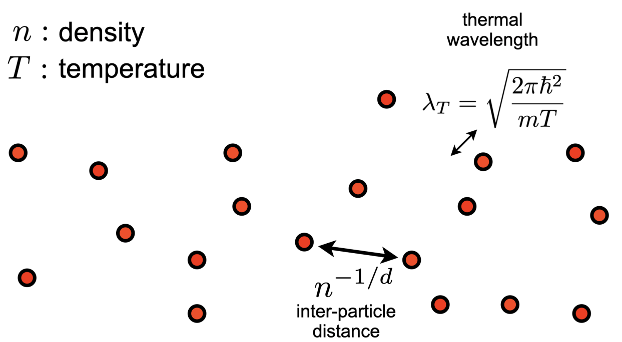
Master project: Interaction effects in degenerate quantum gases

Background: Quantum gases are atomic systems that are cooled to almost absolute zero temperature (indeed, by far the coldest temperatures in the universe are realised in quantum gas experiments). In these regimes, the de Broglie wave length that sets the size of the atomic wave function is no longer tiny but comparable to the average distance between two atoms. This means that the wave function of different atoms will overlap and a classical statistical description no longer holds. Instead, quantum mechanics is essential to describe the thermodynamics of the gas, which is said to be in the quantum-degenerate regime.

The first quantum-degenerate gas was created about twenty years ago, and nowadays the study of quantum gases is a large subfield of atomic physics. What is interesting about quantum gases is that their properties can be probed and manipulated with extreme precision (for example, by using different atom species or different laser configurations that confine the gas in a vacuum chamber, thus creating lattices or two-dimensional systems). This is different from condensed matter experiments, where typical setups are fixed and measurements often have smaller precision. The hope is to emulate and study problems from condensed matter physics (such as high-temperature superconductivity) by using quantum gases.



Left: Sketch of a quantum gas. If the thermal de Broglie wavelength, which increases at low temperature, is comparable to the distance between two atoms, quantum statistics becomes important and the gas is quantum degenerate. Right: The QR code links to an introductory article to quantum gases called "Optically Trapped Fermi Gases" by J. E. Thomas and M. E. Gehm.

Project proposal: It is possible to tune the interaction strength between atoms and create strongly interacting quantum gases. Even though we know the microscopic model (i.e., the Hamiltonian) of such a system, it is still very difficult to solve, since most theory methods rely on a small interaction as an expansion parameter. In this theory project, you will develop and apply quantum-field theoretical methods to describe strongly interacting quantum gases. The aim is to use these results to describe a set of recent experiments.

A basic knowledge of quantum mechanics and quantum field theory is required for this project. Familiarity with a computer algebra system (such as Mathematica) and knowledge of complex analysis would be very useful, but this can be acquired during the project.

Office space at Physics is expected to be available, but depending on future corona-virus restrictions we might have to work remotely.

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