How Did Bohr Reply to EPR? *

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It is rather difficult to pinpoint how Bohr replied to EPR — To such a degree is Bohr's reply hazy. This seems to be the general impression that most physists have. John S. Bell wrote in a brief essay titled "The Position of Bohr" (Appendix 1 to his"Bertleman's Socks and the Nature of Reality") as follows:

> While imagining that I understand the position of Einstein, as regards the EPR correlations, I have very little understanding of the position of his principal opponent, Bohr. Yet most contemporary theorists have the impression that they themselves share Bohr's views!

He concludes the essay by censuring Bohr for committing a petitio principii: "Is Bohr just rejecting the premise —'no action at a distance'— rather than refuting the argument?" It is just because, he argues, Bohr neglects the essential point of EPR to the effect that even if the directly observable first system may be disturbed by an 'uncontrollable interaction', the value of a physical quantity of the second system can be, without in any way being disturbed, predicted with certainty.

This criticism is in line with his other one. Against EPR's criterion of 'reality', i.e.,if, without in any way disturbing a system, we can predict with certainty the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity, Bohr argues as follows. There is of course no 'mechanical disturbance' of the system, but "even at this stage there is essentially the question of an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system!" Bell's complaint is simply that he cannot make sense of the passage just quoted. If it

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means that by different experiments on the first system different kinds of information are given on the second system, he argues, it just neglects the other point of EPR — i.e.,"one could learn either the position or the momentum of the second system."

It is true that the target of Bohr's argumentation is to remove a premise of EPR. But what is meant to be removed is not the premise of 'no action at a distance'. He shares this with EPR. Sharing this with EPR, he removes the other premise which enables the following inference: one could learn either the position or the momentum of the second system, therefore the system possesses the definite values both for the position and for the momentum.

For EPR and Bell, the premise that justifies the inference is simply that of 'no action at a distance'. For Bohr, on the other side, a premise that makes the inference possible is this: a quantum system by itself possesses its physical properties. It is because the supposition of 'physical properties possessed by a system itself' is not permitted that a measurement on the first system prescribes the very conditions of preditability regarding the second one. To think that Bohr rejected EPR's premise of 'no action at a distance' is an utter misunderstanding on Bell's side.

It is on the possibility of a delayed-choice that Bohr based his arguments to preserve the premise of 'no action at a distance' and, at the same time, to abolish the one of 'physical properties possessed by a system itself'. To illustrate the delayed-choice, let's take a double-slit experiment. Did a photon come out through either one of the slits or through both of them simulateneously? To determine this, you have to either fix the first screen with a single slit so that a position-measurement can be made or suspend it by means of a weak spring so that a momentum measurement can be made. Well, there is no difference as regards the observable results between fixing (suspending) the first screen and fixing (suspending) the third screen which is waiting for the photon. It means that whether a photon passed through either one slit or both (of the second screen) can only be determined by the choice of an operation made after the photon has passed through. This is what is

called delayed-choice. If an operation made now were able to affect an event in the past, it would also have an instantaneous effect on the second system in a space-like separated region. But we cannot bring about the past.

Delayed-choice is possible. But changing the past is impossible. This apparent contradiction can be avoided if we require that "no elementary quantum phenomenonis a phenomenon until it is a registered phenomenon" (the gist of Bohr's view as coined by John A. Wheeler). The contradiction seemed to ensue, only because the system itself, abstracted from the whole experimental arrangement, was considered to have physical properties or to constitute a 'phenomenon' in the past. In this case, as was said above, there is nothing absurd in thinking that a measurement on one system in the case given by EPR has instantaneously changed the other one in a space-like separated region. But there is nothing of such a kind happening. Nothing can bring about the past and neither can a 'spooky action at a distance' take place.

Later in his life Bohr wrote a long essay "Discussion with Einstein on Epistemological Problems in Atomic Physics", in retrospect to what the issues of their ten year long discussion were and how he answered him. A remarkable fact about the essay is that he raises the possibility of a delayed-choice to the forefront and suggests that EPR's argument was settled when the photon box Gedankenexperiment, which Einstein had proposed in 1930 in order to throw doubt on the time-energy uncertainty relation, was solved.

> By further examining the possibilities for the application of a balance arrangement [suspending the photon-box], Einstein had perceived an alternative procedure which, even if they did not allow the use he originally intended, might seem to enhance the paradoxes beyond the possibilities of logical solution. Thus, Einstein had pointed out that, after a preliminary weighing of the box with the clock and the subsequent escape of the photon, one was still left with the choice [delayed-choice] of either repeating the weighing or opening the box and comparing the reading of the clock with the standard time scale.

Consequently, we are at this stage still free to [delayedly] choose whether we want to draw conclusions either about the energy of the photon or about the moment when it left the box. Without in any way interfering with the photon between its escape and its later interaction with other suitable [mutually exclusive] measuring instruments, we are, thus, able to make accurate predictions pertaining either to the momentum of its arrival or to the amount of energy liberated by its absorption. Since, however, according to the quantum-mechanical formalism, the specification of the state of an isolated particle cannot involve both a well-defined connection with the time scale and an accurate fixation of the energy, it might thus appear as if this formalism did not offer the means of an adequate description. [All the square brackets and a long underline are added.]

In the passage quoted Bohr does not simply exemplify EPR's argument by means of the photon-box example. A careful reading will show you that he is proposing, in the form of an exposition, his own answers by indicating these points: that the possibility of a delayed-choice is not that of changing a 'phenomenon' in the past, that a 'phenomenon' includes an 'interaction' with a suitable measuring apparatus, and that all that can be spoken about (i.e.its truth and falsity can be asked about) in quantum mechanics ought to be called 'phenomena'. This is why he thought it sufficed only to claim that "in the problem in question we are not dealing with a single specified experimental arrangement, but are referring to two different mutually exclusive arrangements." Even at the stage where EPR's essay is to be discussed he simply says that "the trend of the argument was in substance the same as that exposed in the foregoing pages." EPR's paper did not have an argument that presented a new kind of problem to Bohr.

Bohr was able to share with EPR the premise of 'no action at a distance', just because he gave up the realist claim of postulating 'the physical quantities possessed by a system itself' by making the epistemolgical switch to another realist claim to the effect that only 'phenomena' (in his technical sense) can be spoken of in quantum mechanics. It was his insight into the possibility of a delayed-choice that

turned his resignation into a conviction.

References

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