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1. Entropy production when making continuous measurements

Investigating the relation between entropy and information is of importance both in fundamental physics and for applications in nanotechnology. On small scales, the role of fluctuations and quantum effects is important, which brings about the appearance of new features in the system's behavior. As distinct from single measurements, the effect of continuous quantum measurements (responsible for a system's further evolution at every instant of time) on the general entropy balance has not yet been examined. M Rossi (University of Copenhagen, Denmark) and co-authors have carried out such a study [1] for the first time. Using a test laser beam in the homodyne method, the position of an oscillating membrane in an optical resonator was observed, which allowed recording individual quantum trajectories of a given optomechanical system. The entropy production due to continuous measurements both in the stationary case and upon relaxation after a short impact on the system was found by the shape of quantum trajectories, and a great influence of fluctuations on this process was noticed. For quantum measurements, see [2, 3].

2. Interaction between two time crystals

Time crystals, predicted by F Wilczek [4], have already been demonstrated experimentally. Their properties are repeated in time, similarly to the periodic arrangement of atoms in an ordinary crystal. S Autti (Aalto University, Finland and Lancaster University, Great Britain) and co-authors are the first to investigate the interaction between two time crystals [5]. The time crystals were created in Bose-Einstein condensate of magnons in the superfluid phase 'B' of liquid helium-3 at a temperature of 130 μK in a magnetic field. One of the time crystals arose in the bulk condensate and the second on the surface. Nuclear magnetic resonance was used to observe characteristic periodic time crystal motions associated with coherent spin precession. Exchange of magnons proceeded along the isthmus between the crystals. This induced Josephson oscillations with a frequency equal to the difference between the frequencies of the two time crystals. An additional interaction between the crystals was due to the fact that the bulk crystal introduced perturbations into the potential retaining the surface crystal. The observed behavior of interacting time crystals was successfully reproduced in numerical simulations. In the future, it will also be possible to examine more complicated interactions among time crystals, including their collisions. For Bose–Einstein condensation of magnons, see [6].

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3. Investigation of molecular quantum states

K Najafian (University of Basel, Switzerland) and co-authors have developed a new method of phase-sensitive measurements of the structure of quantum levels in molecules when they interact with other molecules in an optical field [7]. The investigated molecular ions $^{14}N_2^+$ and the auxiliary ions $^{40}Ca^+$ were placed in an optical lattice formed by laser beams. The $^{14}N_2^+$ ions were affected by two variable forces whose phase difference was changed in the experiment, and at the same time the Stark shift of the levels was registered. Investigations carried out for different rotational states of $^{14}N_2^+$ molecules allowed classifying their electronic and vibrational levels. The new method may prove beneficial for the study of molecules with a dense quantum-level structure when the use of ordinary spectroscopic methods is difficult. For the interaction of molecules with lasing, see [8].

4. Quantum astronomy

Experiments on quantum teleportation of particle states over various distances, including thousands of km from a satellite to Earth, have been performed in recent years. A Berera (University of Edinburgh, Great Britain) has considered theoretically the question of what maximum distance photons can cover in interstellar space sustaining quantum coherence [9], e.g., as photons of a quantum-entangled pair. On their way in the Galaxy, photons interact with free electrons, atoms, and molecules, and with photons in the interstellar background. The consideration of these elementary processes suggests a conclusion that radio-frequency range photons can cover distances from ~ 100 to $\sim 10^6$ pc without scattering, exceeding in the latter case the size of the Galaxy. An additional obstacle leading to polarization plane rotation (destruction of coherence in spin states) may be interstellar magnetic fields. Still longer cosmological distances can be covered by X-ray photons. The existence of cosmological objects whose radiation shows quantum coherence, for instance, hypothetical cosmic strings or evaporating primordial black holes, is not ruled out.

5. Gravitational waves from mergers of record massive black holes

Two gravitational wave detectors, LIGO and Virgo, have registered in [10] the gravitational burst GW190521 from the merger of black holes (BHs) with masses of $85^{+21}_{-14} M_{\odot}$ and $66^{+17}_{-18} M_{\odot}$ at the red shift $z \simeq 0.8$. The signal-to-noise ratio in this observation is equal to 14.7. The mass of the larger BH and the total mass of the two BHs of $\sim 150 M_{\odot}$ are a record size among LIGO/Virgo events registered hitherto. According to the current classification, the ultimate BH with a mass of $\sim 142 M_{\odot}$ that was due to the merger and radiation of gravitational waves is a BH of intermediate mass — between the masses of BHs of stellar origin and of supermassive BHs in galactic nuclei. The origin of the more massive of the two merged BHs is not yet clear, since the production of such a massive BH during star evolution is hardly probable because of the pair instability effect. This BH itself may have resulted from the merger of two BHs with smaller masses. For the properties of binary BHs as given by LIGO/Virgo observations, see [11].

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