Quantum Mysteries

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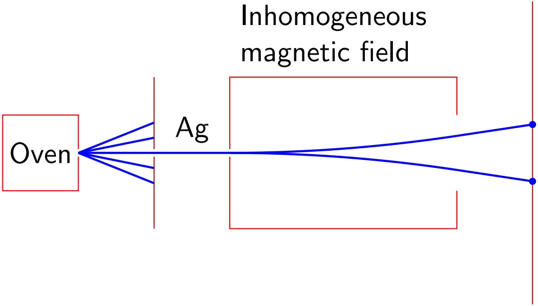
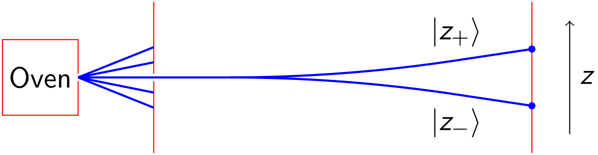
Stern-Gerlach experiment (1922)



- expect a range in amount deflection
- get exactly *two* types of deflection
- puts the *quantum* in quantum mechanics

The Superposition Principle



- Particles that deflect up have state $|z_+\rangle$.
- Particles that deflect down have state $|z_-\rangle$.

Prior to the deflection, the particle can be in a *superposition* of $|z_+\rangle$ and $|z_-\rangle$.

$$|\psi\rangle = \frac{3}{5}|z_+\rangle + \frac{4}{5}|z_-\rangle$$

The coefficients $\frac{3}{5}$ and $\frac{4}{5}$ are probability amplitudes.

Probability and probability amplitude

Suppose a silver atom has the state

$$|\psi\rangle = \frac{3}{5}|z_+\rangle + \frac{4}{5}|z_-\rangle .$$

If we measure in the z direction, the probability of the result "up" is

$$\left|\frac{3}{5}\right|^2 = \frac{9}{25} = 0.36$$

and the probability of the result "down" is

$$\left|\frac{4}{5}\right|^2 = \frac{16}{25} = 0.64.$$

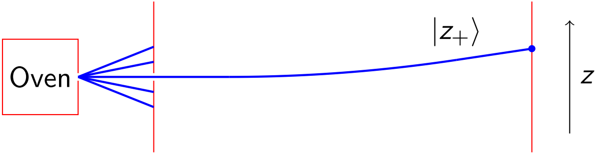
Probability is the square of the magnitude of the probability amplitude.

Collapse of the wavepacket

Suppose a silver atom has the state

$$|\psi\rangle = \frac{3}{5}|z_+\rangle + \frac{4}{5}|z_-\rangle .$$

If we measure in the z direction, and obtain the result "up",



then the state after measurement is

$$|\psi\rangle = |z_+\rangle .$$

We say that the state has collapsed to $|z_+\rangle$.

The measurement problem

Measurement in conventional quantum theory is different because the superposition principle holds together alternative, and eventually mutually exclusive, possibilities right until the last moment, when suddenly one of them alone surfaces as the realized actuality on this occasion. (Polkinghorne, page 44)

How does this come about? (Polkinghorne, page 45)

What settles that this time the answer shall be "up" and not "down"? (Polkinghorne, page 46)

The essence of the measurement problem is the search to understand the origin of this specificity. (Polkinghorne, page 46)

Responses to the measurement problem

- Irrelevance
  - QM needs no interpretation
- Large systems
  - Copenhagen interpretation
- New physics
  - not an interpretation
- Consciousness
- Many worlds
- Determinism
  - Bohmian mechanics

4 of the responses are *interpretations* of quantum mechanics

EPR

of lanthanum is 7/2, hence the nuclear magnetic moment as determined by this analysis is 2.5 nuclear magnetons. This is in fair agreement with the value 2.8 nuclear magnetons determined from La III hyperfine structures by the writer and N. S. Grace.[9]

[9] M. F. Crawford and N. S. Grace, Phys. Rev. **47**, 536 (1935).

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

A. Einstein, B. Podolsky and N. Rosen, *Institute for Advanced Study, Princeton, New Jersey*

(Received March 25, 1935)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

1.

Any serious consideration of a physical theory must take into account the distinction between the objective reality, which is independent of any theory, and the physical concepts with which the theory operates. These

Whatever the meaning assigned to the term *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

EPR

If you measure particles 1 and 2 in the same direction, they always have opposite results.

Particle 1	
Measurement	Result
z	$\uparrow$
z	$\downarrow$
x	$\rightarrow$
x	$\leftarrow$

Particle 2	
Measurement	Result
z	$\downarrow$
z	$\uparrow$
x	$\leftarrow$
x	$\rightarrow$

EPR

Einstein
We can measure x on 1 and z on 2 and know both x and z results for both.

Others
Measurement on 1 produces instantaneous change at 2.