $-\pi/4 < \alpha < -\pi/4 + \delta$ and for $3\pi/4 < \alpha < 3\pi/4 + \delta$, the amplitude squares (i.e. the random variables) on both sides are greater than 1/2.

The area F is equal to the area F', and therefore

$$F \;=\; \int_{\frac{-\pi}{4}}^{\frac{-\pi}{4}+\delta} \cos^2\alpha \, d\alpha \;-\; \delta\,\frac{1}{2} \;=\; \frac{1}{2}\sin^2\delta \qquad (8)$$

With $n\to\infty$, the sum in (7) corresponds exactly to this area F.

The sum in (6) corresponds to the area, which is enclosed by the $\cos^2$-curve and the 1/2-straight between $-\pi/4$ and $\pi/4$; therefore the result of (6) corresponds exactly to that of (7), if in (7) δ is set to $\pi/2$; thus it amounts to 1/2.

With this we have reached our intended target. In (6) and (7), the sought probabilities are expressed as functions of subsets of the random variables on one side, that is: by local conditions. Also in the case that the attribute by which a subset is defined, refers not only to the random variables on one side but – as in (7) – also to the ones on the other side, there does not occur any problem, because for setting up equation (7), only the *existence* of this attribute must be presupposed.

Hitherto we have only discussed the case where the angle between the polarization directions of the pairwise emitted photons is equal to $\pi/2$. The generalization to any desired angle ζ is trivial, because evidently the relation between the values of the amplitudes which pass through the polarizers to the left and to the right, depends in any case on the difference angle $(\zeta - \delta)$.

Thus I will just present the equation. It reads as follows:

$$w_{LR} = \frac{\pi}{n} \sum_{i \in I_{LR}} (X_i - 1/2) = 1/2 \ \cos^2(\zeta - \delta) \quad \left[= \frac{\pi}{n} \sum_{i \in I_{LR}} (Y_i - 1/2) \right] \tag{9}$$

Equation (9) produces in all possible cases results which are identical with the quantum mechanical ones. (E.g. from $\zeta = 0$ (which means that the measured photons have the same polarization) follows $W_{LR} = 1/2 \cos^2\delta$.)

1.5. Additional Notes

1. In this local model, it is presupposed that the discrete transitions in the detectors are caused by continuous accumulation of waves. From this follows that in general it is not possible to assign the electromagnetic waves that are underway simultaneously to a single such accumulation process, the consequence of which will then be the detection of a photon. Instead it must be assumed that they contribute to many such processes. Thus, in general, a transition which represents a *detected photon* cannot be traced back to a transition which represents a *generated photon* (or photon pair, respectively). This is the reason why – as in the example with the balls – Bell's inequality does not apply. More to that will immediately follow in the next section.

2. The waves with different polarization directions that are emitted as pairs can also originate *from one single decay.* (This assumption does not contradict quantum mechanics, where these waves don't even exist.)

3. Equations (6), (7) and (9) apply also in the case of a series of *single processes* (event pairs), which are experimentally separated from each other. However also in this case, there are at any time other simultaneously proceeding accumulation processes that have *not yet* led to transitions.

4. The model presented here is local in every detail: Pairs of waves are emitted during a transition between two different states of an object. They are polarized at a certain angle to one another and symmetrical in every other respect. Their amplitudes are reduced by polarizers with a given direction. The squares of these amplitudes represent the random variables X and Y. The event probabilities are expressed as functions of those random variables the carriers of which actually arrive at one of the two detectors.

In general the following applies: One can only be sure that there is no non-local connection between two measurements at different positions, if the entire causal chains are known that eventually lead to the values of those variables located directly at the positions of the measurements, by which the measurement values – which are defined as functions of them – are calculated. This presupposes in turn that both causal chains start at the same point. (Otherwise they would lead ever further into the past.)

Exactly these conditions are met here.

1.6. Why is Bell's Inequality not applicable here?

In the local model, it is assumed that in the detectors continuous accumulation processes are running simultaneously which later will lead to transitions (detected "photons").

Where and when transitions occur that correspond to detected photons depends on the waves which arrive at the detectors *and* on the specific conditions in the detectors. However in any case part of these conditions are the waves that come from antecedent decays and have *not yet* led to transitions.

It is obvious that, under these presuppositions, there cannot be any event pairs which are independent from the course of the experiment. However because of the importance of this fact I will go a bit more into detail.

If one would e.g. try to express the event pair with the number k as function of the waves which have arrived at the detectors since the event pair with the number k-1,[6] then this purpose must fail, because the k^{th} event pair does not only depend on *those* waves but also on the waves that have arrived at the detectors already before.

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[6] This would correspond to a *move* in the example with the balls given in 1.3.

Another possibility would be to assign to a photon event the set of random variables which contains exactly those variables that have *in fact* contributed to this specific transition.

So let A_k be the k^{th} event to the left, $A_k = 1$ (a photon is detected). Let $\{X\}_k$ be the set of random variables which caused this event. $\{X\}_k$ contains then not only waves from the k^{th} decay but also waves from the decay with the numbers 1 to k-1.

The chronological order of the emitted waves with different polarization directions changes with every experiment. Therefore, it depends on the specific course of the experiment, which random variables are contained in $\{X\}_k$. With $n \rightarrow \infty$ (n number of the random variables) the probability comes to zero that, in any other experiment with identical polarizer directions, the set $\{X\}_k$ will lead *again* to exactly *one* transition. With certainty, in any other experiment the random variables of $\{X\}_k$ will not cause one single transition, but contribute to many different transitions.

Thus also with this definition the events cannot be separated from the specific course of the experiment.

In fact there is no definition at all by which such a separation could be substantiated. Rather the following applies:

In the local model, there are no event pairs A and B which are independent of the course of the experiment and could therefore also occur in any other experiment. Instead there are pairs of events $A_k(E_m)$ and $B_k(E_m)$ which are *inseparably* bound to the course of the specific experiment E_m, which means that they can occur only in *this* experiment exactly at *this* point in time.

Therefore it is not possible to predict anything about the results of other measurements on the same objects.

In the interpretation of the scenario with entangled photons which serves as basis for the derivation of Bell's inequality, there is no such limitation. Here, every event pair is independent of all previous event pairs and, therefore, also independent from the course of the experiment. Thus the events are not bound to a specific experiment. Assumptions about other measurements on the same objects are permitted.

Exactly this difference between Bell's interpretation and the one presented here is the reason why it is not possible, to deduce any inequality of Bell's kind in the local model, because in order to deduce such an inequality, information about the results of the *one* experiment that was actually performed does not suffice – in any case information about other measurements *on the same objects* is involved.

To conclude the issue, this shall now be demonstrated using Bell's paper[7] from 1964 as an example.

In the following, λ stands for any variables, which the measurement results A and B can depend on in any possible way. ($A = \pm 1$, $B = \pm 1$; +1 means: photon, −1: no photon.)

$\vec{a}$, $\vec{b}$ and $\vec{c}$ are unit vectors in the directions of the polarizer planes. ρ is the normalized probability distribution of λ. $P(\vec{a},\vec{b})$ is the expected value of the product of A and B.

Just before the end of the derivation, we find the equation

$$P(\vec{a},\vec{b}) - P(\vec{a},\vec{c}) = -\int d\lambda\, \rho(\lambda) \left[A(\vec{a},\lambda)\, A(\vec{b},\lambda) - A(\vec{a},\lambda)\, A(\vec{c},\lambda) \right] =$$

$$= \int d\lambda\, \rho(\lambda)\, A(\vec{a},\lambda)\, A(\vec{b},\lambda) \left[A(\vec{b},\lambda)\, A(\vec{c},\lambda) - 1 \right]$$

Here it is presupposed that $A(\vec{b},\lambda)\, A(\vec{b},\lambda) = 1$, which, in the usual view (and notation!), appears as a matter of course.

But in the local model, the two expressions $A(\vec{b},\lambda)$ are *not* identical. As the following steps of the derivation show

$$\Rightarrow \quad \left| P(\vec{a},\vec{b}) - P(\vec{a},\vec{c}) \right| \leq \int d\lambda\, \rho(\lambda) \left[1 - A(\vec{b},\lambda)\, A(\vec{c},\lambda) \right]$$

$$\Rightarrow \quad 1 + P(\vec{b},\vec{c}) \geq \left| P(\vec{a},\vec{b}) - P(\vec{a},\vec{c}) \right|$$

they must be assigned to events of two different experiments: the first one to an event of an experiment with the polarizer directions ($\vec{a}$, $\vec{b}$) and the second one to an event of another experiment

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[7] John Stewart Bell, *On the Einstein Podolsky Rosen Paradox*, Physics, 1, 195-200 (1964). (Bell's proof relates to spin ½ particles. However it applies also to photons.)

with ($\vec{b}$, $\vec{c}$). However in the local model, as demonstrated just before, no conclusion is possible from the event of the first experiment to the event of the second experiment. The assumption $A_k(E1) * A_j(E2) = 1$ is not permitted for any (k, j).

Thus the derivation of the inequality fails, and the same applies, as mentioned above, for any inequality of this kind.

1.7. Summary, Closing

To anyone who is not familiar with the EPR scenario, the deliberations of the last two sections may have seemed rather complicated. Fortunately, the actual reason why a local interpretation has been ruled out by the hitherto prevailing view of the EPR paradox and why it is possible in the new interpretation is actually very simple.

So let us finally compare the common view of the course of an experiment with entangled objects with the view which the alternative local model is based on:

In the common view, there are pairs of entangled objects which cause pairs of events. After every event pair, the respective physical process is completely finalized, and with the next decay a new process starts that is totally independent of all the previous ones. Every experimental series is a sequence of such processes that are independent from each other.

If one adds to that – as EPR did – the condition **A1** from Section 1.3 (the independence of the measurements on both sides), then also the condition **A2** (statements about further measurements on the same objects are possible) is met, and Bell's Inequality can be derived. *Locality is ruled out*.

In the alternative local model, this is completely different. Indeed, also here both sides are independent from one another, and the measurement result is determined already before the measurement – however it depends not only on the current object-pair but also on the whole preceding course of the experiment.

Thus the series of measurements in an experiment is no longer a sequence of separate processes that are finished with the according measurement result – rather the whole experiment must be seen as *one total process* where any previous measuring procedure affects any later one. (In the same way as in the illustrative example with the balls.)

No event pair can be separated from such a specific total process. [8]

Then, however, the condition **A2** is not met: predictions about further measurements on the same objects are not permitted, and Bell's Inequality cannot be derived. *Locality is possible.*

Of course, also in the local model the entanglement condition must be satisfied – this is the objective of the function through which the quantum mechanical predictions are reproduced – but it applies only to pairs of events that occur during a certain measurement series. Statements about further measurements on any object pair of this series are not possible.

In short, the decisive point is the following one:

In the local model, the event pairs depend on the course of the experiment. But for the derivation of Bell's inequality, they would have to be independent of all other event pairs. Therefore, in the local model the inequality cannot be deduced.

Then, however, the proof of non-locality disappears, and the path to local descriptions is open. And using this openness leads in fact to success, as just demonstrated with the example of entangled photons.[9]

With this, the assertion is falsified that the measurement results on entangled photons cannot be generated by any theory with only local parameters. However the function presented in (9) does not make much physical sense, which however is without any relevance as regards the falsification. I chose it only because of its simplicity.

An understandable and physically meaningful solution – which however originates from the same scheme – will be presented after the interpretation of special relativity and the alternative description of both the Photoelectric and the Compton Effect, subsequent to the interpretation of quantum theory.

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[8] In the case of the measurement of a single event pair, the preparation of the experiment provides for the correctness of the predictions. (In other words: it makes sure that a series of such measurements leads to the predicted distribution of the measured values.)

[9] In the introduction, I said that the everyday language, augmented by some mathematics, is more appropriate for the solution of some problems than the physical terminology. The local solution of the EPR paradox is an example for that: If the 2-photon system is seen as a vector in the product space of the 2-dimensional Hilbert spaces of the two particles, then the just performed deliberations are impossible. The reality that lies behind the formalism and substantiates it has vanished.

All these descriptions will turn out to be elements that unite to a mosaic, to a graphically intelligible model which permits to re-institute also other principles of reason – in the same way as it has just happened with the principle *locality.*

Note:

The problem of "impossibility proofs" is that they must apply *in all possible worlds*. The "set of possible worlds", however, is unknown.

Therefore it can happen – as has been demonstrated in the just performed refutation of Bell's proof of the impossibility of local descriptions of entangled systems – that a world is overlooked, which is out of sight not because of its strangeness or improbability, but simply because it is unreachable on the well-trodden interpretation paths.

I remind you once again of the ball example from 1.3, which illustrates the new view: Here, no strange or exotic reality is presented, but a completely understandable, local and objective reality – and of exactly this kind is the reality that underlies the quantum mechanical description of entangled systems.