Structure Properties of Hadron Stars Under Strong Magnetic fields

Suman Thakur* and Shashi K. Dhiman†
Department of Physics, Himachal Pradesh University Shimla-171005, INDIA

Introduction

The Astrophysical compact stars are providing us the opportunity to study the strongly interacting dense nuclear matter under the extreme condition in their interior, which has not yet reproduced in the laborartory environment. Theoretically, it is discussed that the composition of compact stars is ranging from the mixture of hadrons, leptons to various phases of superconducting quark matter under beta equilibrium. Many recent observations of gravitational maximum masses and extraction radius of the neutron stars and pulsars have imposed restriction on their composition, to as a plausible set of equations of state (EOS) must support the limits of observed maximum gravitational masses of compact stars. Other physical properties characterises a neutron star, their fast rotation (or spin) and their strong magnetic field.

In the present work, we study the effect of strong magentic fields on the structure properties of neutron star. We have constructed a set of equations of state with composition of neutron, proton, hyperons and lepton in beta equilibrium under the strong magnetic field varying upto eB = $1.2\times10^{-2} GeV^2$. To study the influence of magnetic field in the steller interior, we consider altogether two decay modes of a density-dependent magnetic field, a fast decay(γ=3.00, β=0.02), a slow decay(γ=2.00, β=0.05).

Theoretical Framework

The total energy density and total pressure of dense nuclear matter in the framework of Field Theoretial Based Relativisitic Mean Field (FTRMF) can be written as,

$$\mathcal{E}^H = \mathcal{E}_m + \mathcal{E}_l + \frac{[B(\frac{\rho}{\rho_0})]^2}{2}, \qquad (1)$$

$$P^H = P_m + P_l + \frac{[B(\frac{\rho}{\rho_0})]^2}{2}, \qquad (2)$$

where $\mathcal{E}_m$ and $\mathcal{E}_l$ corresponds to energy densities of baryons and leptons, respectively. The P_m and P_l, corresponds to pressures of baryons and leptons, respectively. The $B(\rho/\rho_0)$ is representing density-dependent magnetic field [1]. The expression of $\mathcal{E}_m$ in FTRMF can be written as,

$$\begin{aligned}\mathcal{E}_m &= (\mathcal{E}_b^c + \mathcal{E}_b^n) + \frac{1}{2}m_\sigma^2\sigma^2 - \frac{1}{2}m_\omega^2\omega^2 \\ &- \frac{1}{2}m_\rho^2\rho^2 + \frac{1}{2}m_{\sigma^*}^2\sigma^{*2} - \frac{1}{2}m_{\omega^*}^2\omega^{*2} \\ &+ \sum_B (g_{\omega B}\omega\rho_B + g_{\rho B}\tau_{3B} + g_{\omega^* B}\omega^*\rho_B\rho) \\ &+ \frac{\overline{\kappa}}{6}g_{\sigma N}^3\sigma^3 + \frac{\overline{\lambda}}{24}g_{\sigma N}^4\sigma^4 - \frac{\zeta}{24}g_{\omega N}^4\omega^4 \\ &- \frac{\xi}{24}g_{\rho N}^4\rho^4 - \overline{\alpha_1}g_{\sigma N}g_{\omega N}^2\sigma\omega^2 \\ &- \frac{1}{2}\overline{\alpha_1}' g_{\sigma N}^2 g_{\omega N}^2\sigma^2\omega^2 - \overline{\alpha_2}g_{\sigma N}g_{\rho N}^2\sigma\rho^2 \\ &- \frac{1}{2}\overline{\alpha_2}' g_{\sigma N}^2 g_{\rho N}^2\sigma^2\rho^2 - \frac{1}{2}\overline{\alpha_3}' g_{\omega N}^2 g_{\rho N}^2\omega^2\rho^2, \qquad (3)\end{aligned}$$

where $\mathcal{E}_b^c$ and $\mathcal{E}_b^n$ are the energy densities of charged and uncharged baryons [1], respectively.

Results and Discussions

In present theoretical calculatiom, we have employed BSR12 parametrisation [2] for computing the energy density and pressure of EOSs. The Interaction strength couplings of

*Electronic address: sumanthakur88@gmail.com
†Electronic address: shashi.dhiman@gmail.com

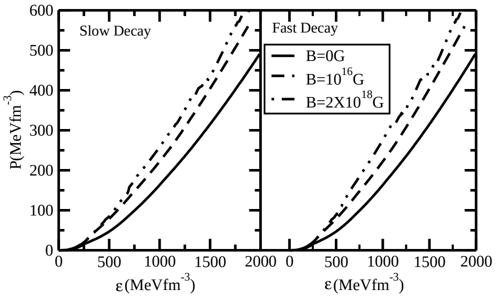

FIG. 1: The variation of energy density $\mathcal{E}^H$ and pressure P^H in units of MeVfm^{-3} is displayed with increasing magnetic fields from eB = 0 - 1.2$\times$ $10^{-2}GeV^2$ for BSR12 model parametrisation.

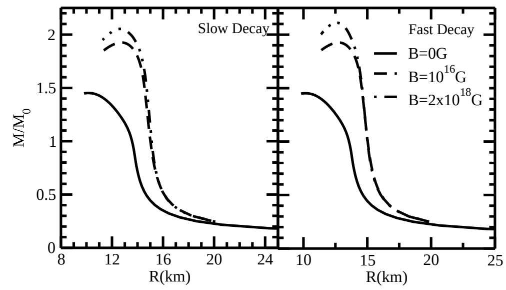

FIG. 2: The Mass-Radius relationship of neutron stars under the influence of strong magnetic field for BSR12 model parametrisation.

hyperons with the meson fields and hyperons with strange meson field are employed as suggested in [2]. For charged particles, the effect of Landau quantization appears as $\sqrt{m_b^{*2} + 2\nu eB}$ in the energy spectra from field equation. Here, ν, representing the Landau level, varying in integer as, $\nu = 0, 1, 2, ., ., ., ..$

In Fig.(1), we present the variation of energy density $\mathcal{E}^H$ and pressure P^H in units of MeVfm^{-3} with increasing magnetic fields from eB = 0 - 1.2$\times$ $10^{-2}GeV^2$. It is observed that EOS get stiffened as the magnetic fields increased and the EOS of dense matter become unastable beyond eB = 1.2$\times$ $10^{-2}GeV^2$, in the present model calculation for both case of decays.

In Table (I and II), we present variation in gravitational radius, R(km), gravitational maximum mass $M_{Max}(M_\odot)$ and corresponding moment of inertia, MI($10^{45}gcm^2$) with increasing magnetic field. It is observed from Tables(I and II) that the M_{Max} and its MI is increasing to the order of magnitude $\approx$ 0.50$M_\odot$ and 0.9$\times 10^{45}gcm^2$, respectively, as the magnetic field increased from 0G to 10^{16}G. Thereafter, there is a small variation in mass of compact star to the order of 0.1$M_\odot$. The gravitational radius increased by a magnitude of 2.60km, as the magnetic field increased from 0G to 10^{16}G, and, then it remains almost constant as the variation in the radius of compact star is about 0.1km with increase of magnetic field from $10^{16}G$ to $2 \times 10^{18}G$.

In Fig.(2) we present the Mass-Radius relationship of hadron stars under the influence of strong magnetic field for BSR12 model parametrisation.

TABLE I: The variation in gravitational radius R in km, gravitational maximum mass in unit of solar $M_\odot$ and coresspounding values of moment of inertia of neutron stars with increasing magnetic fields in fast decay.

B	$R(km)$	$M_{max}(M_\odot)$	MI($10^{45}gcm^2$)
$0G$	10.1576	1.4522	0.664
$10^{16}G$	12.7448	1.9262	1.522
$2 \times 10^{18}G$	12.6219	2.1109	1.660

TABLE II: Same as Table I but in slow decay.

B	$R(km)$	$M_{max}(M_\odot)$	MI($10^{45}gcm^2$)
$0G$	10.1576	1.4522	0.664
$10^{16}G$	12.7521	1.9256	1.525
$2 \times 10^{18}G$	12.6587	2.0539	1.610

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