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Fakultät für Naturwissenschaften
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Einladung

zum

Seminar des Instituts für Quantenphysik

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THE QUANTUM THEORY OF THE LASER AND ITS APPLICATION TO: Bose Condensates, Unruh Radiation, and Fröhlich Protein Phase Transitions

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10:00 Uhr
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Abstract: A quantum master equation analysis of laser operation was developed by Lamb and Scully [1]. Equations of motion for the density matrix of the quantized electromagnetic field are derived. These equations describe the irreversible dynamics of the laser radiation in all regions of operation (above, below, and at threshold). Nonlinearities play an essential role in this problem. The diagonal equations of motion for the radiation are found to have an apparent physical interpretation. At steady state, these equations may be solved via detailed-balance considerations to yield the photon statistical distribution $\rho_{n,n}$. The resulting distribution has a variance which is significantly larger than that for coherent light. The off-diagonal elements of the radiation density matrix describe the effects of phase diffusion in general and provide the spectral profile $| E(\omega) |^2$ as a special case. More recently, we have carried out experiments measuring, for the first time [2], the temporal evolution of higher order off-diagonal elements.

The current studies of Bose Einstein Condensation (BEC) and coherent atom optics draw from and contribute to the general subject of coherence effects in many body physics and quantum optics. It is in this spirit that the present talk sketches some recent application of techniques, ideas, and theorems which have been developed in understanding lasers and squeezed states to the condensation of N Bosons.

In particular, we find that the quantum theory of the laser and the laser phase transition analogy yields a treatment of BEC, which provides a resolution to the above three problems (and much more), and is in excellent agreement with computer simulation [3].

Concerning the interacting Bose gas, Bogoliubov made a giant step forward providing the first microscopic description of the superfluid flow of HeII. Furthermore, the Bogoliubov quasi particle operators and have long been touted as being an early example of the operator algebra of squeezed states of the radiation field.

Turning the tables, we have recently shown how certain theorems developed in the study of squeezed states of the radiation field make it possible to obtain the partition function for the interacting Bose gas in the Bogoliubov limit for the first time [4,5]. An important conclusion from this work is that the ground state occupation shows fluctuations, which are not Gaussian even in the thermodynamic limit. Furthermore, we clearly establish the fact that fluctuations in the interacting gas are closely related to those of the ideal gas but reduced by one half. Physically, this is due to the fact that the atoms are strongly coupled in correlated pairs such that the number of degrees of freedom is only ½ N, not N as in the ideal gas.

In recent work, we have shown [6] that atoms falling into a black hole (BH) emit Unruh radiation which, under appropriate initial conditions, looks to a distant observer much like (but is different from) Hawking BH radiation. In particular, we find the entropy of the acceleration radiation via a simple laser-like analysis. We call this entropy horizon brightened acceleration radiation (HBAR) entropy to distinguish it from the BH entropy of Bekenstein and Hawking. This analysis also provides insight into the Einstein principle of equivalence between acceleration and gravity. Most recently, we have shown how such studies address subtle features of acceleration radiation [7].

Fröhlich discovered the remarkable condensation of polar vibrations into the lowest frequency mode when the system is pumped externally. For a full understanding of the Fröhlich condensate one needs to go beyond the mean field level to describe critical behavior as well as quantum fluctuations. In recent work [8], we found that the energy redistribution among vibrational modes with nonlinearity included is essential for realizing the condensate and the phonon-number distribution, revealing the transition from quasi-thermal to super-Poissonian statistics with the pump. We further studied the spectroscopic properties of the Fröhlich condensate, which are especially revealed by the narrow linewidth. This gives the long-lived coherence and the collective motion of the condensate. Finally, we found that the proteins such as bovine serum albumin and lysozyme are most likely the candidates for observing such collective modes in THz regime by means of Raman or infrared spectroscopy.

Finally, in a recent paper [9], the quantum theory of the laser formalism has been applied to the PT symmetric microcavity problem. They show how to better understand gain saturation and exceptional points as exotic degeneracies in non-Hermitian systems.

References

[1] M.O. Scully, W.E. Lamb, “Quantum Theory of an Optical Maser I. General Theory,” Phys. Rev., 159(2), 208-226 (1967).

[2] T. Peng, Y. Shih, and M. Scully, TBP.

[3] M.O. Scully, “Condensation of N bosons and the laser phase transition analogy, “ Phys. Rev. Lett., 82(20), 3927-3931.(1999).

[4] V.V. Kocharovsky, Vl.V. Kocharovsky, M.O. Scully, “Condensate statistics in interacting and ideal dilute Bose gases,” Phys. Rev. Lett., 84(11), 2306-2309 (2000)

[5] V. V. Kocharovsky, Vl. V. Kocharovsky, and M. O. Scully, “Condensation of N bosons. III. Analytical results for all higher moments of condensate fluctuations in interacting and ideal dilute Bose gases via the canonical ensemble quasiparticle formulation,” Phys. Rev. A, 61, 053606 (2000).

[6] M. Scully, S. Fulling, D. Lee, D. Page, W. Schleich, A. Svidzinsky, “Quantum optics approach to radiation from atoms falling into a black hole,” PNAS, 201807703 (2018).

[7] M. Scully, A. Svidzinsky, W. Unruh, “Acceleration radiation, causality and more,” TBP.

[8] Zhang, Z, Agarwal, G., and Scully, M, "Quantum Fluctuations in the Fröhlich Condensate of Molecular Vibrations Driven Far From Equilibrium", Phys. Rev. Lett., 122, 158101 (2019).

[9] I. Arkhipov, A. Miranowiicz, O. Di Stefano, R. Stassi, S. Savasta, F. Nori, S. Ozdemir, “Scully-Lamb quantum laser model for parity-time-symmetric whispering – gallery microcavities: Gain saturation effects and nonreciprocity” Phys. Rev. A, 99, 053806 (2019).