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"The saddle point free energy in alkali atoms"

به صورت پوستر ارائه نمودند.

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The saddle point free energy in alkali atoms

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ABSTRACT

We consider a polarized Fermi mixture. We concentrate on the saddle point free energy of the system. We obtain the functional dependence of the free energy of the system on average and imbalanced chemical potentials with numerical calculations.

Much of the interest in ultra-cold Fermi gases comes from their amazing tunability. In balanced mixtures of fermions, this tunability is exploited to study the crossover from a Bose-Einstein condensate (BEC) of molecules to a Bardeen-Cooper-Schrieffer (BCS) superfluid [1]. In the case of imbalanced mixtures of spin polarized Fermi gases, since the BCS-phase cannot support polarization at zero temperature, one typically expects, in a harmonic trap, phase separation into an unpolarized superfluid core, surrounded by the polarized normal Fermi gases. However much research has been done about this subject [2-3]. One of the interesting results in this connection is the thermodynamic potential for these systems. The Ginzburg–Landau (GL) approach is a powerful tool for this aim. Recently, the GL method was re-derived in the context of superfluid ultracold Fermi gases [4].In this paper, we consider a system consist of two spin species. With masses $m_\uparrow$ and $m_\downarrow$, and chemical potentials $\mu_\uparrow$ and $\mu_\downarrow$. The $\uparrow - \downarrow$ interaction is assumed to be a contact interaction characterized by the coupling constant $V = -4\pi\hbar^2 a/m_R$ with $m_R = 2m_\uparrow m_\downarrow / (m_\uparrow + m_\downarrow)$. Also a is the scattering length. We define the imbalanced chemical potential,

$h_\sigma = (\mu_\sigma - \mu_{\bar{\sigma}})/2$, and the average chemical potential, $\mu_\sigma = (\mu_\sigma + \mu_{\bar{\sigma}})/2$. Using the Bogoliubov-de Gennes equations, one finds the spectra in superfluid phase as[5]

$$E_p = -h_\sigma \pm \frac{\hbar^2 k^2}{2m_\sigma} + \sqrt{\mu_\sigma^2 + \Delta^2} \qquad (1)$$

where $\varepsilon_p = (\hbar^2 k^2)/2m_\sigma - \mu_\sigma$) and $m_\sigma = 2m_\uparrow m_\downarrow / (m_\uparrow - m_\downarrow)$. Δ is the gap function.

Also, using the functional integral formalism over the fermion fields (the Grassmann variables) and Green's functions technique in quantum field theory, the saddle point free energy for this system is given by [4] :

$$\Omega_\uparrow = -\int \frac{d\vec{k}}{(2\pi)^3} \left[\frac{1}{\beta} \ln\left(2\cosh\beta E_p + 2\cosh\beta h_\uparrow\right) - \varepsilon_p - \frac{m_\uparrow \Delta^2}{k^2} \right] - \frac{m_\uparrow \Delta^2}{4\pi a} \qquad (2)$$

where $\beta = 1/K_B T$, T is the temperature, K_B is the Boltzmann constant. It should be noted that in fact, an exact solution is not possible to obtain the free energy. There is a way, in essence non-perturbative, to approximate the integral existing in the action, called saddle point method. In this approximation, the fields near the lowest point of the action functional contribute most to the path integration, extracting this lowest point gives zeroth approximation of the integral. For obtaining the saddle point free energy, $\Omega_\uparrow$, we should first obtain the values of the proper parameters, such as $h_\uparrow$, existing in Eq (2). Thus find $h_\uparrow$ and $\mu_\uparrow$ via the Clogston limit. Also, we write the $m_\uparrow$ and $m_\downarrow$ in terms of mass ratio, $m_\uparrow = m_\downarrow / m_\downarrow$, and take the allowed range of the values of $m_\uparrow$. By fixing the value of $m_\uparrow$ & $\mu_\downarrow$ & and using the allowed values of these relevant physical parameters [6], we plot the free energy, $\Omega_\uparrow$, as a function of these proper parameters. It should be

mentioned that in the numerical calculations, the energies (such as $\Omega_\uparrow$, $h_\uparrow$, $\mu_\uparrow$ and Δ) are measured with respect to $K_B T_F$ (T_F is Fermi temperature; also, throughout the paper, we used $K_B = 1$). Figure 1 shows the saddle point free energy, $\Omega_\uparrow$, in terms of average chemical potential, $\mu_\uparrow$. The free energy decreases with the average chemical potentials. This result is due to the existence of the term $-\mu_\uparrow N$ in the free energy (thermodynamic potential).

Fig 1. $\Omega_\uparrow$ versus $\mu_\uparrow$ for a constant temperature and a constant mass ratio

Figure 2 shows the saddle point free energy, $\Omega_\uparrow$, in terms of $h_\uparrow$

Fig 2. $\Omega_\uparrow$ versus $h_\uparrow$ for a constant temperature and a constant mass ratio

Conclusions

We considered a mixture of polarized Fermi gases. The dependence of the saddle point free energy for this system with the average and imbalanced chemical potentials of the system were numerically calculated. The free energy decreases with the average chemical potentials. This result is reversed for the imbalanced chemical potentials (the free energy increases with the imbalanced chemical potentials). We claim the free energy can be controlled by experimentalist via average and imbalanced chemical potentials.

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