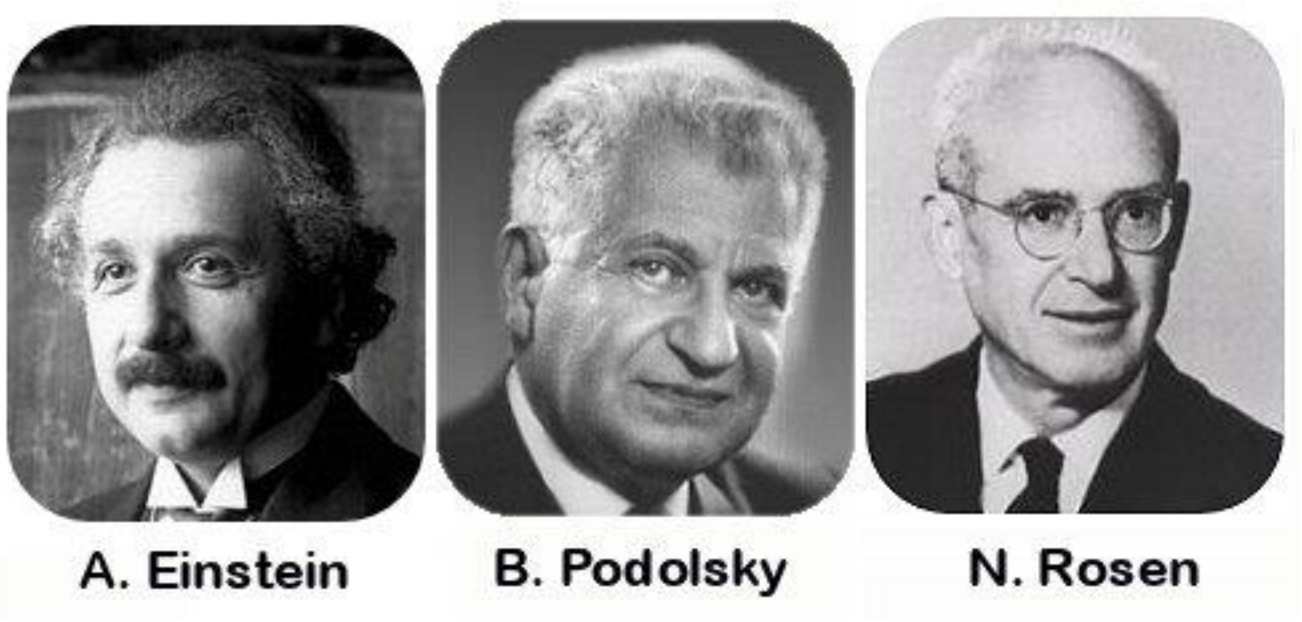
EPR paradox



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Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

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- ranked by impact, EPR is among the top ten of all papers ever published in *Physical Review* journals
- According to Bohr’s views at that time, observing a quantum object involves an uncontrollable physical interaction with a measuring device that affects both systems.
- Einstein began to probe how strongly the quantum theory was tied to irrealism and indeterminism.

- **Einstein**:
- *Quantum mechanics is very impressive. But an inner voice tells me that it is not yet the real thing. The theory produces a good deal but hardly brings us closer to the secret of the Old One. I am at all events convinced that He does not play dice.*

-Letter to Bohr

- **Bohr :**
- *There is no quantum world. There is only an abstract physical description. It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature.*

-Bulletin of the Atomic Scientists

Can all physically relevant truths about systems be derived from quantum states?

complete, the following requirement for a complete theory seems to be a necessary one: *every element of the physical reality must have a counterpart in the physical theory.* We shall call this the condition of completeness. The second question

reasonable. *If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.* It

-concept of the state
-wave function ψ

$$A\psi = a\psi$$

$$\psi = e^{(2\pi i/h)\,p_0 x}$$

$$p = (h/2\pi i)\partial/\partial x$$

$$q\psi = x\psi \neq a\psi$$

$$P(a,b) = \int_a^b \bar{\psi}\psi dx = \int_a^b dx = b - a$$

From this follows that either (1) *the quantum-mechanical description of reality given by the wave function is not complete* or (2) *when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality.*

-2 systems which we permit to interract

$$\Psi(x_1, x_2) = \sum_{n=1}^{\infty} \psi_n(x_2) u_n(x_1)$$

- Observable A is measured has the value a_k

$$\psi_k(x_2) u_k(x_1)$$

- Consider another observable B, after measure we obtain value b_r

$$\Psi(x_1, x_2) = \sum_{s=1}^{\infty} \varphi_s(x_2) v_s(x_1)$$

Thus, *it is possible to assign two different wave functions* (in our example ψ_k and φ_r) *to the same reality* (the second system after the interaction with the first).

- suppose that the two systems are two particles

$$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} e^{(2\pi i/h)(x_1 - x_2 + x_0)p} dp$$

- let A be momentum of the first particle, its eigenfunctions corresponding to the eigenvalue p will be

$$u_p(x_1) = e^{(2\pi i/h)px_1}$$

Since we have the case of continuous spectrum:

$$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} \psi_p(x_2) u_p(x_1) dp$$

where

$$\psi_p(x_2) = e^{-(2\pi i/h)(x_2 - x_0)p}$$

is the eigenvalue of operator $P = (h/2\pi i)\partial/\partial x_2$

corresponding to the eigenvalue –p

- B is coordinate of the first particle, it has for eigenfunctions:

$$v_x(x_1) = \delta(x_1 - x)$$

In this case we become: $$\Psi(x_1, x_2) = \int_{-\infty}^{\infty} \varphi_x(x_2) v_x(x_1) dx$$

where $$\varphi_x(x_2) = \int_{-\infty}^{\infty} e^{(2\pi i/h)(x - x_2 + x_0)p} dp$$

$$= h\delta(x - x_2 + x_0)$$

This φ_x is the eigenfunction of the operator $Q = x_2$

Corresponding to the eigenvalue $x + x_0$ of the second particle

- We have shown: $PQ - QP = h/2\pi i,$

- ψ_k and φ_r are eigenfunctions of noncomuting operators
- eigenvalues p_k and q_r
- by measuring A or B we can predict with certainity
- P,B-elements of reality
- ψ_k and φ_r belong to the same reality

From this follows that either (1) *the quantum-mechanical description of reality given by the wave function is not complete* or (2) *when the operators corresponding to two physical quantities do not commute the two quantities cannot have simultaneous reality.*

Thus the negation of (1) leads to the negation of the only other alternative (2). We are thus forced to conclude that the quantum-mechanical description of physical reality given by wave functions is not complete.

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Can Quantum-Mechanical Description of Physical Reality be Considered Complete?

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It is shown that a certain "criterion of physical reality" formulated in a recent article with the above title by A. Einstein, B. Podolsky and N. Rosen contains an essential ambiguity when it is applied to quantum phenomena. In this connection a viewpoint termed "complementarity" is explained from which quantum-mechanical description of physical phenomena would seem to fulfill, within its scope, all rational demands of completeness.

EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.

- 1951 David Bohm –dissociations of a diatomic molecule

$$\mathcal{H} = J\,\mathbf{S}_1 \cdot \mathbf{S}_2$$

$$E = \frac{J}{4} \quad \text{(3 times) and } -\frac{3J}{4}$$

$$\psi_1 \equiv \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad \psi_2 \equiv \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \\ 0 \end{pmatrix} \quad \psi_3 \equiv \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \quad \psi_4 \equiv \begin{pmatrix} 0 \\ \frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} \\ 0 \end{pmatrix}$$

Bell's Inequality (1964)

(experimentally Aspect and co-workers, 1981)

"There does not exist any local hidden variable theory consistent with outcomes of quantum physics"

Consequences

- Entanglement is not paradossal
- Quantum correlations in an EPR pair are "stronger" than classical correlations

Ďakujem za pozornosť