Stoner criterion for degenerate neutron-proton system in astrophysics

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The research is done according to the suggestion of V.G. Baryshevsky and V.V. Tikhomirov. For the model of extremely degenerate mixture of neutron and proton gases with contact nuclear interaction magnetic susceptibility is calculated and Stoner ferromagnetism criterion is obtained for the case of weak external magnetic field:

$$\nu_{0p}^2(\nu_{0n}((g_s - g_t)^2 - g_{pp}g_{nn}) + g_{pp}) + (1 - g_{nn}\nu_{0n})(\frac{e^2 m_p^2}{2\pi^3\hbar^4} - \nu_{0p}) > 0,$$

$$\nu_{0i} = \frac{3m_i n_i^{1/3}}{2\hbar^2(3\pi^2)^{2/3}}, g_{t,s} = J_{np}a_{t,s}, g_{ii} = J_{ii}a_i, J_{ij} = \frac{\pi\hbar^2(m_i + m_j)}{m_i m_j}.$$

Here $i = n, p$; n_i and m_i are nucleon densities and masses, respectively. The values of scattering lengths are (in fm): a_t=5.42 (triplet neutron-proton), a_s=-23.71 (singlet neutron-proton), a_n=a_p=-17.2 (singlet). The last equality is valid when proton Hartree energy is compensated by electrons. Landau quantizing for protons is neglected. The approach applied here was used to obtain Stoner criterion for 1-component Fermi-gas [1,p. 187, 198].

Minimal nucleon densities necessary for ferromagnetism and polarizatonal magnetic fields initiation are about $3.156 \cdot 10^{34}$ cm^{-3}. Ferromagnetism for symmetric nuclear matter is expected to occur at densities of $\sim 6 \cdot 10^{35}$ cm^{-3}. It can be possible at Supernovae II explosions, where neutrons appear at collisions between protons and antineutrinos. Perturbation theory is not appliable for contact nuclear interaction at such densities. The consideration of Coulomb exchange interaction between protons: 1) slightly decreases the minimal ferromagnetic density for protons but doesn't change it for neutrons; 2)leads to formation of extra region of ferromagnetism including the neutronization threshold. The last case corresponds also to the upper layers of white dwarfs and can explain the origin of their magnetic fields, but perturbation theory is not appliable for proton Coulomb interaction at such densities.

[1]L.S. Levitov, A.V. Shitov.*Green Functions* [in Russian] (Fizmatlit, Moscow, 2003).