The in-medium properties of charm mesons ($D$ and $\bar{D}$) in a hot and dense matter are studied. A self-consistent coupled-channel approach is driven by a broken SU(4) s-wave Tomozawa-Weinberg interaction supplemented by an attractive isoscalar-scalar term. As medium effects, we include Pauli blocking, baryon mean-field bindings, and $\pi$ and open-charm meson self-energies. The dynamically generated $\tilde{\Lambda}_c$ and $\tilde{\Sigma}_c$ resonances in the $DN$ sector remain close to their free space position but acquire large widths. The resultant $D$ meson spectral function, which shows a single pronounced quasiparticle peak close to the free mass that broadens with increasing density, also has a long low energy tail associated with smeared $\tilde{\Lambda}_cN^{-1}$, $\tilde{\Sigma}_cN^{-1}$ configurations. The low-density approximation for the $\bar{D}N$ is questionable already at subsaturation densities. We touch upon the implication of our study for $J/\Psi$ suppression at FAIR.

Keywords: Open-charm mesons, self-consistent coupled-channel calculation, finite temperature, $\Lambda_c(2593)$ and $\Sigma_c(2770)$ resonances

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The future CBM (Compressed Baryon Matter) experiment of the FAIR project at GSI will investigate, among others, the properties of open and hidden charmed mesons in a hot dense baryonic environment. The $J/\Psi$ suppression observed at higher energies might also take place at CBM conditions. A simple explanation for this via $J/\Psi \rightarrow D\bar{D}$ dissociation assuming the in-medium meson mass reduction of Refs. 1 may be inadequate due to the strong $DN$ coupled channels. A self-consistent coupled-channel approach should be due taking into account possible resonance generations.

In this work, we study the spectral properties of $D$ and $\bar{D}$ mesons in nuclear matter at finite temperature within a self-consistent coupled-channel approach and examine the possible implications in the $J/\Psi$ suppression at FAIR.

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Fig. 1. Left: $I=0 \tilde{\Lambda}_c$ and $I=1 \tilde{\Sigma}_c$ resonances in a hot medium. Right: The $q=0$ $D$ meson spectral function at $\rho_0$ for $T=0, 100$ MeV.

The $D$ and $\bar{D}$ self-energies at finite temperature are obtained from a self-consistent coupled-channel calculation, whose driving term ($V$) is a broken SU(4) $s$-wave Tomozawa-W einberg (TW) interaction supplemented by an attractive isoscalar-scalar term ($\Sigma_{DN}$). The multi-channel transition matrix ($T$), $T = V + VGT$, is solved using a cutoff regularization, which is fixed by reproducing the position and the width of the $I=0 \Lambda_c(2593)$ resonance. A new $\Sigma_c$ resonance in the $I=1$ channel is generated around 2800 MeV.

The in-medium finite temperature solution is obtained incorporating Pauli blocking effects, mean-field bindings of baryons via a temperature-dependent $\sigma-\omega$ model, and $\pi$ and open-charm meson self-energies in the intermediate propagators.

The $D(\bar{D})$ self-energy ($\Pi_{D(\bar{D})}$) is obtained self-consistently summing the in-medium $T_{D(\bar{D})N}$ amplitudes over the thermal nucleon Fermi distribution and the in-medium spectral function reads

$$S_{D(\bar{D})}(q_0, \vec{q}, T) = -\frac{1}{\pi} \frac{\text{Im} \Pi_{D(\bar{D})}(q_0, \vec{q}, T)}{|q_0^2 - \vec{q}^2 - m_{D(\bar{D})}^2 - \Pi_{D(\bar{D})}(q_0, \vec{q}, T)|^2}.$$ \hspace{1cm} (1)

On the l.h.s. of Fig. 1 we show the in-medium $I=0 \Lambda_c(2593)$ and $I=1 \Sigma_c(2770)$ resonances, denoted as $\tilde{\Lambda}_c$ and $\tilde{\Sigma}_c$, respectively, at saturation density ($\rho_0 = 0.17$ fm$^{-3}$) for three different cases: i) the self-consistent dressing of $D$ mesons only (dotted lines), ii) including the mean-field binding of baryons (MFB) (dash-dotted lines) and iii) with MFB and the pion self-energy dressing (PD) (solid lines). The thick lines correspond to model A ($\Sigma_{DN} \neq 0$) while the thin-dashed lines are case (iii) within model B ($\Sigma_{DN} = 0$).

At $T=0$ the medium modifications lower the position of the $\tilde{\Lambda}_c$ and $\tilde{\Sigma}_c$ resonances with respect to their free values, in particular with the inclusion of MFB. Their widths, which increase due to $Y_c N \rightarrow \pi N \Lambda_c, \pi N \Sigma_c$ processes, differ according to the phase space available. The PD has a small effect in the resonances because
of reduced charm-exchange channel couplings. Still it is seen in the positions and widths through the absorption of these resonances by one and two nucleon processes when the pion self-energy is incorporated. Moreover, models A and B show qualitatively similar features.

The Pauli blocking effects are reduced at finite temperature due to the smearing of the Fermi surface. Both resonances move up in energy closer to their free space position while they are smoothen out, as seen in Ref. 3. At $T = 100$ MeV, $\Lambda_c$ is at 2579 MeV and $\Sigma_c$ at 2767 MeV for model A, while model B generates both resonances at higher energies: $\Lambda_c$ at 2602 MeV and $\Sigma_c$ at 2807 MeV.

We display in the r.h.s. of Fig. 1 the $D$ meson spectral function at zero momentum for $\rho_0$ in cases (i) to (iii) for model A (thick lines) and in case (iii) for model B (thin line). Two peaks appear in the spectral function at $T = 0$: that corresponding to $\Lambda_c N^{-1}$ excitations at lower energies and at higher energies the quasi($D$)-particle peak mixed with the $\Sigma_c N^{-1}$ state. The lower energy mode goes up by about 50 MeV relative to (i) when MFB effects are included: the meson requires to carry more energy to excite the $\Lambda_c$ in order to compensate for the attraction felt by the nucleon. The same effect is observed for the $\Sigma_c N^{-1}$ configuration that mixes with the quasiparticle peak. As expected, the PD does not alter much the position of $\Lambda_c N^{-1}$ excitation or the quasiparticle peak. For model B (case (iii) only), the absence of the $\Sigma_{DN}$ term moves the $\Lambda_c N^{-1}$ excitation closer to the quasiparticle peak, while the latter completely mixes with the $\Sigma_c N^{-1}$ excitation.

Those structures are diluted when finite temperature effects are included while the quasiparticle peak gets closer to its free value and narrower. In this case, the self-energy receives contributions from $DN$ pairs at higher momentum where the interaction is weaker.

In the $\bar{D}N$ sector, we start by calculating the $\bar{D}N$ scattering lengths. For model A (B) those are $a^{I=0} = 0.61$ (0) fm and $a^{I=1} = -0.26$ ($-0.29$) fm. The zero value of the $I = 0$ scattering length for model B is due to the vanishing coupling coefficient of the TW $\bar{D}N$ interaction. This is in contrast to the repulsive $I = 0$ scattering length in Ref. 4, while agreement is found in the $I = 1$ contribution. In the case of model A, the non-zero value of the $I = 0$ scattering length is due to the magnitude of the $\Sigma_{DN}$ term. Our results are consistent with those of a recent calculation based on meson- and one-gluon exchanges. 8 The $\bar{D}$ mass shift in cold nuclear matter for both A and B models is repulsive due to the $I = 1$ dominant component. We also find that, despite the absence of resonances in the $\bar{D}N$ interaction, the low-density $T \rho$ approximation is questionable at relatively low densities.

Finally, in Fig. 2 we compare the $D$ and $\bar{D}$ optical potentials at $q = 0$ MeV/c as functions of temperature for $\rho_0$ and $2\rho_0$. For model A (B) at $T = 0$ and $\rho_0$, the $D$ meson feels an attractive potential of $-12$ ($-18$) MeV while the $\bar{D}$ feels a repulsion of $11$ ($20$) MeV. A similar shift for $D$ meson mass is obtained in Ref. 3. The temperature dependence of the repulsive real part of the $\bar{D}$ optical potential is very weak, while the imaginary part increases steadily due to the increase in the collisional width. The picture is somewhat different for the $D$ meson due to the
overlap of the quasiparticle peak with the $\Sigma_c N^{-1}$ mode. Therefore, the in-medium behavior of the $\Sigma_c N^{-1}$ mode is determinant for understanding the effect of the $\Sigma_{DN}$ term on the $D$ meson potential.

Regarding the $J/\Psi$ suppression in an hadronic environment, the in-medium $\bar{D}$ mass increases about $10 - 20$ MeV while the tail of the quasiparticle peak of the $D$ spectral function extends to lower "mass" due to the thermally spread $\bar{Y}_c N^{-1}$. However, it is very unlikely that this lower tail extends as far down by $600$ MeV with sufficient strength for the $J/\Psi \rightarrow D\bar{D}$ to go. So the only way for the $J/\Psi$ suppression to take place is by cutting its supply from the excited charmonia ($\chi_{c1}(1P)$ or $\Psi'$) due to multi-nucleon absorption.

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