liquids with the topological charge differing from that which is inherent in ordinary Fermi liquid. We have analyzed few remarkable features of such systems. Among them: i) presence of two subsystems one of which named the condensate contains the macroscopic number of quasiparticles with the same single-particle energies $\varepsilon(\mathbf{p}) = \mu$ but with the different momenta p, ii) change of the structure of the single particle Green functions which reveals itself in vanishing the jump in the momentum distribution of particles at the point $p = p_F$, iii) nonregular behavior of the density of states $\rho(\varepsilon)$ near the phase transition point, iv) the absence of BSC-exponential smallness of the gap Δ in the single particle excitation spectrum of the superfluid system with the fermion condensate.

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A SYSTEMATIC CONTRIBUTION TO THE BINDING ENERGY OF NUCLEI

A. Bulgac[1)], V. R. Shaginyan

[1)] *Department of Physics, Box 351560, University of Washington, Seattle, WA 98195-1560, USA*

The Okamoto–Nolen–Schiffer anomaly in the binding energy differences of mirror nuclei [1] has attracted much interest during the last 3 decades. Most of the earlier attempts of resolving the anomaly addressed many–body effects suspected of being at the root of the problem. During the last years the efforts have shifted towards trying to explain the magnitude of the anomaly in terms of the Charge Symmetry Breaking (CSB) nuclear forces. A correction arising from CBS forces, taken within the usual perturbative estimate, has a volume character and its main term should be proportional to the number of protons (or neutrons). The correction we are discussing here has a completely different mass dependence and is proportional to the nuclear surface, i.e. in case of the Coulomb interaction is $\propto Z^{2/3}$. We show that there is a systematic many–body mechanism, which enhances the contribution due to the Coulomb interaction in particular, and which is based on the common feature of a self-sustaining system, the presence of the surface [2].

The ground state energy E of nucleus can be written in terms of the density functional approach as follows

$$E = F_0[\rho_p(\mathbf{r}), \rho_n(\mathbf{r})] + F_c[\rho_p(\mathbf{r}), \rho_n(\mathbf{r})]. \tag{5}$$

Here F_0 is the main part of the functional related to isospin symmetry conserved forces dependent symmetrically on the densities ρ_p, ρ_n, while F_c is due to CSB forces, i.e., to the Coulomb interaction in our case, the densities $\rho_p(\mathbf{r})$, $\rho_n(\mathbf{r})$ are the single particles densities of neutrons and protons, respectively. The well-known Skyrme functional can be considered as a possible realization of F_0, and F_c is given by

$$F_c[\rho_p(\mathbf{r})] = \frac{e^2}{2} \int \rho_p(\mathbf{r}_1)\rho_p(\mathbf{r}_2)\frac{1}{|\mathbf{r}_1 - \mathbf{r}_2|}\, d\mathbf{r}_1 d\mathbf{r}_2 \tag{6}$$

$$-\frac{e^2}{2}\int[\mathrm{Im}\chi_p^0(\mathbf{r}_1,\mathbf{r}_2,\omega)+\pi\rho_p(\mathbf{r}_1)\delta(\mathbf{r}_1-\mathbf{r}_2)\delta(\omega)]\frac{1}{|\mathbf{r}_1-\mathbf{r}_2|}\frac{d\mathbf{r}_1 d\mathbf{r}_2 d\omega}{\pi}.$$

Here the first term on r.h.s is the Hartree term, the second is the Fock one, $\chi_p^0(\mathbf{r}_1,\mathbf{r}_2,\omega)$ is the linear response function of the non-interacting protons moving in a self-consistent field. Now let us recall that the nucleons move in a correlated manner in the nucleus. That is, instead of the linear response function $\chi_p^0(\mathbf{r}_1,\mathbf{r}_2,\omega)$, we have to use the linear response function $\chi_p(\mathbf{r}_1,\mathbf{r}_2,\omega)$ calculated with $V(\mathbf{r}_1,\mathbf{r}_2)$ being the effective interaction, related with the strong nucleon-nucleon interaction. As a result, we have to add on r.h.s. of Eq. (2) the third term F_c^{corr}, which comes from the difference $\chi_p-\chi_p^0$ and gives rise to the so called Coulomb correlation energy, being the first order in the Coulomb interaction:

$$F_c^{corr}[\rho_p(\mathbf{r})]=-\frac{e^2}{2}\int\mathrm{Im}[\chi_p(\mathbf{r}_1,\mathbf{r}_2,\omega)-\chi_p^0(\mathbf{r}_1,\mathbf{r}_2,\omega)]\frac{1}{|\mathbf{r}_1-\mathbf{r}_2|}\frac{d\mathbf{r}_1 d\mathbf{r}_2 d\omega}{\pi}. \tag{7}$$

The systematic contribution to the binding energy we are discussing here, arises from the correlation part of the energy, Eq. (3). We shall discuss this correlation energy contribution first in infinite homogeneous nuclear matter as a function ot the density, then in semi-infinite matter and at last in finite systems. We shall study the correlation energy within the well-known jellium model in order to get rid of the Hartree part of the Coulomb energy.

Since the residual interaction V has a strong density dependence and in the region of low densities the *isoscalar* part is strongly attractive, the uniform nuclear matter becomes unstable around $\rho\simeq 0.6\rho_0$. The *isoscalar* part of the linear response function χ has a pole at $\omega=0$ at the point where the nuclear compressibility vanishes (and the spinodal instability sets in) and as result the *isoscalar* Coulomb correlation energy diverges. It is noteworthy to remember that the instability occurs in the *isoscalar* channel, and even though the Coulomb interaction seemingly breaks the isospin symmetry and one might naively expect that the isovector collective modes would be perhaps more relevant, the major contribution occurs in the isoscalar channel. With decreasing density the isovector Coulomb correlation energy decreases monotonically in magnitude and no singularity ever appears in this channel.

The above remarks allow us to draw at once several qualitative conclusions. First of all the Z-dependence of various terms in Eqs. (2,3) for a finite systems should read as follows

$$\Delta E_H\sim Z^2,\qquad \Delta E_{ex}\sim Z,\qquad \Delta E_{corr}\sim a_v Z+a_s Z^{2/3} \tag{8}$$

and most likely the major contribution to the Coulomb correlation energy will arise from the surface of a nucleus (i.e. $|a_v|\ll a_s$). Moreover one can fairly well expect that $a_s>0$, since in the surface region the residual interaction is attractive, while the Coulomb exchange contribution is negative and one can expect a partial cancelation of these contributions.

Because of the above mentioned instability in the isoscalar response at low densities, the surface region requires a more thorough treatment. The isoscalar and isovector Coulomb correlation energies for semi-infinite nuclear matter have a quite different behavior as functions of the density $\rho_p(\mathbf{r})$. The isovector part, while larger in the interior as compared to isoscalar part, is much smaller and decreasing in the surface region. At the same time the isoscalar component of the Coulomb correlation energy has a very prominent peak at the surface, as one might have expected from our earlier argument for the case of infinite homogeneous matter of low density. It is worthy of note that it is the peak that gives the main contribution to the surface tension σ_c and, as one could anticipate, to the binding energy

differences of mirror nuclei. Using these results for semi–infinite nuclear matter one can now extract the volume and surface terms in the Coulomb correlation energy, and thus one gets $a_v \approx -0.1 \pm 0.1$ MeV and $a_s \approx 1.0 \ldots 1.2$ Mev respectively.

We have considered the four pairs of mirror nuclei mass differences (^{15}O-^{15}N; ^{17}F-^{17}O; ^{39}Ca-^{39}K; ^{41}Sc-^{41}Ca). These differences have been calculated, using $SIII$ interaction and including the Coulomb correlation energy. We have included also the electromagnetic corrections, the vacuum polarization, and the finite radius of a neutron and proton. The results of the calculations are in a good agreement (within 70 keV) with the experiment [1]. The contribution of the Coulomb correlation energy to the Coulomb displacement energy is $\delta E_{corr} = 0.33$ MeV in the $A = 40$ region, and $\delta E_{corr} = 0.25$ MeV in the $A = 16$ region. We estimate the accuracy of the calculation of δE_{corr} within 20%.

We have also carried out direct computations of δE_{corr}, considering finite nuclei. Since the enhancement of the Coulomb correlation energy is due to the existence of the surface, and thus is determined by gross nuclear features, we can limit our analysis of this phenomenon within the framework of simple models, choosing the effective interaction of separable form. The calculated δE_{corr} are of the order 200 ... 300 keV in either oxygen or calcium region, i.e. of the same magnitude as the Okamoto–Nolen–Schiffer anomaly. Thus, the direct calculations of δE_{corr} are in a good agreement with the calculations of δE_{corr} which have been based on semi-infinite matter model.

It is worthy of note that the Coulomb correlation energy can lead to strong effects in barrier tunneling in heavy nuclei, giving the appreciable contribution to the surface tension, as it can be seen from the found value of $a_s \approx 1$ MeV. We do not claim that the effect we have described here, the strong enhancement of the Coulomb correlation energy, due to the existence of a nuclear surface, is fully responsible for this anomaly. One has of course to consider the contribution of the CSB nuclear forces as well, and very likely a similar enhancement mechanism for their contribution. An analysis which we have performed shows that the mechanism we have described here can lead to a significant reduction of the estimated strength of CSB nuclear forces.

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