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MSW effect with quark matter: Neutron Star as a case study

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Abstract: Recent astrophysical observations and *ab initio* studies increasingly hint at the possible existence of strange quark matter and baryonic resonances such as Λ^0, Σ^0, Ξ, and Ω in the dense cores of neutron stars. Motivated by these developments, we investigate the Mikheyev–Smirnov–Wolfenstein (MSW) effect in quark matter and explore its role in quark flavor conversion under extreme conditions. In particular, we study resonant oscillations between down and strange quarks in a dense medium. We find that the resonance condition for complete conversion of down quarks into strange quarks requires extremely large matter densities, of the order $\rho_u \simeq 10^5\ \mathrm{fm}^{-3}$. Although such densities are unattainable in ordinary environments, neutron stars naturally provide conditions where quark flavor conversion can become statistically significant, with densities comparable to those expected from charge neutrality constraints in dense matter. Within the Standard Model of particle physics, there exist three generations of quarks and leptons. In the leptonic sector, neutrinos are known to undergo flavor oscillations as they propagate through space-time, a phenomenon that is strongly modified in the presence of matter and played a crucial role in resolving the long-standing solar neutrino puzzle. This matter-induced enhancement of flavor conversion, known as the MSW effect, has been experimentally verified and provides a compelling motivation to explore analogous phenomena in the quark sector. Extending this idea, we propose a novel mechanism of quark flavor oscillation driven by medium effects in dense quark matter. Since neutron stars are composed primarily of neutrons and therefore fundamentally consist of up and down quarks, and given growing evidence for the presence of strange quarks in their interiors, resonant down–strange quark oscillations offer a natural pathway for enhanced strange quark production. Such a mechanism may have important implications for resolving the hyperon puzzle and for understanding the equation of state of dense baryonic matter in neutron stars.

Keywords: Neutron stars; quark matter; MSW effect