Confinement-induced Sarma phase in Resonantly interacting Fermi mixtures

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Trapped Fermi mixtures

All ultracold atom experiments[1,2] are performed in a harmonic trap to avoid contact of the atoms with material walls. Due to this trapping potential the atomic cloud is never homogeneous. However, typically the trapping frequency corresponds to a small energy scale, so that we may use the so-called local-density approximation (LDA).
But even if the trap frequency is small, LDA may still break down. An important example is the presence of an interface in the trap due to a first-order phase transition...

Interaction effects

The normal equation of state is known exactly from Monte-Carlo results[3], also the superfluid state is known. They appear to behave mean-field like. We therefore model the fully interacting states in the following way,

$$\tilde{\mu}_\sigma = \mu_\sigma + f_\sigma(\mu_1, \mu_2, |\Delta|) \qquad (2)$$

This *f* is choosen such that the eos exactly reproduces the know eos in the nomal state and in the superfluid state.

Gradient term

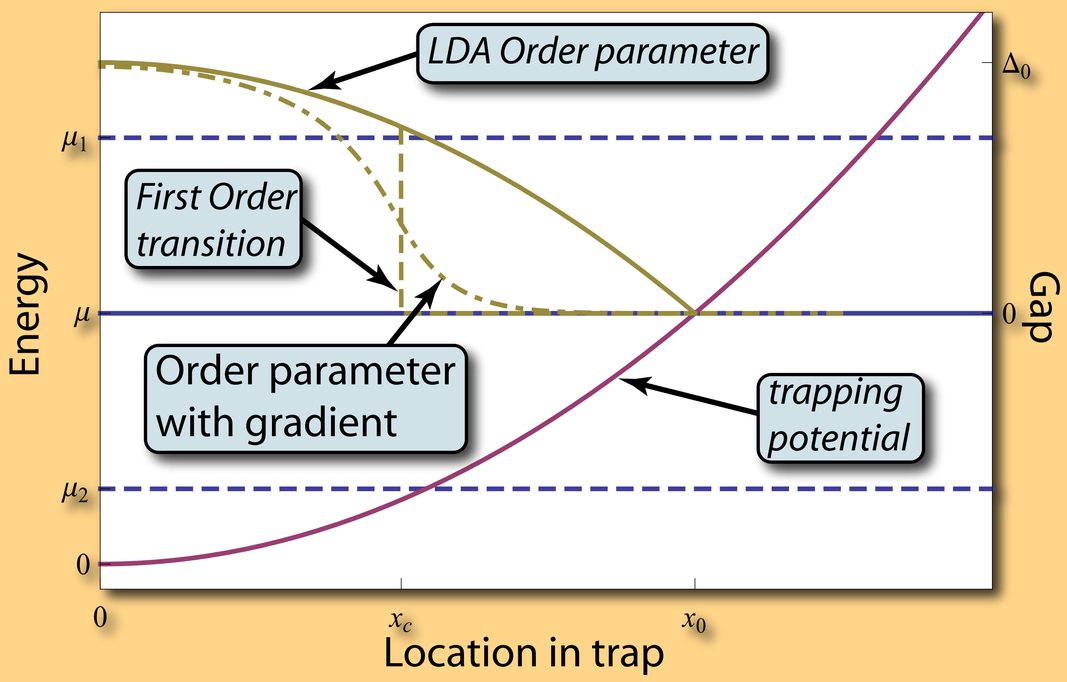
The energy functional we use also describes the system when Δ is not in a minimum, allowing us to investigate inhomogeneous effects. We try to model these effects by adding a single gradient term to the energy functional,

$$\Omega_{\mathrm{grad}} = \Omega_{\mathrm{BCS}}[\tilde{\mu}_1, \tilde{\mu}_2] + c\ (\nabla\Delta)^2 \qquad (3)$$

The constant *c* can be calculated in certain limits, however because the strong interactions, a fitted value might be a bit different (in this case a bit larger).

The trap

The particles in the experiments are confined to a harmonic trap. This can be modeled by letting the chemical potential depend on *x*, $\mu(x) = \mu - V(x)$.
The order parameter is proportional to μ, and therefore follows the shape of the trap.



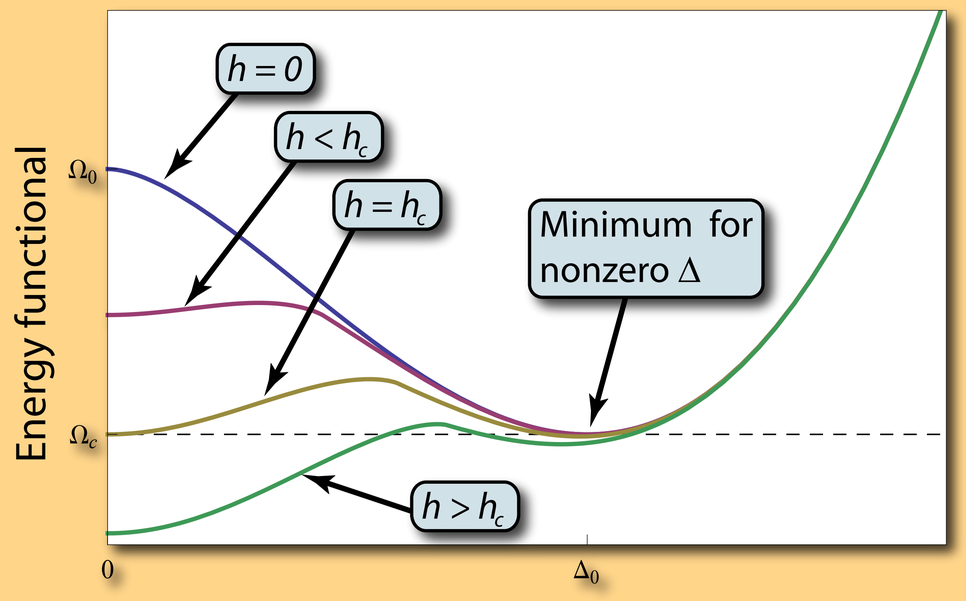
At a certain critical location in the trap, the relative chemical potential difference hits a critical value, making the gas normal again.

A superfluid

The experiments have two Fermion species that interact with each other, at low enough temperatures, this causes the particles to pair up and form Cooper pairs, which is superfluidity. At a Feshbach resonance the interaction parameter (scattering length) diverges, so we use a more phenomenological method, a Landau-Ginzburg energy functional, instead of a perturbative approach.
This energy functional gives an energy for different values of the order parameter (Δ) which is a measure for the pairing. We use the standard BCS expression,

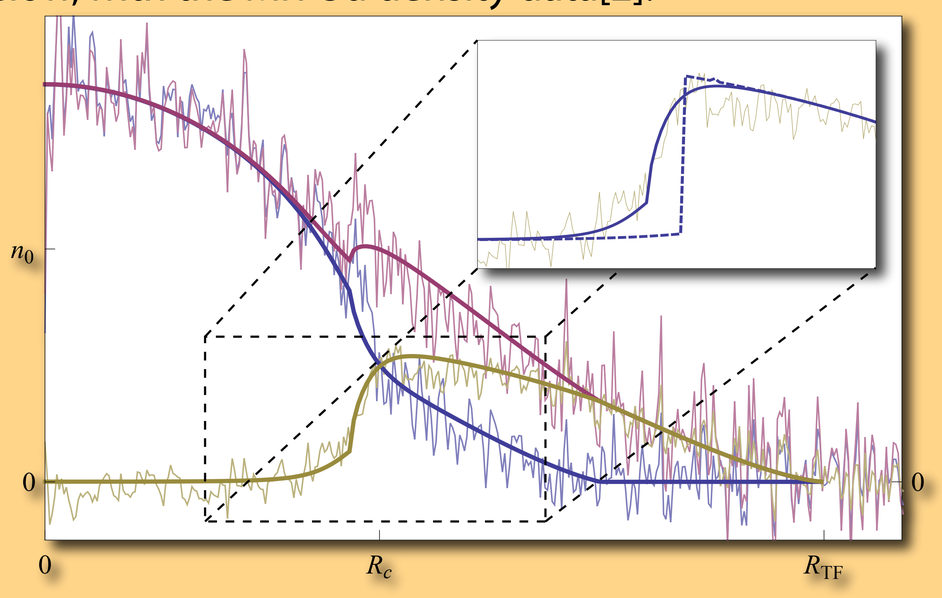
$$\Omega_{\mathrm{BCS}}[\mu_1, \mu_2] = \frac{1}{V}\sum_{\boldsymbol{k}}\left(\epsilon_{\boldsymbol{k}} - \mu - \hbar\omega_{\boldsymbol{k}} + \frac{|\Delta|^2}{2\epsilon_{\boldsymbol{k}}}\right) - \frac{1}{V\beta}\sum_{\boldsymbol{k},\sigma}\log(1 + \mathrm{e}^{-\beta\hbar\omega_{\boldsymbol{k},\sigma}}) \qquad (1)$$

with, $\hbar\omega_{\boldsymbol{k}} = \sqrt{(\epsilon_k - \mu)^2 + |\Delta|^2}$ and $\hbar\omega_{\boldsymbol{k},\sigma} = \hbar\omega_{\boldsymbol{k}} + (\mu_\sigma - \mu_{\bar{\sigma}})/2$.
The functional is plotted for various chemical potential differences as a function of the order parameter:



Result - Induced Sarma phase

The density is computed as $n_\sigma = -\partial\Omega/\partial\mu_\sigma$
At zero temperature the best fit is shown in the figure below, with the MIT 3d density data[2]:



The kink in the densities signals the transition to a gapless phase, which is the exotic Sarma phase[4]. This phase is unstable homogeneously, but is stabilized by the trapping potential.

[1] G. B. Partridge, W. Li, R. I. Kamar, Y.-a. Liao, and R. G. Hulet, Science 311, 503 (2006).
[2] Y. Shin, C. Schunck, A. Schirotzek, and W. Ketterle, Nature 451, 689 (2008).
[3] C. Lobo, A. Recati, S. Giorgini, and S. Stringari, Phys. Rev. Lett. 97, 200403 (2006).
[4] K. B. Gubbels, M. W. J. Romans, and H. T. C. Stoof, Phys. Rev. Lett. 97, 210402 (2006).