Eur. Phys. J. A **18**, 547–549 (2003)
DOI 10.1140/epja/i2002-10280-8

THE EUROPEAN PHYSICAL JOURNAL A

Mott effect and J/ψ dissociation at the quark-hadron phase transition

D. Blaschke[1,2,a], G. Burau[1], Yu. Kalinovsky[3], and T. Barnes[4,5]

[1] Department of Physics University of Rostock, D-18051 Rostock, Germany
[2] Bogoliubov Laboratory for Theoretical Physics, JINR Dubna, 141980 Dubna, Russia
[3] Laboratory for Information Technologies, JINR Dubna, 141980 Dubna, Russia
[4] Oak Ridge National Laboratory, Oak Ridge, TN 37831-6373, USA
[5] Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996-1501, USA

Received: 30 September 2002 /
Published online: 22 October 2003 –

Abstract. We investigate the in-medium modification of pseudoscalar and vector mesons in a QCD-motivated chiral quark model by solving the Dyson-Schwinger equations for quarks and mesons at finite temperature for a wide mass range of meson masses, from light (π, ρ) to open-charm (D, D^*) states. At the chiral/deconfinement phase transition, the quark-antiquark bound states enter the continuum of unbound states and become broad resonances (hadronic Mott effect). We calculate the in-medium cross-sections for charmonium dissociation due to collisions with light hadrons in a chiral Lagrangian approach, and show that the D- and D^*-meson spectral broadening lowers the threshold for charmonium dissociation by π- and ρ-mesons. This leads to a step-like enhancement in the reaction rate. We suggest that this mechanism for enhanced charmonium dissociation may be the physical mechanism underlying the anomalous J/ψ suppression observed by NA50.

PACS. 05.20.Dd Kinetic theory – 12.38.Mh Quark-gluon plasma – 14.40.-n Mesons – 25.75.Nq Quark deconfinement, quark-gluon plasma production, and phase transitions

1 Introduction

Charmonia, in particular the J/ψ-meson, play an important role in the experimental search for the quark-gluon plasma (QGP) in relativistic heavy-ion collisions. The anomalous suppression of J/ψ production found by the NA50 Collaboration at CERN SPS in 158 A GeV Pb-Pb collisions [1] is reminiscent of the signal for QGP formation suggested by Matsui and Satz [2], although one should also consider the competing, non-QGP mechanisms for J/ψ suppression such as charmonium dissociation through collisions with projectile and target nucleons [3] and by co-moving hadrons formed in the collision [4]. A combination of hadronic and quark/gluon processes appears to give a satisfactory parametrization of the NA50 data [5,6]. However, we should inquire as to whether we do now have a consistent picture of anomalous J/ψ suppression. In this contribution we consider a unified theoretical approach based on the quark (gluon) substructure of hadrons, which predicts a characteristic energy dependence of the J/ψ dissociation cross-sections through collisions with light hadrons, as well as the dissociative "Mott effect" at the chiral/deconfinement phase transition.

[a] e-mail: david.blaschke@physik.uni-rostock.de

2 The Mott effect and spectral function for D-mesons

Due to their strong couplings to two-body decay channels, light mesons such as the ρ and the controversial light σ can be modeled as quark-antiquark bound states or alternatively as meson-meson interactions in the corresponding channel. In the $I = 0$ $\pi\pi$ "*sigma*" channel, the total spectral width $\Gamma_\sigma(T)$ associated with a σ-meson shows a minimum that correlates with the chiral restoration phase transition in the phase diagram of strongly interacting matter [7], since the hadronic decay width $\Gamma_{\sigma\to 2\pi}$ is already negligible but the coupling $\Gamma_{\sigma\to q\bar{q}}$ is still small. The transition from a bound state with vanishing decay width (infinite lifetime) to a resonance in the continuum of unbound states is called the Mott transition [8], and can be described by the behavior of the spectral function

$$A_h(s;T) = \frac{1}{N}\frac{\Gamma_h(T)M_h(T)}{\left[s - M_h^2(T)\right]^2 + \Gamma_h^2(T)M_h^2(T)}\,, \qquad (1)$$

where $M_h(T)$ and $\Gamma_h(T)$ are the temperature-dependent mass and width of the hadron h. Critical phenomena related to the Mott transition for mesons at the chiral transition have been discussed in the context of the NJL model

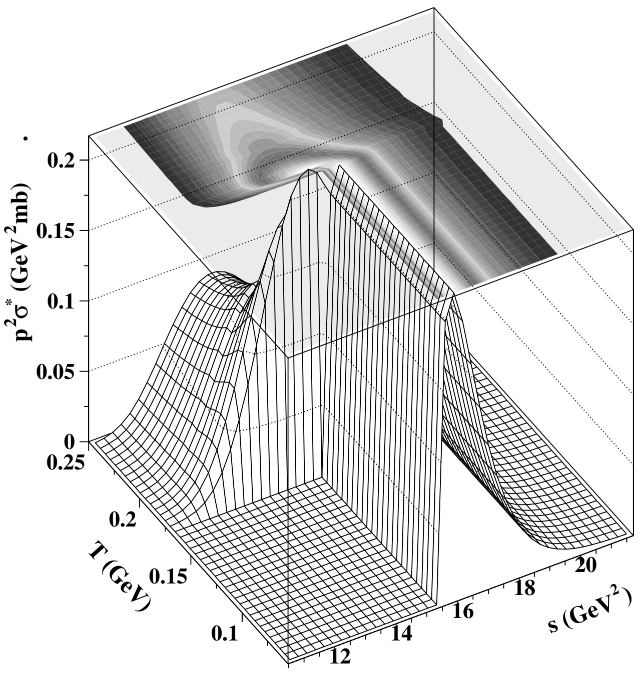

Fig. 1. In-medium cross-sections σ_h^* for $J/\psi+\pi \to D^* + \bar{D}$ as a function of s and T, using the spectral function of ref. [11].

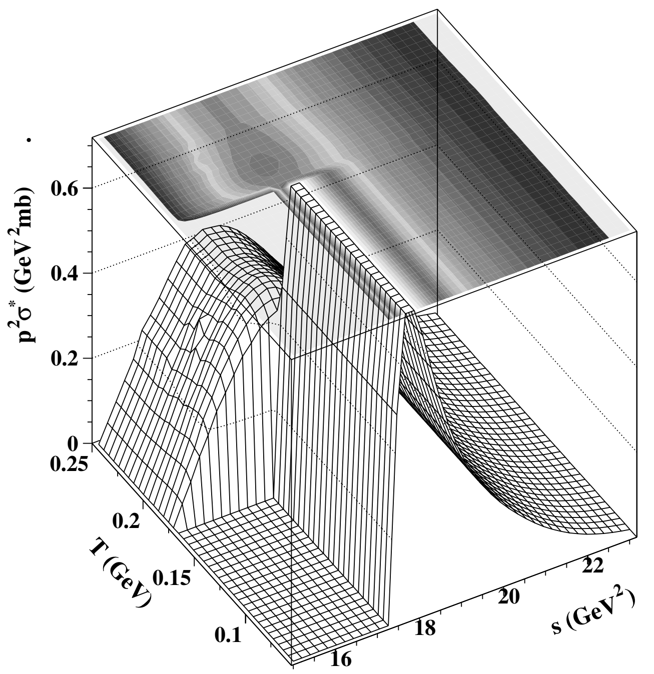

Fig. 2. Same as fig. 1 for the process $J/\psi + \rho \to D^* + \bar{D}^*$.

for quark matter in ref. [9]. In this model it was found that the Mott transition temperature for D-mesons is very close to that of the π- and K-mesons [10]. To estimate spectral function parameters (1) for the light and open-charm mesons, we use a modified NJL model in which unphysical quark production thresholds below the Mott temperature are excluded by an infrared cutoff [11]. In the following section we investigate the consequences of the meson Mott effect for charmonium dissociation processes.

3 In-medium J/ψ dissociation cross-section

The in-medium dissociation cross-section is defined in the Green function formalism by

$$\sigma^*_{\psi h}(s;T) = \int \mathrm{d}s_1 \int \mathrm{d}s_2 A_{D_1}(s_1;T) \times A_{D_2}(s_2;T)\sigma^{\mathrm{vac}}_{\psi h}(s;s_1,s_2). \quad (2)$$

(For details of this approach see ref. [12].) The cross-sections for the processes $J/\psi+\pi \to D^*+\bar{D}$ and $J/\psi+\rho \to D^* + \bar{D}^*$ are displayed in figs. 1 and 2, respectively. The vacuum cross-sections $\sigma^{\mathrm{vac}}_{\psi h}$ assumed here follow from the chiral Lagrangian approach of ref. [13].

In both cases the Mott effect ($T^{\mathrm{Mott}} \approx 172\,\mathrm{MeV}$) increases the spectral width in (1) of the D- and D^*-mesons, and hence effectively lowers the threshold for charmonium dissociation reactions. At temperatures above T^{Mott} these reactions become exothermic, whereas they were endothermic for $T < T^{\mathrm{Mott}}$. In addition to the lowered reaction thresholds, in figs. 1 and 2 one can also see a decrease in the maximum values of these exclusive cross-sections multiplied by the squared momentum p^2 of the incoming light particles. This behavior is slightly larger in $J/\psi + \pi$ than $J/\psi + \rho$ at high temperatures. In general, $J/\psi + \rho$ is the dominant dissociation process. In ref. [14] it was shown that this behavior of the in-medium cross-section leads to a strong enhancement in the thermal averaged dissociation cross-section, *i.e.* in the inverse lifetime of the J/ψ given by $\tau^{-1} = \tau_\pi^{-1} + \tau_\rho^{-1}$, with

$$\tau_h^{-1} = \langle \sigma^*_{\psi h} v\rangle n_h(T) \quad (3)$$
$$= \int \frac{\mathrm{d}^3p}{(2\pi)^3} \int \mathrm{d}s' A_h(s';T) f_h(p,s';T) j_h(p,s') \sigma^*_{\psi h}(s;T)\,,$$

where $f_h(p,s';T)$ is the Bose distribution function with the energy momentum $E(p,s') = (p^2+s')^{1/2}$ and $j_h(p,s')$ is the flux factor for the ψ-h collisions , $h = \{\pi,\rho\}$. The thermal average of this total J/ψ dissociation cross-section as a function of T, usinge the in-medium cross-sections shown in figs. 1 and 2, is displayed in fig. 3. This J/ψ dissociation rate due to impact by hadronic resonances shows a step-like enhancement by an order of magnitude above T^{Mott} for mesonic states due to their spectral broadening and thus the effective lowering of the breakup threshold. The effect is dominated by the ρ-meson subprocess shown in fig. 2 and its magnitude is quite sensitive to the detailed temperature dependence of the D- and D^*-meson spectral functions, as was discussed in [14].

The hadronic Mott effect scenario described here could be the dominant physical mechanism underlying the anomalous J/ψ suppression [1]. It could also contribute to an understanding of fast chemical equilibration [15] reported for the NA50 results on charm production. The role of the Mott effect on charmonium recombination ($D\bar{D}$ fusion) is an interesting topic for further investigation. It

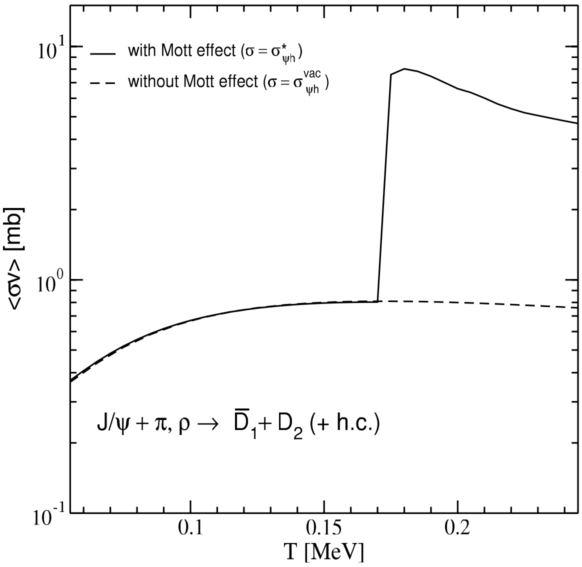

Fig. 3. Total thermal averaged J/ψ dissociation cross-section as a function of T without (dashed line) and with Mott effect for the π-, ρ- and D-mesons (solid line), using the spectral functions of ref. [11].

remains to be investigated which role dissociation processes by quark and gluon impact in the plasma phase have to play. A preliminary comparison with the NA50 data [16] shows that the bulk of the anomalous J/ψ suppression pattern can be explained by dissociation due to hadronic resonance impact, provided the dramatic changes of mesonic spectral functions obtained from the modified NJL model calculation [11] turn out to be realistic.

4 Conclusion

An understanding of the quark substructure of mesons is essential for determining meson-meson vacuum cross-sections as well as their modifications in hadronic matter. We have shown that the D-meson Mott effect at the QGP phase transition reduces the threshold for charmonium dissociation, which leads to a large increase in the J/ψ dissociation rate. A new finding reported here is that J/ψ dissociation is dominated by $J/\psi + \rho$ collisions, so that a direct connection to the in-medium ρ spectral function, as measured, for example, by NA45 (CERES), should be investigated. In subsequent research we plan to model the temperature-dependent meson spectral functions, using QCD Dyson-Schwinger equations as an improvement over the NJL model. Comparison with recent lattice QCD results for these spectral functions [17] is a promising approach for future studies of the hadronic Mott effect at the quark-hadron phase transition.

We are grateful to many colleagues for discussions, in particular to P.-B. Gossiaux, J. Hüfner, C.-M. Ko, S.H. Lee, Y. Oh, P. Petreczky, A. Polleri, R. Rapp and C.Y. Wong. Yu.K. acknowledges support from DFG grant No. 436 RUS 17/129/02, G.B. was supported by the DFG Graduiertenkolleg "Stark korrelierte Vielteilchensysteme", and D.B. and G.B. acknowledge support from the DAAD for their visits to the Oak Ridge National Laboratory and the University of Tennessee in Knoxville. T.B. acknowledges support from NSF grant No. INT-0004089.

References

1. NA50 Collaboration (M.C. Abreu *et al.*), Phys. Lett. B **477**, 28 (2000).
2. T. Matsui, H. Satz, Phys. Lett. B, **178**, 416 (1986).
3. C. Gerschel, J. Hüfner, Phys. Lett. B **207**, 253 (1988).
4. R. Vogt, M. Prakash, P. Koch, T.H. Hansson, Phys. Lett. B **207**, 263 (1988).
5. L. Grandchamp, R. Rapp, Nucl. Phys. A **709**, 415 (2002).
6. X.M. Xu, C.Y. Wong, T. Barnes, Phys. Res. C, **67**, 014907 (2003), arXiv:nucl-th/0207018.
7. E.A. Kuraev, M.K. Volkov, D. Blaschke, G. Röpke, S. Schmidt, Phys. Lett. B **424**, 235 (1998).
8. R. Redmer, Phys. Rep. **282**, 35 (1997).
9. J. Hüfner, S.P. Klevansky, P. Rehberg, Nucl. Phys. A **606**, 260 (1996).
10. F.O. Gottfried, S.P. Klevansky, Phys. Lett. B **286**, 221 (1992).
11. D. Blaschke, G. Burau, M.K. Volkov, V.L. Yudichev, Eur. Phys. J. A **11**, 319 (2001).
12. G. Burau, D. Blaschke, Yu. Kalinovsky, Phys. Lett. B **506**, 297 (2001).
13. V. Ivanov, Yu. Kalinovsky, D. Blaschke, G. Burau, *Chiral Lagrangian approach to the J/ψ breakup cross section*; [arXiv:hep-ph/0112354], and references therein.
14. D. Blaschke, G. Burau, T. Barnes, Yu. Kalinovsky, E. Swanson, in *Proceedings of the Budapest '02 Workshop on Quark & Hadron Dynamics* (2002) 261, arXiv:hep-ph/0210265.
15. P. Braun-Munzinger, J. Stachel, Phys. Lett. B **490**, 196 (2000).
16. G. Burau, *Charmonium Dissoziation am QCD Phasenübergang* PhD Thesis, Rostock (2002), unpublished.
17. F. Karsch, S. Datta, E. Laermann, P. Petreczky, S. Stickan, I. Wetzorke, Nucl. Phys. A **715**, 701 (2003), arXiv:hep-ph/0209028.