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Is quantum theory exact or approximate?

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Quantum mechanics has puzzled the scientific community from the beginning. One of the major sources of difficulties comes from the measurement problem: why do measurement processes always have definite outcomes, despite the fact that the Schrödinger equation allows for superpositions of states? And why are such outcomes random (distributed according to the Born rule), while the Schrödinger equation is deterministic? New experiments and observations could help to answer such questions by providing a more precise idea of the possible limits of validity of quantum theory (Adler and Bassi 2009).

Most solutions to the measurement problem look for a reinterpretation of the formalism of quantum mechanics. Models in which the wave function collapses spontaneously, however, follow a different route. They purposely modify the Schrödinger equation by adding new nonlinear and stochastic terms, which break quantum linearity above a scale fixed by new parameters. Physically, the wave function is coupled (nonlinearly) to a white-noise classical scalar field, which is assumed to fill space.

By modifying the Schrödinger equation, collapse models make predictions that differ from those of standard quantum mechanics and that can be, in principle, tested. The scale at which deviations from standard quantum behaviour can be expected gives indications of the sensitivity that experiments should reach if they are to provide meaningful tests of collapse models and quantum mechanics.

There have already been experiments that directly or indirectly test collapse models against quantum mechanics and others are proposed for the future. Probably the best known are the diffraction experiments with macromolecules (C_{60}, C_{70}, $C_{30}H_{12}F_{30}N_2O_4$), which set an upper bound 13 decades above the most conservative value of the collapse parameter λ (related to the noise strength) and five decades above the strongest value suggested. Other tests include the decay of supercurrents and proton decay, but the upper bounds are even weaker than in the diffraction experiments. One interesting proposal is an experiment that includes a tiny mirror mounted on a cantilever, within an interferometer: it will set an upper bound of 9 (1) decades on the weakest (strongest) value of λ.

The strongest bound, however, comes from the spontaneous emission of X-rays from germanium-76, as predicted by the continuous spontaneous localization (CSL) model, the most popular collapse model. It sets an upper bound of only six decades on the weakest value of λ. The strongest value is disproved by these data, but the bound is weakened if non-white-noise is considered with a frequency cutoff. The data coming from spontaneous X-ray emission are very raw, and several contributions from known sources (e.g. gamma-ray contamination, double beta-decay) have not been subtracted. A dedicated experiment on spontaneous photon emission could set a much stronger upper bound and would represent the most accurate test of quantum mechanics against the rival theory. Such a project is under discussion between the University of Trieste and the INFN, Laboratori Nazionali di Frascati.

Collapse models also make predictions that have cosmological implications. The apparent violation of energy conservation arising from the interaction with the collapsing noise places important upper bounds. The strongest comes from the intergalactic medium: requiring that the heating produced by the noise remains below experimental bounds places an upper bound of 8 (0) decades on the weakest (strongest) value of λ.

About the author

Stephen L Adler and Angelo Bassi 2009 *Science* 325 275.

www.qmts.it/research/drm/main_drm.html.

Featured Events

18th Hellenic School and Workshops on Elementary Particle Physics and Gravity
31 August – 28 September 2018 Corfu, Greece
http://www.physics.ntua.gr/corfu2018

7th International Beam Instrumentation Conference
9-13 September 2018 Shanghai, China
https://indico.sinap.ac.cn/event/3/

Vacuum Expo 2018
10-11 October 2018 Coventry, UK
http://www.vacuum-expo.com/