Introduction to Ultracold Gases and Spin-asymmetric Josephson Effect

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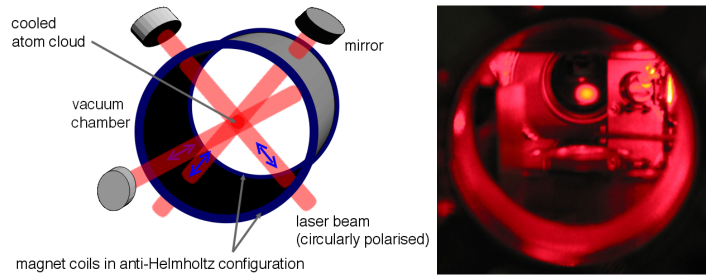
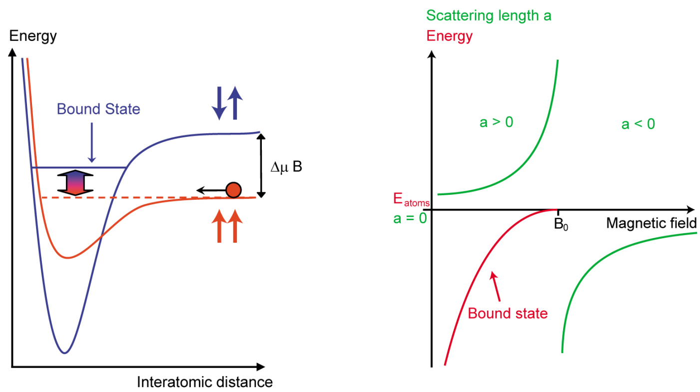
INTRODUCTION TO ULTRACOLD GASES

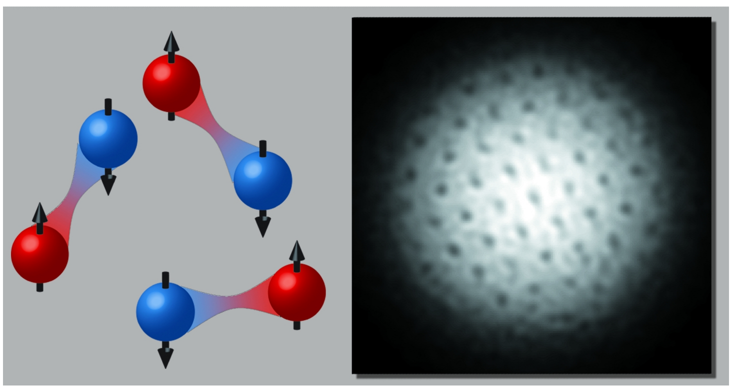
Ultracold gases are atomic systems cooled down to temperatures where effects of quantum statistics become manifest. The unprecedented degree of tunability and purity of ultracold gases make them a versatile tool for improving our understanding of condensed matter physics and exploring fundamentals of quantum mechanics.



(*Left*) Magnetic and optical trapping confine a dilute gas. Laser cooling techiniques bring the gas down to ultracold temperatures - to the regime of quantum statistics. (*Right*) A sample of Lithium atoms in an experiment by Tilman Esslinger's Quantum Optics group at ETH Zürich.



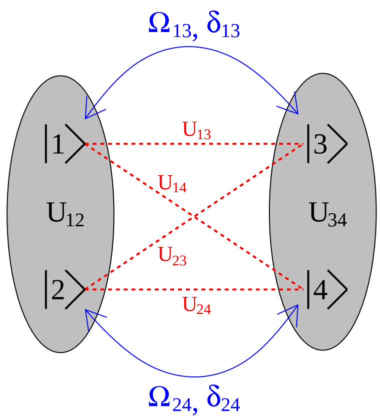
The Feshbach resonance allows for tuning the interaction strength between the atoms with the external magnetic field strength. The credit for the picture belongs to Wolfgang Ketterle's Alkali Quantum Gases group at MIT.



(*Left*) A two component Fermi gas can form a BCS state (*i.e.* Cooper pairs) and become a superfluid - the same thing happens to electrons in a superconductor. (*Right*) Compelling evidence of the superfluidity of a two component Fermi gas. A rotating superfluid forms a vortex lattice as demonstrated here by Wolfgang Ketterle's group at MIT.

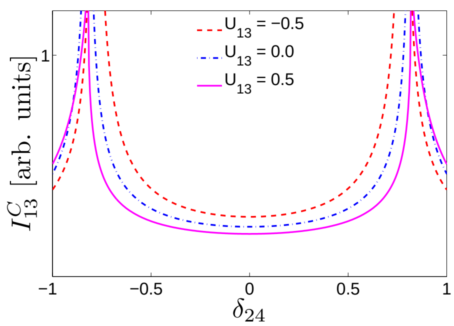
SPIN-ASYMMETRIC JOSEPHSON EFFECT

We propose that with ultracold Fermi gases one can realise a spin-asymmetric Josephson effect in which the two spin components of a Cooper pair are driven asymmetrically. We predict that the spin components oscillate at the same frequency but with different amplitudes. [1]

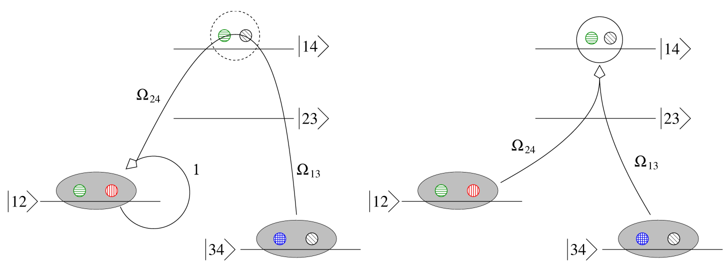


The system consists of two BCS superfluids (grey ovals) coupled by radio frequency (RF) fields, which is equivalent to two weakly linked superconductors. The detunings δ_{ij} play the role of voltage but are mutually independent control parameters for each channel. In the limit of weak RF coupling the currents in the system are

$$I_1(t) = \langle \dot{\hat{n}}_1 \rangle = I_{13}^S(\delta_{13}) + I_{13}^C(\delta_{24}) \sin[(\delta_{13} + \delta_{24})t + \varphi],$$
$$I_2(t) = \langle \dot{\hat{n}}_2 \rangle = I_{24}^S(\delta_{24}) + I_{24}^C(\delta_{13}) \sin[(\delta_{13} + \delta_{24})t + \varphi].$$



This asymmetric result contradicts the standard interpretation of the Josephson effect as tunneling of bosonic pairs.



The new explanation: The Josephson effect is a result of interfering Rabi processes to which also broken Cooper pairs contribute.

References

[1] M.O.J. Heikkinen, F. Massel, J. Kajala, M.J. Leskinen, Gh.-S. Paraoanu, and P. Törmä, arXiv:0911.4678 (2009)