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Does Special Relativity Contradicts Quantum Mechanics?

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Introduction

The average theoretical physicist will answer this question immediately with "No". However, the great majority of people working on the foundations of quantum mechanics, think that there is such a contradiction. All sort of ideas, most of them quite complicated, or even absurd, are suggested to meet this pseudo-problem

We shall show in this talk that all this is based on misunderstanding; the average physicist is right; there is no contradiction.

My general research program

This talk describes a small part of my present research program, which uses a new method of studying the interpretation of quantum theory.

For this I have developed a formalism, which describes side by side classical and quantum physical systems. It is completely equivalent to the usual formalism, but makes it possible to view matters from a new angle.

It is eminently suitable for the purpose of studying foundational questions, and leads to unexpected, even provocative results. I shall say more on this further on in my talk.

The problem

Suppose we measure an observable a, find a certain value α, and then do a little bit later a second measurement of a different observable b and find a value β for this. It is believed that the same value is also found by a second observer, at a great distance. This is supposed to be instantaneously, which is in contradiction with Einstein's theory of special relativity, according to which no information can be transmitted faster than the velocity of light. Einstein could not believe this; he called this "Spooky action at a distance".

Solution of the problem

The problem is caused by confusing of what is objective and what is subjective knowledge. The instantaneous result of the measurement of a and b at a great distance is for us a subjective fact. An observer at the far away place will find his result not at the same time as we do – that would indeed be forbidden by special relativity. It is for him (or her) an objective fact.

An example

John Stuart Bell (1928-1990), a particle physicist from Northern Island, gave the following example.

Suppose the queen of England dies suddenly in her palace in London. The crown prince, who happens to be traveling in Australia will be immediately the new king. Of course he will not know this at the same moment. His being the new king is our subjective knowledge. He will immediately be told by telephone of the death of his mother. Due to special relativity, this message will reach him a bit later. The slightly retarded knowledge of this is an objective fact for him.

This illustrates what the solution of Einstein's paradox of "Spooky action at a distance" is.

The interpretation of quantum theory

There is an enormous literature on the foundations of quantum theory, with many conflicting interpretations.

We shall briefly discuss here a new *minimal* interpretation, as we call it, because of its simplicity and also because it is very effective.

We define for this an *algebraic dynamical system (ADS)*, which, for what we need here, describes simultaneously classical and quantum systems, and which is completely equivalent to the usual formalism.

It has four basis axioms:

1. A definition of the observables of a system.
2. A definition of a state of a system.
3. The interpretation of 1 and 2.
4. Time development.

The main axioms

1. The observables a of a system consist of the elements of a complex associative unitary algebra $\mathcal{A}$.

2. The state of the system is a positive normalized linear functional ω on $\mathcal{A}$ (expectation functional).

3. A state ω defines for each observable $a \in \mathcal{A}$ an average value $\alpha = \omega(a)$, and in fact a complete probability distribution $P_a^\omega(\alpha)$.

4. Time development is described by a 1-parameter group of automorphisms of the algebra of observables.

Note that all this applies to classical as well as quantum systems. Here we discuss only quantum systems.

Density operators and wave functions

It is not difficult to prove that a consequence of axiom 2 is that $\omega(a)$ can be uniquely written as

$$\omega(a) = Tr(\mathrm{D}a),$$

This is the general case, a mixed state (quantum statistical mechanics). In the special case D is just a single 1-dimensional projection, on a unit vector ψ, defined up to a phase factor, and to be called E_ψ. We then have $\omega(a) = (\psi, a\psi)$, with ψ the usual wave function.

I shall only look at this special case.

Surprising results

By using our approach we can show that things that are widely discussed in the literature, just do not exist, or are irrelevant. I have in mind the following three examples:

a. The 'Collapse of the Wave Function'.

b. 'Schrödinger's Cat'.

c. The 'Measurement Problem'.

These three cases will be briefly discussed next.

The collapse of the wave function

Many authors believe that when an observable a is measured, the wave function suddenly collapses.

What happens actually?

Our knowledge of the system at every instant of time consist of a time-dependent probability distribution $P_a^\omega(\alpha, t)$, for every observable a.

When we measure a at $t = t_1$, we find a sharp value $\alpha = \alpha_1$.

Instead of a probability we now have certainty. The distribution has disappeared or has become trivial.

That is all. Exactly like in classical probability, where one does not use the term 'collapse'.

Schrödinger's cat

Another show piece in discussions on the foundations of quantum theory. It is a thought experiment, due to Schrödinger, to counter the ideas of Einstein.

A living cat is placed in a closed box. In this there is some radium. When this decays, a small container of poison is hit. The cat dies.

As long as we have not opened the box, we dot not know whether the cat is alive or death.

One says that there is a superposition of a living and a dead cat.

This does not make sense.

The correct description of this thought experiment:

We assume that in general quantum theory is the underlying description of every physical system.

However, when there is no observable difference between the classical and the quantum description, we should use the simplest one, i.e. by classical theory (Ockham's Razor).

In this thought experiment there are only two relevant variables, the cat alive (1) or the cat dead (2).

Furthermore, we may replace the radium by some classical stochastic device.

This makes the situation completely classical.

Conclusion:

The Schrödinger Cat is a simple classical stochastic process, which, as a thought experiment, has nothing to do with quantum theory.

The measurement problem

There are various forms of the measurement problem, none of which I completely understand.

One possibility is that it means that one considers a coupled system, consisting of the original quantum system together with the classical system with the observer. Fine.

But then there should be a third system observing this coupled system. Ad infinitum....

Philosophical remark

What do we mean by reality?

The various answers can be represented by points on a straight line.

- On the far left we have the 'naive' idea of reality.

It is that things exists independent of a observer. This was Einstein's idea.

"Is the moon there when nobody looks at it?"

- On the far right there is *solipsism*, which holds that observing reality is purely subjective.

Every individual person sees his own reality, with no connection with others.

Completely logical; totally absurd.

- To the left there is Emmanuel Kant.

"Das Ding an Sich" cannot be known.

Our senses determine what we know of reality.

- This is, more or less, also my point of view.

As long as not making an explicit observation, not doing a measurement, we know nothing of the existence of an object, or about its properties.

We obtain knowledge, maybe only a probabilistic knowledge, by a measurement.

- The content of Bohr's and Heisenberg's Copenhagen interpretation is similar, minus Bohr's notion of complementarity.

In any case, it is always difficult to know what Bohr meant.

In his younger years Bohr did very important work. Later he became a prophet, with many followers, who appreciated the more and more vague papers that he wrote.

It was the same with Eugene Wigner. Brilliant work when he was young. Then more and more vague philosophical papers.

Entanglement

A notion introduced by Schrödinger, in his battle with Einstein.

As usual it was thought that it had deep connections with various aspects of foundational matters.

This is not so. It is a simple matter of constructing many particle states.

Basic example:

Two spin 1/2 particle ψ_1 and ψ_2, for which the position is neglected.

They live in 2-dimensional complex Hilbert spaces $\mathcal{H}_1$ and $\mathcal{H}_2$.

A 2-particle state is, in first instance, a 4-dimensional tensor product, the direct sum of a symmetric and an anti-symmetric part,

$$\mathcal{H}_1 \otimes \mathcal{H}_2 = (\mathcal{H}_1)_s \oplus (\mathcal{H}_1)_a.$$

Because of Fermi's Exclusing Principle, only the symmetric part survives.

This state $(\mathcal{H}_1)_a$ is an *entangled* state. It is made from ψ_1 and ψ_2, but does no longer contain these states.

That is all.

The methods of physics

What do we concretely mean doing physics?

Answer: trying to understand what happens in a certain physical situation.

For this one constructs, in a trial and error method, a *theory*, i.e. a rigorous and consistent mathematical model. Significant parts of this model are connected with aspects or parts of the physical situation.

This is the *interpretation* of the theory.

Further reading

A much more extensive discussion of the foregoing material can be found in a discussion piece that I have written, and that can be requested from

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