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What did Bohr really mean?

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A Clash of Quanta:
a mini-course and a round table
on the interpretation(s) of Quantum Mechanics
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Bohr against EPR

Of course there is in a case like that just considered no question of a mechanical disturbance of the system under investigation during the last critical stage of the measuring procedure. 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 future behavior of the system*. Since these conditions constitute an inherent element of the description of any phenomenon to which the term '"physical reality" can be attached, we see that the argumentation of [EPR] does not justify their conclusion that quantum-mechanical description is essentially incomplete.

N Bohr, "Can quantum-mechanical description of physical reality be considered complete?", *Physical Review* **48**, 696-702 (1935)

What is the quantum theory for?

[…] **the whole point of the formalism of the quantum theory is to deduce probabilities of observations that are made under given experimental conditions**. […] all contradictions are eliminated by the mathematical consistency of the formalism while the completeness of the description, in the domain where it can be used, is expressed by its applicability to any experimental set-up.

N Bohr, Atomfysik og menneskelig erkendelse II p 116, Schultz, Copenhagen, 1964
[translation from the Danish E.A.]

What is an experiment?

The deciding point is here the recognition of that the description of the experimental set-up and the registration of our observations have to be done in normal language, finessed as required with standard physical terminology. This is a simple logical requirement as we by the word “experiment” can only mean a **way forward where we are able to communicate to others what we have done and what we have learnt**.

N Bohr, Atomfysik og menneskelig erkendelse II p 13, Schultz, Copenhagen, 1964
[translation from the Danish E.A.]

What is the wave function?

In the treatment of atomic problems the calculations are most comfortable done with the help of a Schrödinger state function, from which the statistical laws, that hold for observations which can be made given conditions, can be deduced by definite mathematical operations. **One should however clearly realize that we are here dealing with a purely symbolic method of calculation, the unambiguous physical interpretation of which in the end requires reference to a completely determined experimental set-up**. Not taking this into consideration has sometimes introduced confusion.

N Bohr, Atomfysik og menneskelig erkendelse II p 16, Schultz, Copenhagen, 1964
[translation from the Danish E.A.]

Exegesis of Bohr-EPR

No mechanical disturbance means that no non-local (faster-than-light) physical interactions are considered.

An influence on the very conditions… and "…*possible types of predictions regarding future behavior of the system*" and, finally, "…*an inherent element of the description of any phenomenon*…" all mean to say that a reference to an experimental set-up specifying what is to be measured is needed.

Since these conditions constitute an inherent element... means that in Bohr's view the EPR argument is not (completely) within quantum mechanics because their paradox posits reality to phenomena with no experimental set-up to measure them.

EPR, QM and relativity

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Locality *is* a very natural notion. One can find statements closely similar to Einstein's in the EPR debate by physicists who are otherwise known adherents of the Copenhagen view.

> It is one of the fundamental principles of physics (indeed, of all science) that experiments that are sufficiently separated in space have unrelated results. The probabilities for various collisions measured at Fermilab should not depend on what sort of experiments are being done at CERN at the same time. If this principle were not valid, then we could never make any predictions about any experiments without knowing everything about the universe.

S. Weinberg The Quantum Theory of Fields: Volume 1 Foundations, Cambridge University Press (1995), page 177

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Other forgotten earlier thinking to be revived?

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Field measurements

[…] the field components at each space-time point […] is an idealization that only has a restricted application in quantum theory […] the interpretation of individual measurement results require a still greater caution in the case of field measurements […]

N Bohr, L Rosenfeld "On the question of the measurability of electromagnetic field quantities", *Mat-fys Medd Dan Vid Selsk* **12** (1933)
Transl A Petersen, in *Selected Papers of Léon Rosenfeld* and Wheeler & Zurek (1983)

By an informal survey I have found that this (long and difficult) argument of Bohr to be largely forgotten. Two recent exceptions:

F Dyson "Is a Graviton Detectable?", *International Congress of Mathematical Physics* (2012)
G Baym, T Ozawa, "Two-slit diffraction with highly charged particles: Niels Bohr's consistency argument that the electromagnetic field must be quantized", *PNAS* (2008)