

EPFL Master course

*Philosophical perspectives on
science and its history*

The quantum measurement problem

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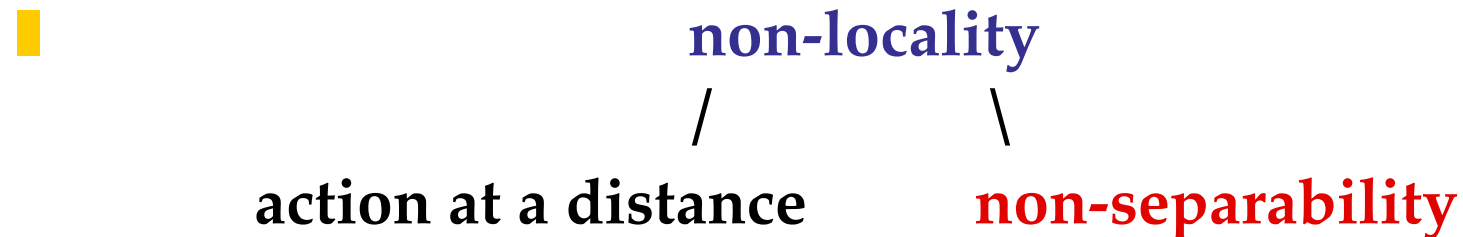
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Tim Maudlin (1995)

- A The wave-function of a system is *complete*, i.e. the wave-function specifies (directly or indirectly) all of the physical properties of a system.
- B The wave-function always evolves in accord with a linear dynamical equation (e.g. the Schrödinger equation).
- C Measurements of, e.g., the spin of an electron always (or at least usually) have determinate outcomes, i.e., at the end of the measurement the measuring device is either in a state which indicates spin up (and not down) or spin down (and not up).

Entanglement

- **micro-macro: Schrödinger's cat**
- **over arbitrary distances: singlet state, Bell experiments**
- **non-locality (Bell's theorem):** the probabilities for certain measurement outcomes to be obtained at a space-time point are not completely determined by what there is in the past light-cone of that point; events that occur at points separated by a space-like interval from that point contribute to determining the probabilities for what happens at that point.



Ontic structural realism

- **structure:** network of concrete physical relations that do not require underlying objects which possess an intrinsic identity
- relations as the ways (modes) in which the objects are
- **structures modal:** nomological role essential
- ***physical structures causal***, thereby distinct from mathematical structures and integrated into dynamics: structures as a whole bring about certain effects

Decoherence

- **not C:** A & B & account needed how determinate values appear to observers
- **Decoherence:** wave-function in mathematical space develops such that the interference terms between the superposed correlations vanish.
- **How to get from this development of wave-functions in a mathematical space to observers to whom determinate values appear?**

Many worlds



- decoherence induces splitting of the universe into many non-interfering branches
- **subsequent to splitting:** universe physical structure consisting in objects being many times copied in non-interfering branches whose dynamical properties have determinate values that are correlated within each branch and across these branches (Everett 1957).
- **no intrinsic identity of objects in a branch**

Many worlds?

- **When does the splitting happen?** Decoherence continuous / **splitting instantaneous**
- **How is it carried out?** Each physical system including its mass and charge many times copied.
- **What exactly does it involve?** If it does not involve space-time, contradictory predicates apply to one and the same space-time region. **If it does, how can space-time itself be copied so that many superposed space-times come into being?**
- Since splitting is instantaneous, **how could it be Lorentz-invariant?**

Many worlds?

- **prior to splitting:** entangled state of the universe causal structure that includes disposition to bring about splitting through decoherence
- **objects being smeared out in space-time that upon decoherence get split up into all their possible determinate values of position in different branches of the universe?**
- **if not in time, how does entangled state of the universe create a four-dimensional space-time with objects being localized in such a space-time and how does it, in doing so, bring about many copies of that space-time?**

Hidden variables

- **not A:** wave-function does not tell the whole story about what there is in the physical world.
 - Bohmian mechanics (Bohm 1952)
- **trivial fact:** macroscopic systems cannot have a determinate position unless the microscopic systems that compose them also do so.
- **controversial claim:** microscopic systems cannot acquire a determinate position unless they always have one.
 - position as additional variable

Bohmian mechanics?

- **non-locality:** development of position of particle depends on state of the universe
- **non-separability:** position of any particle at a given time derives from state of the universe at that time
- **ontic structural realism:** universe structure of objects whose positions are correlated with each other
- **causal:** structure of the world at a given time includes as a whole disposition to develop in a certain manner; that disposition expressed by a law of motion.
- Is it possible to elaborate on a complete and precise answer to the question what quantum mechanics tells us about the physical world without introducing additional variables and without forgoing Lorentz invariance?

Textbook quantum mechanics

- **A and not B and C:** the wave-function completely describes the properties of physical systems, but under certain circumstances quantum systems change in such a way that they acquire a determinate value of position, that change being represented by the collapse of the wave-function.
- **only precise elaboration:** Gisin (1984) Ghirardi, Rimini, Weber (1986) (GRW): dynamics for the transition from quantum systems in entangled states to these systems acquiring a determinate localization

GRW mass density?

- **Ghirardi:** when particle does not have determinate position, it is smeared out in physical space, creating a mass density field.
 - universe is a structure of objects with smeared out values of their dynamical properties that are correlated with each other; that structure includes the disposition to develop under certain circumstances into correlated determinate values.
- **tails problem:** even if Schrödinger's cat is alive, there also is a tiny dead cat. Again, contradictory predicates apply to same space-time region.
 - **difficulty in taking textbook quantum mechanics literally:** no dynamics that describes a development from smeared out values of physical properties to determinate values in a physically precise manner.

GRW flash

- **Bell:** GRW spontaneous localizations as flashes centred around space-time points; **these flashes *all* there is in the universe.**
 - Starting with an initial distribution of flashes, wave-function nothing more than tool to calculate probabilities for occurrence of further flashes.
 - Collapse of the wave-function misleading description of the fact that new flashes occur and that the information available for the calculation of the probabilities for future flashes has to be updated.
- **universe structure of flashes that includes disposition (propensity) to produce further flashes**

GRW flash?

- Lorentz-invariant, since abandons the idea of trajectories of anything in space-time.
- **Bell: macroscopic objects galaxies of flashes**
- **But: nothing with which measuring device could interact: no particle that enters it, and no wave or mass distribution that touches it either; only a flash in its past light-cone.**

My conclusion

- (1) **not C:** no precisely spelled out, complete and coherent theory available that answers the question of what the physical signification of the theory of wave-functions developing in a high-dimensional mathematical space is.
- (2) **not B:** no prospect of dynamics leading from smeared out values to determinate values as measurement outcomes.
- (3) One gets determinate positions of anything only if one presupposes that the fundamental physical objects (whatever they may be) always have a determinate position. **No determinate positions in, no determinate positions out.**
 - Bohminan mechanics (not A) and GRW flash (not B). But GRW flash too sparse an ontology.
 - **At most one solution to measurement problem – or not even one, depending on whether or not one is prepared to accept determinate positions as primitive.**