On the measurement problem in quantum mechanics

Elisabeth Andriantsarazo

What is the measurement problem (in briefness)

- How should one evaluate quantum states? How and why does a wave function reduce?
- Can one obtain additional information about a state? (EPR: the description provided by QM is incomplete and needs to add hidden variables)
- If one had access to this additional information, could one precisely determine the outcome?
- What is the difference between subject and object in QM?
- And can these problems be solved by a different approach? (Bohmian mechanics)

DISCLAIMER

- I am not telling you what to think, please form your own opinion. I am just providing what I learned about this interesting topic.

Quantum state evaluation

- QM system has observables represented by Hermitian operators in complex linear vector space, QM state itself is represented by a vector in this space
- Measurement of an observable yields an eigenvalue
- The quantum formalism is hence a “measurement” formalism
- Reduction of the wave packet: no mechanical arguments for this process (is could be just a mathematical convenience with no real consequences)
- Is there really no quantum reality, only abstract description with observations producing what is measured?

The pilot wave theory

- de Broglie, and later David Bohm, refused to give up on classical understanding of reality and created ”the most physical theory out there”
- The pilot wave: $(\psi, \mathbf{x})$, where the ψ is a physical field (although it's propagating 3N dimensional space), thus it exists even when unobserved, and $\mathbf{x}$ is just a particle configuration
- The wave is a real wave (not an ”informational” wave), it's also never reduced and there is no subject-object division
- It drives the particle towards places with large $|\psi|^2$
- This theory also fixes tunneling times, escape times, escape positions or quantum chaos... plus it gives us a classical analogue

The pilot wave theory

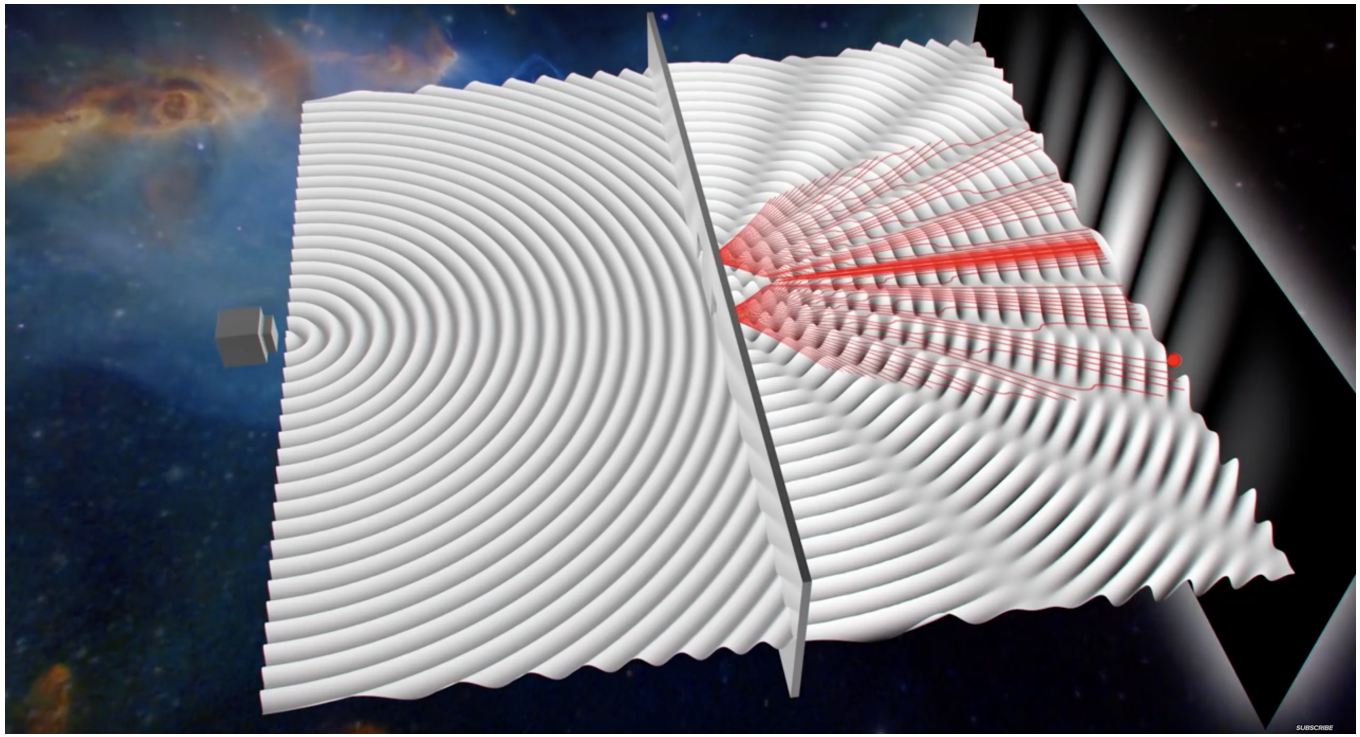

Figure: The particle is pushed by a real wave, and if the initial conditions were perfectly known one could determine where the particle lands precisely.

The subject-object distinction problem

Quantum mechanics:

- System as an object, measurer as a subject (what is the distinction?)
- Measured natural processes jump into an eigenstate of a dynamical variable (instantaneously)
- Not physically precise: what actions can be considered observations?

Bohmian mechanics:

- A theory which can refer to events in a given system without requiring observation by another system
- Has the same distinction as classical physics, real fields vs. potentials
- The theory should give precise physical meaning to the algebra of local observables

Does pilot wave help to restore locality?

- Requirement of locality: the result of a measurement on one system is unaffected by operations on a distant system the first system has interacted with in the past
- One of the apparent non-localities, collapse, can then be viewed as a mathemathical device, but there are other problems
- Local ”beables” are assigned to bounded space-time region with hope to formulate some notion of local causality
- EPR: additional variables were to restore causality and locality to the theory, the statistical character of QM is a consequence of incomplete description

Does pilot wave help to restore locality?

- But due to quantized vacuum non-locality might be unavoidable so the best description might be statistical and/or probabilistic
- Another possible origin of non-localities: propagation of the guiding wave in multidimensional space
- Maybe the experimentalists choice is also predetermined (we might just be a part of some deterministic whole-world wave function)
- Nothing helps to reduce the apparent correlations between entangled states
- Or maybe it is futile to try to see behind the observed phenomena...

Problems with Bohmian mechanics

- An abstract wave function extending through space is just as mysterious in this framework as it is in the Copenhagen interpretation
- Needs more math: guiding equation (how particles move in the waves)
- The particle-wave dynamics can not reproduce quantum mechanics in general
- The theory doesn't implement relativity (although there are attempts to create Bohmian version of QFT)
- Bohr: no parameters can be introduced with the help of which the indeterministic description could be transformed into deterministic one
- So the questions remain unanswered

Sources

Anders, et al. Double-slit experiment with single wave-driven particles and its relation to quantum mechanics. Physical Review E, 2015, 92.1: 013006.

John S.; BELL, John Stewart. Speakable and unspeakable in quantum mechanics: Collected papers on quantum philosophy. Cambridge university press, 2004.