PANDORA'S CAT: ON BOHMIAN MECHANICS AND GRW THEORY

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Analysis of the history of what happened after Schroedinger's cat problem:

- A plethora of theories have been developed
- I will discuss Bohm's theory and different interpretations of GRW theory:
  - Bare GRW
  - GRWm
  - GRWf
- I will underline how they show a common structure (contrarily to what is usually thought)

The starting point: the measurement problem

E. Schroedinger: Die Gegenvartige Situation in der Quantenmechanik, Naturwissenschaften 23, 807-812 (1935); english translation by J. D. Trimmer:The Present Situation in Quantum Mechanics: a Traslation of Schroedinger's "Cat Paradox" Paper.

These three assumptions cannot go together:

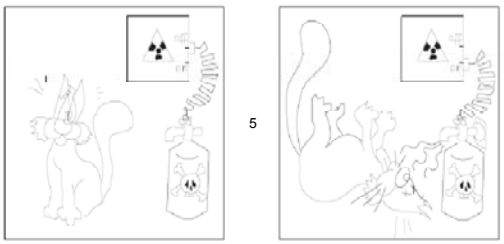
1 - the wave function is complete
2- it evolves according to Schroedinger's equation
3- measurements have results

then it follows that

Bare quantum mechanics (in which there is the wave function alone) cannot provide a complete description of the physical world.

The cat experiment:

A cat in a box connected with a device, activated by the decay of a radioactive element, connected with a bottle of poison
if the atom decays, the poison diffuses and the cat dies,
if the atom does not decay, the cat remains alive



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Assume the wave function is complete:

the atom is in the superposition state

$$\Psi_{\text{decayed}} + \Psi_{\text{undecayed;}}$$

Because of the **linearity** of the Schroedinger's evolution:

the cat is in the superposition state

$$\Phi_{\text{dead}} + \Phi_{\text{alive}}$$

Therefore, the measurement has **NO result**

Possible ways out:

- **quantum theory WITH the observer:** she collapses the wave function... severe problem with this view

-**quantum theories WITHOUT the observer**

Bell, J. S.: Are There Quantum Jumps? In C. W. Kilmister (ed.) Schroedinger. Centenary Celebration of a Polymath. Cambridge: Cambridge University Press ***(1987), pp. 41-52.***

*"**Either the wave function, as given by the Schroedinger equation, is not everything, or it is not right.**"*

QT Without O:THREE POSSIBLE ALTERNATIVES:

-Bohm's theory

-Bohm, D.: A Suggested Interpretation of the Quantum Theory in Terms of Hidden" Variables, I and II. Physical Review 85: 166-193 (1952).
-Duerr, D., Goldstein, S., Zanghi', N.: Quantum Equilibrium and the Origin of Absolute Uncertainty. Journal of Statistical Physics 67: 843-907 (1992).

the wave function is not complete

-GRW theory

-Ghirardi, G.C.; Rimini A.; Weber, T.:: Unified Dynamics for Microscopic and Macroscopic Systems. Physical Review D 34: 470-491 (1986).

the wave function does not evolve according to the Schroedinger equation

-Many Worlds

-Everett III, H.: Relative State Formulation of Quantum Mechanics. Review of Modern Physics 29, 454–462 (1957).

the measurements have no results

Bohm's theory

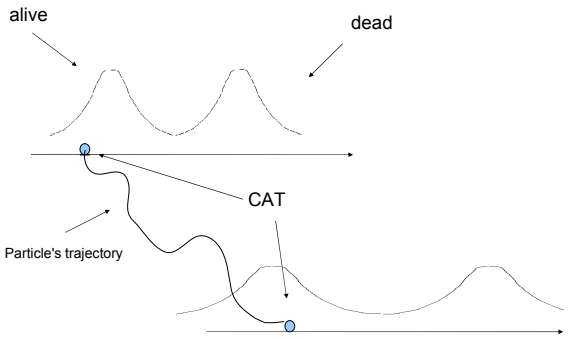
(Bohmian Mechanics, de Brogie-Bohm, pilot-wave theory)

-The world is made of particles with positions $(q_1,\ldots,q_N)=Q$ evolving in time guided by the wave function
-the complete description of the world is given by the couple (Ψ,Q)
Fundamental equations:

$$\frac{dQ_i}{dt} = v_i^{\psi}(Q_1,\ldots,Q_N) = \frac{\hbar}{m_i}\Im\frac{\psi^*\nabla_i\psi}{\psi^*\psi}(Q_1\ldots,Q_N),$$

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi\,,$$

How Bhom's theory dissolves the cat problem:



(Alleged) problem with Bohm's theory

It is often claimed that Bell has proved Bohm's theory to be impossible but this is simply a mistake: in contrast, Bell has been a great supporter of Bohm's theory
As it is evident from the text (Bell, J. S.: Speakable and Unspeakable in Quantum Mechanics. Cambridge: Cambridge University Press (1987)), what Bell has proven is that **Nature is non local**:

quantum mechanics + locality ⇒ H (noncontextual Hidden variables)
quantum mechanics ⇒ not H
Therefore:
quantum mechanics ⇒ **not locality**

GRW theory

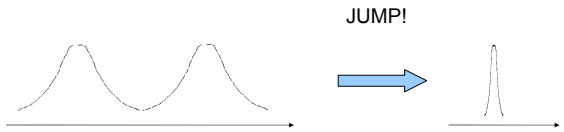
(Spontaneous collapse, Dynamical reduction)

The wave function evolves linearly up to time T_1, then it spontaneously **jumps** at time T_1, then it continues to evolves linearly...

$$\psi_{T_1} = U_{\Delta T_1}\psi_{t_0},$$

$$\psi_{T_1} \mapsto \psi_{T_1+} = \frac{\Lambda_{I_1}(X_1)^{1/2}\psi_{T_1}}{\|\Lambda_{I_1}(X_1)^{1/2}\psi_{T_1}\|}.$$

How GRW theory solves the cat problem:



"The cat is not both dead and alive for more than a split of a second"
(Bell, J. S.: Are There Quantum Jumps? In C. W. Kilmister (ed.) Schroedinger: Centenary Celebration of a Polymath. Cambridge: Cambridge University Press (1987), pp. 41-52.)

...But what is the world is made of according to GRW theory?

Different GRW theories

-Bare GRW (GRW0): the world is made of wave functions

-***Albert, D. Z.: Elementary Quantum Metaphysics. In J. Cushing, A. Fine, and S.***Goldstein (eds), Bohmian Mechanics and Quantum Theory: An Appraisal, 277-***284. Dordrecht: Kluwer (1996).***
-**Nicrosini**, O., **Rimini**, A.: Relativistic Spontaneous Localization: a Proposal. Foundations of Physics 33, 1061-1084 (2003)

-GRWm: the world is made of a field in 3-dimensional space, the mass density

-**Benatti,** F., **Ghirardi**, G.C., **Grassi**, R.: Describing the macroscopic world: closing the circle within the dynamical reduction program. Foundations of Physics 25: 5-38 (1995).

-GRWf: the world is made of flashes, events in space-time

-***Bell, J. S.: Beables for Quantum Field Theory. Physics Reports 137: 49-54 (1986).***
-***Tumulka, R.: A Relativistic Version of the Ghirardi-Rimini-Weber Model. To appear in Journal of Statistical Physics (2006).***

Bare GRW is untenable:

Bell, J. S.: Are There Quantum Jumps? (1987)

Gap between physical and configuration space:

"[...] the wave function as a whole lives in a much bigger space, of 3N dimensions. It makes no sense to ask for the amplitude or phase or whatever of the wave function at a point in ordinary space. It has neither amplitude nor phase nor anything else until a multitude of points in ordinary three-space are specified."

this makes very hard to explain the view of Bell later on....

-**Bell,** J.S.: ***Against \Measurement". In A.I. Miller (ed.) Sixty-Two Years of Uncertainty:*** Historical, Philosophical, and Physical Inquiries into the Foundations of Quantum Physics, volume 226 of NATO ASI Series B. New York: Plenum Press (1990).

"The GRW-type theories have **nothing in their kinematics but the wave function**. It gives the density (in a multidimensional configuration space!) of stuff. To account for the narrowness of that stuff in macroscopic dimensions, the linear Schroedinger equation has to be modified, in the GRW picture by a mathematically prescribed spontaneous collapse mechanism."

in a letter to Ghirardi dated October 3, 1989:

"As regards Y and the **density of stuff,** I think it is important that this density is in the 3N dimensional configuration space. So I have not thought of relating it to ordinary matter or charge density in 3-space. Even for one particle I think one would have problems with the latter. So I am inclined to the view you mention `as it is sufficient for an objective interpretation'... And it has to be stressed that the `stuff' is **in 3N-space**,or whatever corresponds in field theory."

In both GRWm and GRWf, there is MORE in the world than the wave function alone:

The world is made of SOMETHING in 3 or 4 dimensional space

-the mass density field
-the flashes

Bohm's theory and GRW theory seems so different ...But actually they are not!

Allori V., Goldstein S., Tumulka T., Zanghì N.: ***On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory*** **. Quant-ph/0603027.**

Common structure between Bohm's theory and GRW

(i) They are both about an ontology in physical space
(ii) The state vector governs the behavior of the the ontology by means of a given law

... note that the same structure is shared by classical mechanics ...
contrarily to what is commonly thought.

Differences between Bohm's theory and GRW

1-Evolution of the wave function:
Bohm's theory:
deterministic linear evolution
GRW:
stochastic evolution

2-Empirical equivalence:
Bohm's theory:
empirically equivalent to bare quantum mechanics
GRW:
not empirically equivalent (deviation not currently detectable)

the first is not a real difference...

Allori V., Goldstein S., Tumulka T., Zanghì N.:
On the Common Structure of Bohmian Mechanics and the Ghirardi-Rimini-Weber Theory **. Quant-ph/0603027.**

GRWf without collapse

GRWf can be reformulated in such a way that
the wave function does not collapse

BM with collapse

BM can be reformulated in such a way that
the wave function does collapse

This shows that what THE THEORY IS FUNDAMENTALLY ABOUT is **not** the wave function:
what is fundamental is, respectively, the flashes and the particles. They are the **building blocks** of everything else.
In contrast, the wave function is what allows to implement the **law** of evolution for those fundamental entities.

The difference between Bohm's theory and GRW **cannot** be that the wave function collapses in one and not in the other (as commonly thought).

So what is the origin of the empirical inequivalence between the two theories?

This is to be investigated
...