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Heavy flavor relaxation in a hadronic medium

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Abstract

Charm and bottom transport coefficients in a medium constituted of light mesons, such as is formed in the hadronic phase of heavy-ion collisions, are obtained within an effective field theory approach implementing heavy-quark symmetry and chiral symmetry breaking. Heavy flavor propagates in the medium as D/B and D^*/B^* degrees of freedom, and unitarization of the lowest order heavy–light meson amplitudes is used in order to reach high temperatures. The latter accounts for dynamically generated resonances in isospin $1/2$ channels, a feature that leads to a more efficient heavy-flavor diffusion. We discuss the temperature and momentum dependence of the friction and diffusion coefficients in a transport approach up to temperatures of about $T \simeq 150$ MeV, and provide estimates of the charm/bottom relaxation lengths and momentum loss. Implications for heavy-meson spectrum observables in heavy-ion collisions are discussed.

Keywords: Diffusion coefficient; Charmed and bottomed mesons; Heavy-ion collisions; Chiral perturbation theory; Heavy-quark effective theory

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1. Introduction

The features of matter formed in Heavy Ion Collisions (HICs) have been a subject of great interest in the last decades. In this scenario, heavy-flavored hadrons play an essential role since they carry heavy quarks produced in the early stage of the collisions, unlike pions and kaons which can be produced in the thermal medium at later stages.

It is worth noticing that the momentum spectra of charmed and bottomed mesons extracted from HICs undergo modifications due to their interactions with the hadronic medium. In this sense, the diffusion of heavy mesons in an equilibrium hadronic gas should be taken into account in order to compute realistic spectra, for instance, in transport approaches. Unlike other lighter systems, relatively little attention has been devoted to study heavy-meson dynamics in the hadronic phase of a HIC. In addition, there is a considerable dispersion in existing results on the matter, as for instance concerning the value of the charm relaxation length at a given temperature [1–6].

In this talk we report on recent progress in the calculation of the transport coefficients of charmed and bottomed mesons in a hot gas consisting of pions, kaons and η mesons. In order to do this we provide a realistic determination of the relevant heavy–light meson scattering amplitudes in an effective field theory approach, exploiting chiral perturbation theory at next-to-leading order (NLO) together with constraints from heavy-quark symmetry, and implementing exact unitarization in order to reach higher temperatures. The latter is a crucial point in our analysis, leading to dynamically generated states in agreement with our current knowledge of the D and B spectra with a minimal number of parameters, and therefore to a more realistic (and theoretically consistent) determination of the transport coefficients.

2. Modeling heavy-meson interactions in a light-meson gas

We calculate heavy-meson transport coefficients in a Fokker–Planck equation approach. The dynamical input is encoded in the scattering amplitudes of (long-lived) charmed and bottomed mesons with the octet of light pseudoscalar mesons. We assume that the density of heavy mesons is negligible and thus ignore collisions among themselves. For a detailed discussion of the model for charm interactions within the pion gas we refer to our previous work [4].

The amplitude for scattering off a charm (bottom) quark in the light-meson gas, at next-to-leading order (NLO) in the chiral expansion and leading order (LO) in the heavy-quark expansion, irrespective of whether the heavy quark is in a $D(B)$ or a $D(B)^*$ meson state, is given by

$$\begin{aligned}\mathcal{V} = {} & \frac{C_0}{4F^2}(s-u) + \frac{2C_1}{F^2}h_1 + \frac{2C_2}{F^2}h_3(p_2\cdot p_4) \\ & + \frac{2C_3}{F^2}h_5\big[(p_1\cdot p_2)(p_3\cdot p_4) + (p_1\cdot p_4)(p_2\cdot p_3)\big], \end{aligned} \tag{1}$$

where C_i $(i = 0,\dots,3)$ are channel-dependent numerical coefficients in isospin basis. The three (flavor-dependent) parameters h_i are the low-energy constants (LECs) from the NLO chiral Lagrangian, which we constrain with the available experimental information on the heavy-meson spectrum (a list of the relevant states is accounted for in Table 1).

The chiral perturbative expansion is typically bound to work properly only at very low energies, and cannot describe the appearance of resonances in a given scattering channel. In addition, at high energies, perturbative cross sections violate Froissart bounds imposed by the unitarity of