$\mathbf{D_S}$ Mesons in Hot and Dense Hyperonic Medium

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Introduction

The study of medium modifications of meson masses is an important topic in strong interaction physics. This has relevance in nuclear astrophysical objects, e.g. in the interior of neutron stars, as well as in the man-made laboratories, where matter under extreme conditions of density and temperature is created in heavy ion collision experiments.

The current article explores the results of treating such medium dependent effects within the framework of a phenomenological, effective Lagrangian. While this framework, based on $SU(3)_L \times SU(3)_R$ symmetry [1], was originally used to study the medium dependent effects for light hadrons, of late, this approach has been generalized to cover the charm sector as well [2, 3]. The objects of investigation here are the D_S mesons, which, are the lightest pseudoscalar ($J^P = 0^-$) mesons, that are both *strange* and *charmed*.

The Chiral Model

We investigate the in-medium properties of the D_S mesons in the chiral $SU(3)_L \times SU(3)_R$ model, generalized to $SU(4)$ to include the charm sector. This is an effective field theoretical model of baryons and mesons, based on a nonlinear realization of chiral symmetry and broken scale-invariance [1]. The various terms responsible for these medium modifications include the vectorial Weinberg-Tomozawa interaction term (at leading order, from the point of view of chiral perturbation theory), a scalar meson exchange term originating from the explicit symmetry breaking term (which breaks the chiral, $U(1)_A$ and $SU(3)_V$ symmetry), as well as the range terms. This approach has been successfully used to describe nuclear matter, finite nuclei, neutron stars and hypernuclei [1].

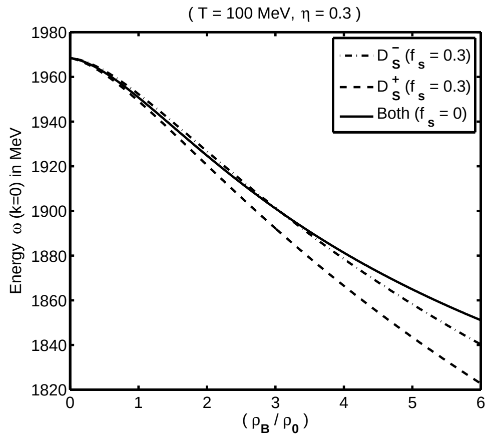

FIG. 1: Mass-degeneracy breaking in hyperonic medium for D_S mesons, as a function of the baryonic density ρ_B (measured in units of the nuclear saturation density, ρ_0), for typical values of temperature, isospin asymmetry and strangeness fraction. Also shown here is the nuclear matter ($f_s = 0$) situation, where both these mesons are observed to be degenerate.

Results and Discussion

We study the medium modifications of D_S mesons in isospin asymmetric, hot, strange hadronic matter, by solving their dispersion relations, obtained from the Lagrangian density within the chiral effective model. The results obtained primarily indicate a reduction in the effective masses of these mesons as compared to their vacuum values, due to a net attractive interaction in the medium. The magnitude of the mass drop is found to grow

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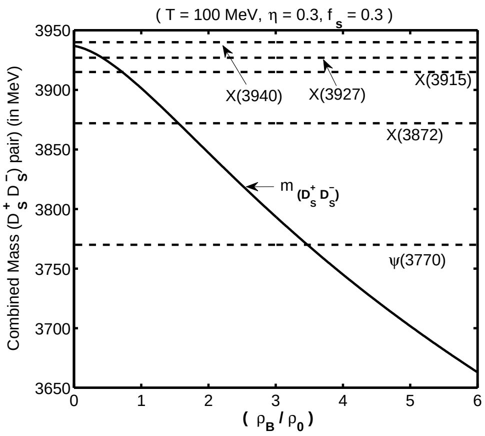

FIG. 2: Mass of $D_S^+ D_S^-$ pair, for typical values of temperature, isospin asymmetry and strangeness fraction, compared to the (vacuum) masses of the excited charmonium states.

with an increase in the baryonic density, but is found to be quite weakly dependent on the isospin asymmetry parameter (η), strangeness fraction (f_s) and the temperature.

Being antiparticles, the two D_S mesons - D_S^+ and D_S^-, possess equal masses in vacuum. In nuclear matter also, this mass degeneracy is respected, even though the in-medium masses are different (reduced) from their vacuum values, as already mentioned. However, upon the inclusion of the hyperons in the medium, this mass degeneracy gets broken (Fig.1). This is due to opposite signs of the Weinberg-Tomozawa term in the interaction Lagrangian (although, its magnitude is the same for both). Further, the magnitude of this interaction term is directly proportional to the number densities of the hyperons, with the result that the mass splitting between D_S^+ and D_S^-, also grows with an increase in the total baryonic density.

Possible Implications

A reduction in the mass of the D_S mesons, with an increase in baryonic density, can result in the opening up of extra decay channels in particle decays of the type $A \rightarrow D_S^+ D_S^-$, above certain threshold density. In fact, a comparison with the charmonium spectrum [4] sheds light on the possible decays, as is shown in Fig. 2 (if we neglect the mass modifications of charmonium states, as a first approximation. However, the decay widths will be modified when the medium modifications of the charmonium states are also taken into account [3]). Above certain threshold density, the mass of the $D_S^+ D_S^-$ pair, is smaller than that of the excited charmonium state, so that the decay of this state into $D_S^+ D_S^-$ pair becomes kinematically possible. The experimental consequences of this effect would be a drop in the yields for these excited charmonium states. Additionally, owing to the semi-leptonic and leptonic decay modes of the D_S mesons themselves [4], with an increased production of D_S mesons, one also expects an overall enhancement in dilepton production from the dense hadronic matter formed, for example, in heavy ion collisions, at moderate collision energies. Apart from an increased production rate, the modifications of the in-medium properties of the D_S mesons can also be reflected in the observed dilepton spectra.

Such experimental consequences are especially interesting in wake of the current and future experimental facilities, such as the (upcoming) Compressed Baryonic Matter (CBM) experiment, at GSI Darmstadt, where such high densities are expected to be reached.

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