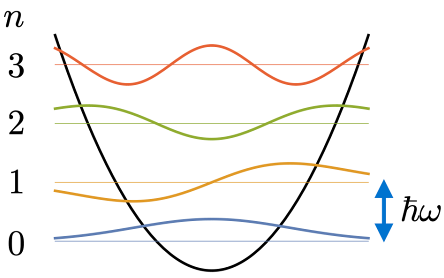
TIFX04-21-24

Magic numbers in interacting quantum gases



Bakgrund: It was realised a long time ago that some atomic nuclei with a specific "magic" number of neutrons and protons are more stable than others. The rough explanation of this effect relies on the Pauli exclusion principle (i.e., quantum mechanics!), which dictates that nucleons may arrange in shells, with fully occupied shells having enhanced stability. The first one to provide this explanation and back it up with quantitative predictions was Maria Goeppert-Mayer, and she was awarded a share in the Nobel Prize in Physics for her work. Nowadays, this shell effect from nuclear physics is extremely important in nanotechnology, where electrons or atoms confined in nanoscale structures play the role of the nucleons.

In particular, in the past years, experimentalists in atomic physics managed to cool atomic gases to extremely low temperatures (down to just a few nanokelvin, so these experiments are by far the coldest places in the universe) and keep them in place using laser beams. At such temperatures, classical physics no longer applies and quantum mechanics is essential to describes the gas. There are now first experiments which observe shell effects in quantum gases that consist of just a handful (less than twenty) atoms.

Problembeskrivning: In this project, you will apply techniques from your quantum mechanics course, such as perturbation theory, to describe few-particle ensembles of cold atoms. The aim is to explain some recent experimental work and to predict properties of more complicated systems, for example, by computing the magic numbers.

Arbetssätt: This is a project in theoretical physics. You will formulate a theoretical model, perform a few (mostly analytical) calculations with it, and compare your results with experimental data. Some knowledge of computer algebra systems (such as Mathematica or Matlab) for the occasional numerical calculation is helpful, but by no means necessary.

Gruppstorlek: This project is suitable for one group of 3-4 students.

Målgrupp: F, GU-fysik, IT, or equivalent — everyone with an interest in quantum mechanics and/or statistical physics

Litteraturtips:

• Two exciting recent experiments are:
[1] G. Zürn et al.: "P*airing in Few-Fermion Systems with Attractive Interactions*'', Phys. Rev. Lett. **111**, 175302 (2013) [https://arxiv.org/abs/1307.5153]
[2] L. Bayha et al.: *"Observing the emergence of a quantum phase transition -- shell by shell'' (2020)*, [https://arxiv.org/abs/2004.14761]
• Some theory:
[3] J. Hofmann, A. M. Lobos, and V. Galitski, *"Parity effect in a mesoscopic Fermi gas"*, Phys. Rev. A **93**, 061602 (2016) [https://arxiv.org/abs/1508.05947]
• A general introduction to quantum gases is:
[4] I. Bloch, J. Dalibard, and W. Zwerger, *"Many-body physics with ultracold gases"*, Rev. Mod. Phys. **80**, 885 (2008) [https://arxiv.org/abs/0704.3011]

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