Will quantum theory be different in the macro-world?

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Abstract

Quantum theory was invented for the microscopic world, and proved accurate there. Is it valid in the macroscopic world as well? Is quantum theory universal from particle physics to cosmology? We might like to think so. Except that the experimental evidences are lacking, the relevant theories limp along, and there are crippling conceptual problems. It is therefore not impossible that quantum theory will be different when it reaches the macro-world. But how different will it be? In quantum theory, the micro-world only affects the macro-world when a measurement is made on the micro-world. Wouldn't there exist certain s p o n t a n e o u s measurements, acting universally everywhere and everytime, negligibly weak in the micro-world and amplified in the macro-world? What does such a theory of spontaneous measurement (i.e., spontaneous wavefunction collapse) look like and what is it good for?

Gradual Extension of QM

- photons (Planck)
- atoms (Bohr)
- micro-world (Schrï£ · dinger, Heisenberg)
- condensed matter
- electrodynamics
- nuclei
- elementary particles PERFECT ↑

- gravitation ? NO EVIDENCE ↓
- cosmology ?
- biology ?
- consciousness ?

Quantum theory was invented for the microscopic world, and proved accurate there. Is it valid in the macroscopic world as well? Is quantum theory universal from particle physics to cosmology? We might like to think so. Except that ...

Quantum gravity — missing

Experimental evidences are lacking

- Micro objects: too week to source testable gravity
- Macro objects: quantumness masked by environment

Theories of quantized space-time limp along:

- Quantized field theory is non-renormalizable
- Wheeler–DeWitt equation: only semiclassical solutions make sense
- Quantized strings, loops: no conclusive result

Crippling conceptual problems

- In Quantum Theory? No!
- In General Relativity? No!
- In their interface? Sure!

Boundary between micro- and macro-world is terra incognita.
Something can happen to QM (to GR, too).

Micro-macro boundary: where and what happens?

Question: Where?

Answer: Where masses become macroscopic.

Arguments: QM is valid for macroscopic dof's of microscopic mass (laser light, supercurrent, magnetizations, etc.) QM is not confirmed for dof's of macroscopic mass (c.o.m. of $\gg 10000 amu$).

Question: What would parametrize the boundary?

Answer: Newton's constant G.

Arguments: If massive dof's matter, they invite gravity because their universal coupling. Gravity is the fundamental theory of the macro-world, it is what stands on the other side of the boundary.

Question: What happens there to QM?

Answer: Spontaneous "unmanned" measurements.

Arguments: "Minimum surgery" on the body of QM, easy to teach, you'll see ...

From standard to spontaneous quantum measurement

In QM: measurement is the only micro-macro interface.

- occasional
- needs macroscopic measuring device
- subjective, needs human perception
- discrete in time
- non-dynamical
- quantum state endures random jumps
- measurement outcomes are random

We shall assume that measurements are not occasional but universal, not requiring measurement devices or human perception but happen spontaneously and objectively. Otherwise the math of these hypothetic measurements is the same as in standard QM (cf.: minimum surgery).

From standard to spontaneous quantum measurement

Our concept is a universal micro-macro interface:

- ~~occasional~~ universal, happens every-where & -time
- ~~needs macroscopic measuring device~~ spontaneous
- ~~subjective, needs human perception~~ objective
- ~~discrete in time~~ continuous in time
- ~~non-dynamical~~ dynamical
- Ψ endures random jumps (collapses)
- measurement outcomes are random

Question: What observables are subjects of the postulated universal spontaneous (objective, dynamical) measurements acting every location $\mathbf{r}$ and every time t?

Answer: spatial mass distribution operator $\hat{\mu}(\mathbf{r}, t)$.

Textbook math of measurements

Selective measurement of observable $\hat{A} = \sum_x \lambda_x \hat{P}_x$.

$$|\Psi\rangle \to \frac{\hat{P}_x|\Psi\rangle}{\sqrt{p_x}} \qquad \mathit{or} \qquad \hat{\rho} \to \frac{\hat{P}_x\hat{\rho}\hat{P}_x}{p_x}$$

outcome probability $p_x = \langle\Psi|\hat{P}_x|\Psi\rangle = \mathrm{tr}(\hat{P}_x\hat{\rho})$

Non-selective measurement is simple:

$$\hat{\rho} \to \sum_x \hat{P}_x\hat{\rho}\hat{P}_x$$

Time-continuous dynamics (part of standard QM):

$$\frac{d\hat{\rho}}{dt} = -\frac{i}{\hbar}[\hat{H},\hat{\rho}] - \frac{\gamma}{8}[\hat{A},[\hat{A},\hat{\rho}]]$$

γ: strength of time-continuous measurement of $\hat{A}$.

Universal spontaneous measurement of mass distribution

$$\hat{\mu}(\mathbf{r}) = \sum_n m_n \delta(\mathbf{r} - \hat{x}_n)$$

$$\frac{d\hat{\rho}}{dt} = -\frac{i}{\hbar}[\hat{H}, \hat{\rho}] - \int_{\mathbf{r}} \int_{\mathbf{r}'} \frac{\gamma(\mathbf{r}, \mathbf{r}')}{8} [\, \hat{\mu}(\mathbf{r}), [\, \hat{\mu}(\mathbf{r}'), \hat{\rho}] \,]$$

$$\gamma(\mathbf{r}, \mathbf{r}') = \frac{4\hbar G}{|\mathbf{r} - \mathbf{r}'|}$$

The new term is measuring the mass distribution $\hat{\mu}(\mathbf{r}, t)$.
Coherence of different mass distributions is suppressed.
The larger the difference the faster the decoherence.
Fast decoherence in massive macroscopic superpositions.
No significance in the micro-world of microscopic dof's.

DP: Spontaneous collapse of massive superpositions

D. 1986, Penrose 1996

$$|CAT\rangle = \frac{|\text{LEFT}\rangle + |\text{RIGHT}\rangle}{\sqrt{2}} \rightarrow \left\{ \begin{array}{c} |\text{LEFT}\rangle \\ \text{or} \\ |\text{RIGHT}\rangle \end{array} \right.$$

$V_G^i\rangle V_G^f$: gravitational self-energy before/after collapse
COLLAPSE RATE: $(V_G^i - V_G^f)/\hbar$
Negligible for small masses: $\sim 10^{-6}/s$ for 1 femtogram
Extreme fast for large masses: $\sim 10^{19}/s$ for 1 gram

EXPLAINS HOW QM GOES CLASSICAL IN THE MACRO-WORLD

Thanks for your attention! You can ask questions if you like!

Your own ones, or from my list:

- Are there better motivations than "minimum surgery"?
- Does Penrose proposal coincide or just overlap with mine?
- Is the theory parameter free?
- How is it different from the similar theories GRW or CSL?
- Does it conserve energy and momentum?
- Is any fundamental irreversibility considered in "standard" quantum-cosmology?
- What about the relativistic generalization?
- Are there experimental tests?
- What was our underground experiment 2022? Did we rule out my theory? Or Penrose's?
- Quantum-gravity is known to become relevant at extreme high energies. Then how can it influence low energy quantized matter?