Quantum Mechanics: The Philosophical Interpretation

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Most of our discussions this semester have been on what Quantum Mechanics says, but not much on what it means.

The philosophical interpretations of quantum mechanics are just as important because this is how we make sense of what is going on, and our understand how it effects reality.

The Wave Function

- The way quantum mechanics obtains solutions to a particles position, velocity, etc. is by solving the Schrodinger equation to get the particle's wave function.

$$H\Psi = E\Psi \quad \rightarrow \quad \Psi(x,t)$$

- The wave function represents the state of a particle. However, it seems rather odd that a wave function, which is spread out in space, represents the state of a particle...

The Statistical Interpretation

- Born's statistical interpretation makes sense of this by stating that the wave function is a probability distribution of finding the particle at a particular point x and time t.
- This interpretation has introduced the indeterminacy of quantum mechanics - we cannot be certain of a particles' position even with all of the information given.
- This has disturbed physicists as well as philosophers, and has sparked a debate on whether this indeterminacy is a fact of nature or a defect in the theory.
- We wonder whether the system had the attribute in question to begin with, or if the act of measuring created the property.
- There are multiple positions that have been taken to answer this question, with three of them being the most plausible.

The Three Interpretations

Consider this question: Suppose the measured position of a particle is point P. Where was the particle located the instant just before this measurement was performed?

The three most plausible responses to this question are:

- *Realist*: The particle was at point P prior to the measurement.
- *Orthodox*: The particle wasn't anywhere to begin with, but the act of measuring forced it at point P.
- *Agnostic*: Refuses to answer because this is an impossible question.

Agnostic

- This position asserts that there is no sense in making assertions about the particle before a measurement when the only way to confirm a prediction is through measurement.
- The question on the location of the particle prior to the measurement is a metaphysical question because it cannot be tested.
- This was dis-proven when J.S. Bell demonstrated that there is an observable difference between the particle having a position prior to the measurement or not.
- Bell's Theorem eliminated the agnostic position and made the question on whether to accept the realist or orthodox position an experimental one.

Realist

- Takes on the view that the particle already had the property in question prior to the measurement.
- If this is true, it means that quantum mechanics is incomplete because it was not able to tell us the outcome of the measurement with certainty.
- A realist would assert that the indeterminacy posed in the statistical interpretation doesn't say anything about the nature of these particles. Rather, it is a demonstration of our ignorance.
- Einstein, Podolsky, and Rosen took on this point of view, and published the EPR paradox in 1935 in an attempt to prove it.

Griffiths describes a simplified version of this introduced by David Bohm:

- Consider the decay of a pi meson into and electron and a positron.

$$\pi^0 \rightarrow e^+ + e^-$$

- Assume the pion was initially at rest, and the electron and positron fly off in different directions.
- The pion has spin zero, so conservation of angular momentum dictates that the electron and positron must have opposite spins. Therefore they must be in the singlet configuration:

$$\frac{1}{\sqrt{2}}((\uparrow_-\downarrow_+) - (\downarrow_-\uparrow_+))$$

The EPR Paradox

Suppose that the particles fly off in opposite directions. Even if the particles are a considerable distance apart, if the electron is measured to have spin up, the positron will be measured to have spin down, and vise-versa.

- A realist won't see anything wrong with this because they would assert that the particles had these properties all along.
- The orthodox view holds that they didn't have these properties until the measurement was performed, and that the act of measuring instantaneously produced the measurement, whether the particles were 10 meters or 10 light years apart.
- Einstein called this "spooky action-at-a-distance" preposterous, and held that the orthodox interpretation is wrong. He held the realist view that the particles had to have had their spin properties all along.

Locality

- Einstein's argument rests on the assumption that no influence can propagate faster than the speed of light.
- This assumption is concerning when considering a case where the particles are a considerable distance apart (10 light years).
- At this distance, if someone measure the spin of the electron to be up, then there's a chance the positron could also be measured with spin up. This is a violation of the conservation of angular momentum.
- Einstein argued that this violation could be accounted for by asserting that these properties existed from the time the particles were created.
- This argument was used as an attempt to prove the realist position, although experiments heavily favor the orthodox position.

Orthodox

- Takes on the view that the particle does not have a precise position (or other measured value), and the act of measuring actually creates the result we find.
- It also states that if the same measurement is repeated on the same particle, it must return the same value.
- In order to account for this, we are forced to assume that measurements collapse a particles' wave function.
- If this view is correct, it means that there's something strange about the act of measuring.
- Although this is the standard view in physics textbooks, it is not very good and needs revision.

Entanglement

- Instantaneous collapse of a particle's wave function, even at a considerable distance, gives rise to the idea of entanglement.
- This describes a phenomenon where pairs or groups of particles have interacted in a way such that the quantum state of one of the particles cannot be described independently of the other.
- When the electron and positron are generated from pion decay, they are entangled. Because they are entangled, the spin of one cannot be independent of the other.
- Problem 12.1 in Griffiths provides a proof that entangled particles cannot be described independently of one another.

Entangled States (Problem 12.1 in Griffiths)

Entangled State: A two particle state that cannot be expressed as the product of two one-particle stats.

Example of an entangled state (singlet spin configuration):

$$\frac{1}{\sqrt{2}}\left((\uparrow_-\downarrow_+) - (\downarrow_-\uparrow_+)\right)$$

Consider a two level system $|\phi_a\rangle$ *and* $|\phi_b\rangle$ with $\langle\phi_i\rangle\,\phi_j = \delta_{ij}$

Prove that the two-particle state

$$\alpha\,|\phi_a(1)\rangle\,|\phi_b(2)\rangle + \beta\,|\phi_b(1)\rangle\,|\phi_a(2)\rangle$$

cannot be expressed as a product

$$|\psi_r(1)\rangle\,|\psi_s(2)\rangle$$

for any one particle states $|\psi_r\rangle$ *and* $|\psi_s\rangle$