Stoner criterion for non-degenerate hydrogen in astrophysics

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The main versions of the origin of magnetic fields of white dwarfs (WD) are rotation, hydromagnetic dynamo, magnetic flux conservation during the contraction. WD with hydrogen are the most magnetized ones, and ferromagnetism of protons is also possible.

We consider the relationship between the spin polarization and the energy of protons including the energy of non-interacting protons as well as nuclear energy (contact interaction), exchange and correlational energy. The conditions imposed on the model: 1. The density of hydrogen is enough for metallization (> 10 g/cm^3) but low for neutronization (< 10^7 g/cm^3). 2. The temperature is so high, that there is plasma instead of lattice, and protons are non-degenerate. Such conditions can be fulfilled in outer layers of WD and at Supernovae II explosions. Here is the expression for Stoner criterion for protons:

$$\frac{3\sqrt{\pi}(kT)^{1/2}}{4\alpha(m_pc^2)^{1/2}} + \frac{3\pi\alpha^{1/2}(\hbar c)^{3/2}n_p^{1/2}}{2(m_pc^2)^{1/2}kT} + \frac{kT}{\alpha\hbar c}\left(\frac{1}{|a_n|} + \frac{3r_{0p}m_pkT}{2\hbar^2}\right)^{1} < 1.$$

Here m_p, n_p are proton mass and density of protons (cm^{-3}), respectively; $\alpha = e^2/(\hbar c)$, $r_{0p} = 2.79$ fm, a_n = -17.2 fm ($a_n \approx a_p$ as far as proton Hartree Coulomb energy is compensated by electrons).

One can estimate that ferromagnetism is possible if $T < 10^8$ K, $n_p < 10^{30}$ cm^{-3}. It is more realistic for outer layers of WD than for Supernovae II. For example, if $T \approx 7{\cdot}10^4$ K and $kT \approx 10(3\pi^2n_p)^{2/3}\hbar^2(2m_p)^{-1}$ then $n_p \approx 1.67 \cdot 10^{26}$ cm^{-3}. If proton spin polarization is almost unity then magnetic field strength is $B \approx 4\pi\mu_N\sigma_pn_p \approx 2.97{\cdot}10^4$ Gs, $\sigma_p \approx 2.7928$, μ_N is nuclear magneton. If this magnetic field can affect the spin polarization of protons in lattice in inner layers then the initial magnetic field can be amplified. At $n_p \approx 7.4{\cdot}10^{30}$cm^{-3} (i.e at neutronization threshold) $B \approx 1.31{\cdot}10^9$Gs which is in agreement with observational data [1, p. 4].

Some of the ideas of this work belong to V.G. Baryshevsky and V.V. Tikhomirov.

[1] S. Jordan, R. Aznar Cuadrado, R. Napiwotzki, H.M. Schmid, S.K. Solanki. arxiv.org/abs/astro-ph/0610875v2 – P. 1–10.