I would like to acknowledge my indebtedness to Prof. J. R. Dorfman of the University of Maryland for suggesting the problem and for his most counsel and quidance.

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EFFECT OF A CONSTANT MAGNETIC FIELD ON THE BETA DECAY RATE OF A NEUTRON IMMERSED IN A COMPLETELY DEGENERATE ELECTRON GAS

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Received 23 May 1969

Our previous work on the effect of a constant magnetic field on neutron decay in a vacuum is extended to the case where the process takes place in dense bodies (white dwarfs, neutron stars), at zero temperature.

As part of a general program to examine the various effects of a large magnetic field [1], we have recently calculated [2] the effect of a constant magnetic field on the rate of neutron beta decay in a vacuum and the astrophysical implications [3] arising from same. For consideration of objects such as white dwarfs and neutron stars, where magnetic fields H as large as 10^{14} - 10^{16} G have been speculated to exist [4], it is necessary to take into account the effect on the decay rate of the existing electron sea, the latter being characterized by a number density N, temperature T and chemical potential μ. For $T = 0$, an extension of previous analysis [2, 3] leads to a total β decay rate ($\hbar = c = m_e = 1$)

$$\omega(H,\mu) = \frac{\gamma g_V^2}{\pi^3}(1+3\lambda^2) \times \qquad (1)$$

$$\times \left\{ \sum_{n=0}^{n(\max)} F_n(H, W_0) - \sum_{n=0}^{n'(\max)} F_n(H,\mu)\right\},$$

where

$$F_n(H,Z) = (1-\tfrac{1}{2}\delta_{n0})\{K_n(W_0^2+Z^2-K_n^2)+\tfrac{1}{3}K_n^3 - W_0 K_n Z$$

$$- W_0(Z^2-K_n^2)\ \mathrm{ar\ sinh}[K_n^2/(Z^2-K_n^2)]^{\frac{1}{2}}\}$$

and $K_n \equiv (Z^2 - 1 - 4\gamma n)^{\frac{1}{2}}$, $\lambda = g_A/g_V \approx 1.18$, $W_0 =$ $= 2.53$ is the total decay energy, $\gamma \equiv H/2H_c$ (where $H_c = 4.4 \times 10^{13}$G) and $n(\max)$ and $n'(\max)$

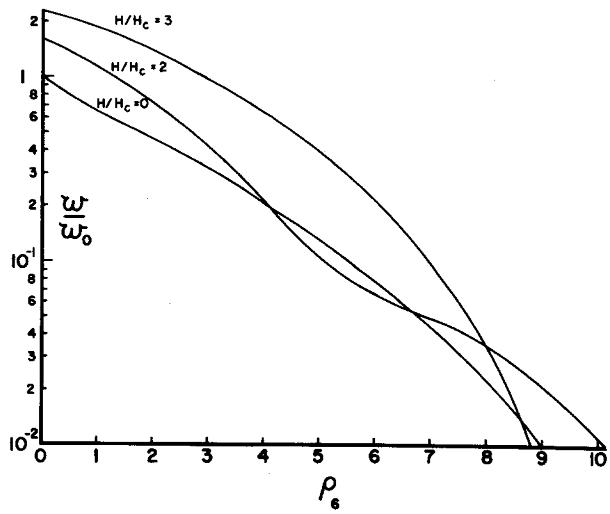

Fig. 1. The dependence of ω, the β decay rate in a magnetic field of a neutron immersed in a completely degenerate electron gas, normalized to the free-field decay rate in vacuum ω_0, as a function of the nuclear matter density ρ_6, for values of H/H_c equal to 0, 2 and 3.

are the largest integers occuring in $(W_0^2 - 1)/4\gamma$ and $(\mu^2 - 1)/4\gamma$, respectively.

Now the energy eigenvalues E of a relativistic electron in a magnetic field $H = H_z$ are [5]

$$E = \{1 + k^2 + (H/H_c)(2n+s-1)\}^{\frac{1}{2}}, \quad (3)$$

where $n = 0, 1, 2$ -----, $s = \pm 1$ and k is the z component of the electron momentum. Thus, the number density is

$$N = \frac{1}{4\pi^2} \frac{H}{H_c} \sum_{n=0}^{\infty} \sum_{s=\pm1} \int_{-\infty}^{\infty} \{1 + \exp[(E-\mu)/kt]\}^{-1} dk, \quad (4)$$

and so, analogous to the non-relativistic case [6], μ may be determined implicitly as a function of N and H. Now N may be related to the nuclear matter density ρ by the relation $m_n N = (\rho/\mu_e)$, where μ_e = (number of nucleons/number of protons), and m_n is the nucleon mass.

In the case of completely degenerate electron gas, the Fermi distribution function reduces to a step function and eq. (4) reduces to

$$\rho_6 = 4.16\ (H/H_c)^{\frac{3}{2}} \sum_{n=0}^{n'(\max)} (1 - \tfrac{1}{2}\delta_{n0})(Q^2 - n)^{\frac{1}{2}}\ \mathrm{g/cm^3} \quad (5)$$

where $\rho_6 \equiv 10^{-6}(\rho/\mu_e)$ and $Q \equiv \{(\mu^2 - 1)/4\gamma\}^{\frac{1}{2}}$. This equation was used for the numerical evaluation of explicit values of μ for various values of ρ_6 and H. In fig. 1 we plotted $\omega(H, \mu)$ as a function of ρ_6 for various values of H and we have also included the $H = 0$ rate for comparison. The number of nodes increases with decreasing H, reflecting the fact that $n'(\max)$ increases with decreasing H. For a given ρ_6, the change in the decay rate as a function of H is essentially caused by the effect of the magnetic field on the density of final states of the electron [7]. Similar phase space effects are relevant to the calculation of the changes produced in the cooling rate of neutron stars [8] by a magnetic field.

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DIAMAGNETIC SUSCEPTIBILITY OF SUPERCONDUCTING TIN ABOVE T_c

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Received 30 May 1969

In a bulk sample of pure tin a small, but strongly temperature and field dependent diamagnetic susceptibility has been found, extending over a temperature range of about 30 millidegrees above the transition temperature to superconductivity.

Recently the onset of superconductivity has attracted much interest [1-5]. The increase of the electrical conductivity above T_c, due to fluctuations of the order parameter has been observed by Glover [1] with thin films.

According to Schmidt [5] these fluctuations should cause a singularity of the diamagnetic susceptibility proportional to the Ginzburg-Landau correlation length in a bulk sample, whereas Aslamazov and Larkin [3] arrive at the statement, that anomalous diamagnetism should be absent.

We have investigated the magnetic behavior of a single crystal of tin with a residual resistivity ratio $(\rho_{4.2}/\rho_{295}) = 5 \times 10^{-5}$ near the transition to superconductivity.