Refutation of Bell's Proof of Non-Locality

Bell's proof (John Stewart Bell, *On the Einstein Podolsky Rosen Paradox*, Physics, 1, 195-200, 1964) relates to the so-called EPR-Paradox, named after the three authors (*Can quantum-mechanical description of physical reality be considered complete?* Phys. Rev. 47, 777, 1935).

To understand the paradox, a few facts will suffice:

(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 two momentums are interconnected in the same way as in classical physics, which means they are identical except for the sign. 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 *nonlocal* 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.

However, as John Bell showed almost 30 years later (John Stewart Bell, *On the Einstein Podolsky Rosen Paradox*, Physics, 1, 195-200, 1964), this apparently so reasonable EPR assumption – that the measurement result on B is determined already before the measurement on A, because it simply corresponds to an *attribute* of B – has a consequence that Einstein, Podolsky and Rosen had not expected.

Bell proved the following:

Provided that the EPR assumption is correct, there are experiments in which the measurement results deviate significantly from the predictions of quantum mechanics. Such experiments were carried out. The decision was clear: the predictions of quantum mechanics were confirmed, the EPR assumption was thus refuted. This means: *Before* the measurement on A, B has no definite momentum, *afterwards* it does have one. The measurement on A actually changed the state of B!

EPR had intended to argue for a *local reality,* i.e. for a reality in which an object cannot act on another, spatially distant object other than through a physical process. However Bell's intervention seems to have proven that there are also connections of a completely different kind: connections which are either mediated faster than light or which even exist without any mediation. Einstein called that "Spooky action at a distance".

John Bell formulated his proof as general as possible. In this generalized form of the proof, it is not necessary that "object properties" specify the measurement result in advance, instead it could be any parameters. In his own words: "Let this more complete specification be effected by means of parameters λ. It is a matter of indifference in the following whether λ denotes a single variable or a set, or even a set of functions, and whether the variables are discrete or continuous." (John Bell, lc, p. 196).

This generalization expands the scope of the proof. And since, apart from the assumption of the parameters λ (and of course logic and mathematics), no further assumptions are necessary for the proof, the following conclusion seems unavoidable:

Any reality that obeys the laws of quantum mechanics is non-local.

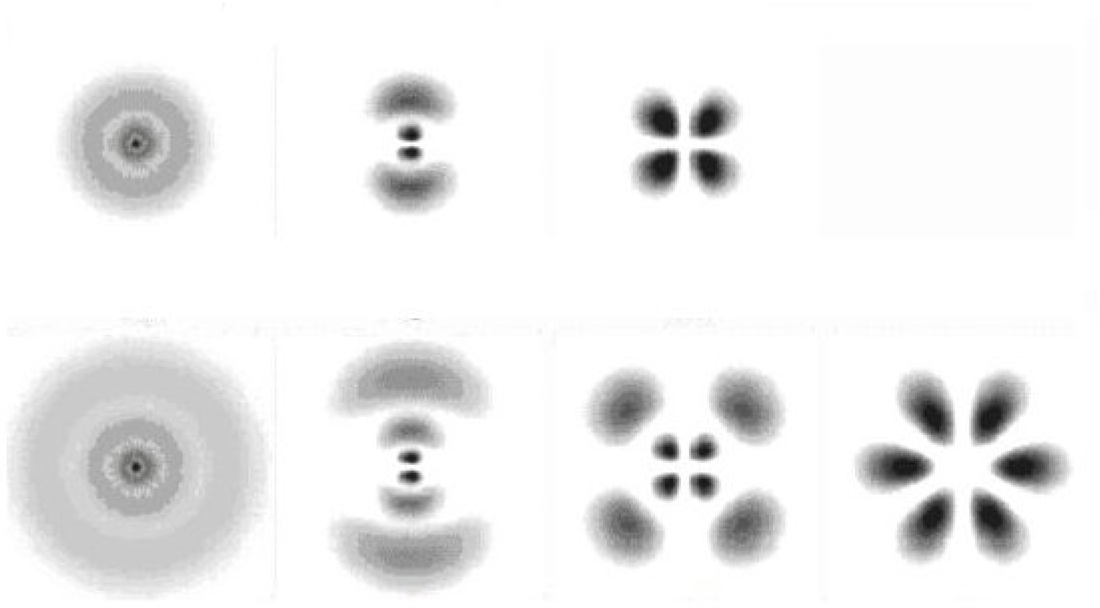
So much for the situation. In physics, the question of locality or non-locality is considered to be settled, and entanglement is a much-noticed, active area of research.

For us, however, the presentation of the usual point of view is only intended to serve as a preparation for our actual task, the answer to the question:

Why does Bell's proof not apply to our reality?

To answer this question, I will draw on the model which I developed in the analysis of the double-slit experiment; It allows a *realistic and local interpretation* of the experiment, which can be transferred to the EPR scenario. So I will briefly outline what, according to my interpretation, *actually* happens in this experiment. (For a more extensive explanation see *The Double-Slit Experiment – What Really Happens*.)

First, an electron detaches from an orbital (an electron shell). The following image shows the pictures of some orbitals:



As can be seen,*"electron shells"* correspond to *oscillation states of a sphere,* in other words: they ARE *three-dimensional standing waves.* If an "electron" is released from such a standing wave, then (so to speak) part of the *standing wave* becomes a *running wave.* The remaining standing wave has one nodal surface less. The electron – the running electron wave – then crosses the double slit. After the double slit, it diverges and interferes with itself. Finally it arrives at the detector plate, and this means: wherever its amplitude is not zero, it hits an orbital – a standing electron wave. Since it must be assumed that several of these standing waves are already close to the limit above which they "jump" to the next higher state – the state with one more nodal surface – the running wave will somewhere trigger such a jump with a certain probability, in other words: at this point an "electron" appears.

The rest of the running electron wave does not disappear as in the standard interpretation, but adds up to the other standing electron waves, whereby the probability increases everywhere that the next incoming electron wave or any subsequent one will cause a jump.

In order to establish the connection with the EPR scenario, let us consider the "object" we have just described, i.e. the "electron".

Let us first ask: *Does this electron have a definite position?*

To the electron that we finally observed on the detector plate, undoubtedly a relatively precisely defined position can be ascribed. But as we know, *this* electron is not *that* electron that was underway before. The newly created oscillation area in the standing electron wave, which in our view *is* the observed electron, contains only a tiny fraction of the entire running wave that the electron was before. The rest of the running wave is now distributed over all other standing waves.

So it is very clear: *The electron that we observe did not have a definite position before the measurement, because before the measurement this "electron" did not even exist!*

From this follows that the model concept which Einstein, Podolsky and Rosen's argument is based on, is completely inappropriate. They thought of an object that always remains identical with itself and moves on a path so that it has a definite position at all times. It is therefore evident that the EPR assumption (that the object attribute already exists before the measurement) is wrong.

What about the above-mentioned generalization in Bell's proof, in which the measured value is not determined by an object attribute but by arbitrary parameters λ?

This question leads us directly to the core of our refutation of Bell's proof. As follows:

As can be seen from the above quotation, Bell assumes the existence of parameters λ which ensure the "more complete" specification of the measured values for any measurements on the selected objects. ("More complete" because in quantum mechanics they do not exist or are "uncertain"). The existence of the parameters λ ensures that we can predict the exact measurement result in any case.

At the center of Bell's proof is an inequality that contains both the results of measurements that can actually be carried out, and the results of further, hypothetical measurements on the same objects. ("Hypothetical" because the measurement objects are of course not available again.)

This means:

The knowledge what results further measurements on the same objects would lead to is necessary for establishing the proof. Without this knowledge, there is no Bell proof.

Let us now return to our model. Is it possible here to predict the results of further measurements on the same objects?

Suppose we have created an electron. It crosses the double slit, diverges and interferes with itself. A tiny part of the electron induces a standing electron wave on the surface of the detector plate to jump to the next higher state. A black point can be seen there, indicating that an electron has appeared. We have measured the position of this electron.

Can we now carry out another measurement with the electron that we have generated just before? (It is *not* the one whose position we have just measured!) Of course not – this "electron" no longer exists because it is now distributed over all orbitals – but we can generate an electron that is almost identical to the one previously generated, and that is sufficient for our train of thought: We cannot carry out another measurement on the same object, but we can repeat the measurement process.

Now to the crucial question: what will happen when *this* electron reaches the detector plate? At which position on the detector plate will an electron appear?

The answer is: we cannot know. The position of the next jump – i.e. the next appearance of an electron – depends not only on the amplitude distribution of the wave that hits the plate, but also on how far the standing electron waves on the plate are away from the jump to the next state, and that is constantly changing. There is no measuring process in which, for all electron waves, the distances from this jump limit are equal to the distances that they have in any other measuring process. ("Distance" is defined here by how large the amplitude square of the impinging electron wave must be at least in order to trigger a jump to the next higher state).

In other words:

It is impossible to predict the exact position of the appearence of any electron.

What we have just shown for a position measurement in the double slit experiment also applies to the measurements of the attributes of entangled objects in EPR scenarios. Let us consider, for example, the case that has been best investigated experimentally: polarization measurements on entangled photons.

First the usual description: Photons are generated in pairs. On their way they reach polarizers which they cross with a certain probability. If they get through, they hit a detector and a photon is registered. If they don't get through, no photon will appear.

Now to the explanation of what is really happening. It follows the same principle as in the double slit scenario: Photons ARE light waves. When passing through the polarizers, their amplitudes decrease by the factor cos α (α is the angle between the direction of oscillation of the wave and the plane of the polarizer). When a light wave reaches the detector, it *possibly* causes a transition of a standing electron wave to a higher state – then a "photon" is detected. If there is no transition, the light wave still adds up to one or more electron waves and thereby increases the probability of a transition when the next light wave hits or one that follows later. This means: every later measurement is affected by every earlier one. Even if we were able to measure the same photon pairs again, it would not be possible to predict the measurement results.

Bell's proof would only be feasible if the test series consisted of measurements that are independent of one another. The following should therefore apply: as soon as a measurement result is available, the respective measurement process is completely finished and does not affect the further measurement processes. (If the order was altered, the measurement results would remain unchanged.)

This is obviously not the case in our model: As just explained, every light wave that reaches the detector changes some of the standing electron waves (orbitals) – even if this change does not lead to a jump to the next higher state. So, here, there are no test series that consist of individual events that are independent of each other, but only test series in which any subsequent measurement is influenced by any preceding one. Thus, the starting conditions of any individual measurement change in an unpredictable way, and this means:

There are no parameters λ from which the measurement results follow. Bell's proof cannot be derived.

In order to avoid any ambiguity here, I would like to emphasize the essential point again. Of course there are parameters in my model that completely determine each measurement result, but since these parameters also include how far the standing electron waves are away from the limit above which they jump to the next higher state, when an incoming light wave hits, these parameters do not meet the condition that must be fulfilled for Bell's parameters λ: Bell's parameters make the measurement on a certain object *repeatable*, they ensure that the results of further measurements on the same object are known. However, the "distances" from the jump limit change each time a new measurement is carried out (presumably they are also subject to constant fluctuations regardless of any measurement), and therefore also the result of the measurement on a certain object changes with each repetition. Thus there is no "more specific" prediction of any measurement – it sticks to the quantum mechanical probability.

We have thus achieved our goal. For this it wasn't even necessary to go into the proof itself – for our reasoning, the analysis of the measurement process was perfectly sufficient.

What is missing here, however, is a *detailed* description of what really happens in EPR test series. If the measured value cannot be predicted before the measurement – what actually ensures the connection between the measured values of the entangled objects?

In *The Concept of Reality*, I have given a formula for the event probabilities that is based on exclusively local parameters and that leads to the same results as quantum mechanics (see here). I think that the simplicity of this formula is already an indication that the specific type of entanglement is somehow contained in the experimental setup and thus also in the statistics of the resulting measurements. However, I refrained from describing the associated physical processes because, in my eyes, several additional assumptions make them unattractive. I believe that the path to a detailed understanding of what is really going on in EPR scenarios will only be possible with experimental support.

The decisive factor, however, is that we succeeded in refuting Bell's proof – or, better said, in overruling it. As a result, it is now possible to claim the locality of reality, just as Einstein had in mind.

I have to admit that this assumption has always appeared to me as an obvious demand of reason.

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