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INTRINSIC MAGNETIC POLARIZABILITY CONTRIBUTION TO THE SUSCEPTIBILITY OF DENSE NEUTRON MATTER

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ABSTRACT

It is shown that, apart from the neutron interaction contribution to the susceptibility of neutron stars, there is an additional contribution coming from the magnetic polarizability β_n of individual neutrons. For $\beta_n \approx \approx 10^{-4}$ fm^3, this part overwhelms the interaction contribution for $k_F \gtrsim 3.5$ fm^{-1}. No transition to ferromagnetic state is predicted in the interesting density region.

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The magnetic susceptibility of neutron stars has been vigorously debated lately in connection with pulsars. If pulsars possess intense magnetic fields, their magnetic properties are of considerable interest. The dense matter properties were studied initially [1] using simplified neutron-neutron potentials, and it was believed that a transition to ferromagnetic state could take place in a region of densities about $k_F \sim (\text{few})\ \text{fm}^{-1}$, where k_F is the momentum of the corresponding Fermi gas. Recently, Pandharipande et al. [2] have shown that the use of a realistic neutron-neutron potential, as the Reid soft-core [3], gives values for the paramagnetic susceptibility which are always below the Pauli paramagnetic susceptibility of the Fermi gas, in the interesting density region. Then no transition to ferromagnetic state is expected.

The purpose of the present note is to show that, in such considerations, it is necessary to include the contribution to the magnetic susceptibility coming from the polarizability of <u>individual</u> neutrons. The nucleons, being objects with internal structure, react to the presence of magnetic fields. If the intrinsic magnetic polarizability of the neutron is denoted by β_n, this contribution gives an additional amount

$$\chi_n = \beta_n \rho = \beta_n \frac{k_F^3}{3\pi^2} \qquad (1)$$

to the susceptibility. In writing Eq. (1), we assume that we are in a region of densities for which the neutrons still maintain their identity. Furthermore, we put the total contribution to be proportional to the density of neutrons. We have therefore considered the virtual excitations of the neutrons as <u>incoherent</u>, a fairly good approximation for our purposes.

An estimate of the contribution (1) is possible if we have a value of the neutron polarizability. Experimentally there is, to our knowledge, no determination of the magnetic polarizability, even as a remotely interesting limit. However, we note that this value should be very close to that of the proton. It is well known from photoproduction processes that the gross features of inelastic excitations are quite similar for protons and neutrons. The effect we consider corresponds to a neutron induced magnetic dipole produced by the external magnetic field. In the case of the proton, this has been observed in Compton scattering. The amplitude for this process is, to second order in the photon energy, determined by two structure constants, apart from mass, charge and magnetic moment. These constants determine the so-called Rayleigh scattering contribution produced by slowly-varying induced electric and magnetic dipoles driven by the electric and magnetic field of the photon. They are the electric α and magnetic β polarizabilities. The magnitude typical for α and β is given by the exact forward dispersion relation [4]

$$\alpha + \beta = \frac{1}{2\pi^2} \int_{\omega_{th}}^{\infty} \frac{d\omega}{\omega^2} \sigma_T(\omega) = (14.2 \pm 0.3) \times 10^{-4} fm^3 \qquad (2)$$

where $\sigma_T(\omega)$ is the total photo-absorption cross-section.

The experimental measurement of the angular distribution of Compton scattering at low energies, for the proton, was undertaken a decade ago by Goldanskii et al. [5] and more recently by Baranov et al. [6),7)]. They conclude from the data that the eletric polarizability α dominates and that the value of β is, at most, (few) $\times 10^{-4}$ fm^3. This result is quite a surprise, in view of the strong contribution of the magnetic transition to the $\Delta(1236)$ isobar in the sum rule (2). The result $\beta \ll \alpha$ implies a strong cancellation between the contributions of the physical channel baryon resonances and t-channel meson resonances, when a backward dispersion relation [8] for the combination α-β is considered. In Ref. 8) only the known physical channel contribution to the backward sum rule was explicitly computed, giving the result $\beta \sim 10^{-3}$ fm^3. As the ϵ exchange is believed to be the most important contribution in the t-channel, the experimental result for the polarizabilities implies a significant radiative coupling constant of this meson.

We emphasize that this experimental value of β is not the one which is needed in this paper. The measured value for the proton corresponds to the structure constant as seen by the magnetic field of radiation. In Eq. (1), however, we have the magnetic polarizability of the neutron as seen by an external magnetic field. In any case, we believe that the order of magnitude is correct.

When the value 10^{-4} fm^3 is used for β_n, the contribution (1) becomes comparable to the Pauli paramagnetic susceptibility of a Fermi gas

$$\chi_F = \left(\frac{e^2}{4\pi}\right) \frac{\mu^2}{4 m_p^2} \frac{m_n}{\pi^2} k_F \qquad (3)$$

for $k_F \gtrsim 3$ fm^{-1} (μ is the magnetic moment of the neutron, in natural units).

The total magnetic susceptibility of the system is obtained adding the intrinsic contribution of the constituents (1) to the interaction contribution. Even for the small value 10^{-4} fm^3, for the neutron magnetic polarizability, both ingredients are of the same order in the interesting density region. In order to show the sensitivity of our input to the total prediction, we plot in the figure the ratio χ_F/χ_T, where $\chi_T = \chi_{int} + \chi_n$, for $\beta_n = 0$, 10^{-4} and 10^{-3} fm^3. The dependence of χ_{int} with density has been taken from the calculations of Ref. 2). We cannot give a particular prediction for χ_T because the precise value of β_n is unknown. However, it is clear from the figure that χ_n cannot be neglected in the discussions about the magnetic properties of dense systems.

Finally, if Eq. (1) gives a realistic estimate of the effect we are considering, the intrinsic contribution, by itself, cannot give a zero in the function χ_F/χ_T. Unless other mechanisms play a role, no transition to ferromagnetic state is obtained. χ_n changes the value of the susceptibility by a big amount and it cannot be neglected in quantitative discussions of χ_T. On the other hand, its density dependence is such that it cannot alone give rise to a phase transition.

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Figure caption

The ratio of susceptibilities X_F/X_T as function of the density. The total value of $X_T = X_{int} + X_n$ is plotted for different values of the magnetic polarizability β_n of neutrons.

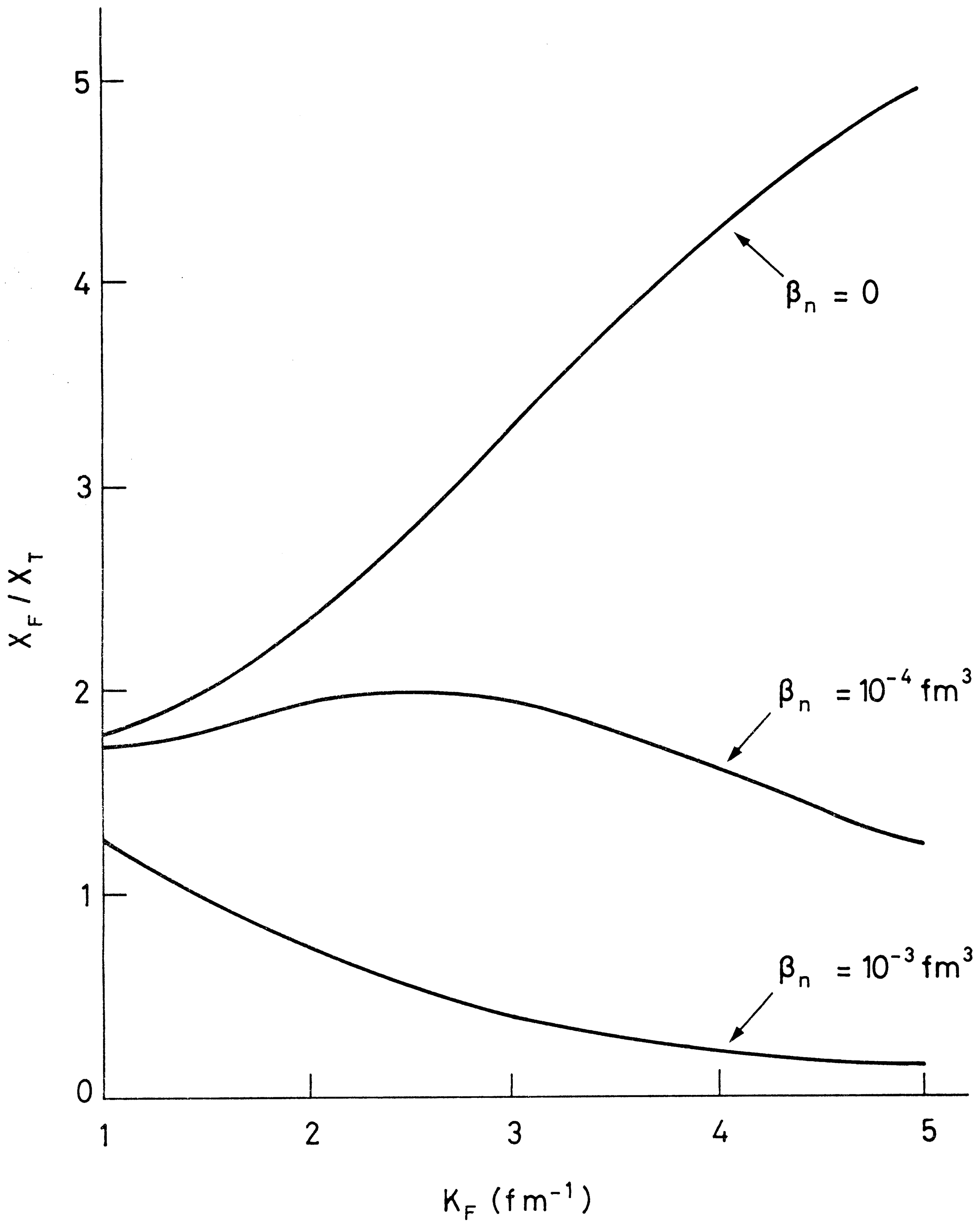

FIG. 1