Coherence and multimode correlations from vacuum fluctuations

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A fundamental theoretical result of modern quantum field theory is that the quantum vacuum is unstable under certain external perturbations that produce otherwise no consequences in a classical treatment. As a result of this instability, virtual fluctuations populating the quantum vacuum are converted into real particles by the energy provided by the perturbation. For example, the application of an intense electric fields extracts electron-positron pairs from vacuum (Schwinger effect), the bending of space-time in the intense gravitational field at event horizons is responsible for the evaporation of black holes (Hawking radiation), the acceleration of an observer in the Minkowski vacuum results in the detection of particles (Unruh effect), and sudden changes in the boundary conditions of electromagnetic field modes or in the speed of light (index of refraction) creates photons (dynamical Casimir effect) [1].

In the vacuum state, fluctuations occurring at different frequencies are fully uncorrelated. However, if a parameter in the Lagrangian of the field is modulated by an external pump, vacuum fluctuations stimulate spontaneous downconversion processes, creating squeezing between modes symmetric with respect to half of the frequency of the pump. We have investigated conversion of virtual microwave quanta in to real entities in superconducting circuitry and determined the ensuing correlations between the quanta. Furthermore, we have demonstrated that by *double* parametric pumping of a superconducting microwave cavity, it is possible to generate yet another fundamental type of correlation, namely coherence between photons in separate frequency modes [2, 3]. The coherence correlations are tunable by the phases of the pumps and are established by a quantum fluctuation that stimulates the simultaneous creation of two photon pairs. Our analysis indicates that the origin of this vacuum-induced coherence is the absence of which-way information in the frequency space.

References

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