acta physica slovaca vol. 44 No. 2, 99 – 104 April 1994

UNIFIED DESCRIPTION OF CHARMONIUM ABSORPTION IN QUARK GLUON PLASMA AND IN HADRON GAS[1]

R.Lietava

Department of Theoretical Physics, Comenius University, 842 15 Bratislava, Slovakia

A.Nogová[2]

Institute of Physics of the Slovak Academy of Science, 842 28 Bratislava, Slovakia

N.Pišútová

Department of Nuclear Physics, Comenius University, 842 15 Bratislava, Slovakia

J.Pišút

Department of Theoretical Physics, Comenius University, 842 15 Bratislava, Slovakia

Received 17 December 1993, accepted 31 January 1994

The absorption of $c\bar{c}$ system in both – Quark Gluon Plasma (QGP) and in the Hadron Gas (HG) can be described by the Schrödinger equation with a complex potential. In the QGP the real part of the potential is Debye screened and deconfining, the imaginary part corresponds to absorption due to collisions with individual partons. In the HG the real part is confining and the imaginary part takes into account absorption due to collisions with hadrons. The unified approach permits a transparent comparison of both cases and introduction of the concept of formation time along the same lines.

According to the original idea of Matsui and Satz [1] the potential between members of $c\bar{c}$ pair in QGP is Debye screened and unable to bind c and $\bar{c}$ to J/ψ . In earlier papers [2,3] on J/ψ suppression this idea together with the concept of the formation time were used as a basis for describing features of J/ψ suppression in heavy ion collisions. Later on the proces of the J/ψ absorption in QGP has been described by the Schrödinger equation with a deconfining real potential [4-11]. As pointed out in Refs. [12,13,14] the Debye screening of the $c\bar{c}$ potential is not the only source of J/ψ absorption in QGP. Collisions with partons present in QGP can disintegrate J/ψ and thus lead to its absorption. This process is described by absorption cross sections, e.g. by a language different from Schrödinger equation with Debye screened

[1]Presented at School and Workshop on Heavy Ion Collisions, Bratislava, 13-18 September 1993

[2]E-mail address: FYZINOGA@SAVBA.SK

potential. Since the use of the optical potentials with a negative imaginary part in analyses of absorption of neutrons by nuclei it is well known that the absorption can be represented by an imaginary potential. We shall proceed below along this line. The imaginary part of the potential in the description of J/ψ absorption by QGP has been already introduced by Cugnon and Gossiaux [10,11]. In their work the imaginary part of the potential is related to the natural decay widths of charmonia and not to the absorption by collisions as in the present approach. Kopeliovich and Zakharov [15], within the formalism of path integrals represented J/ψ absorption in nuclear matter by an imaginary potential and approximated the real part of the $c\bar{c}$ potential by a harmonic oscillator.

The absorption of J/ψ by HG, contrived [16-19] as an alternative explanation of the experimental results of NA38 collaboration [20] on J/ψ suppression used estimates of dissociation cross-sections and the concept of the formation time. Accurate data [21] on J/ψ production in hadron-nucleon collisions, required the introduction of time-dependent cross-sections [22-24], the time-dependence appearing as a consequence of the expanding $c\bar{c}$ wave packet [25]. Also here it would be desirable to have one language describing both the expansion of the $c\bar{c}$ wave packet and its attenuation by collisions with hadrons.

The purpose of the present note is to show that both the expansion of the $c\bar{c}$ wave packet and its attenuation whether in QGP or in HG can be described by the Schrödinger equation with the potential whose real and imaginary parts are chosen so as to represent both the expansion and the absorption.

The basic idea of the introduction of the imaginary part of the potential is rather simple. Consider first the case of an already formed J/ψ in a homogeneous hadron gas. For the moment we are not interested in the internal structure of J/ψ so we are considering only the coordinate of its center of mass.

The Schrödinger equation

$$i\hbar\frac{\partial\Phi(\vec{R},t)}{\partial t} = -\frac{\hbar^2}{2M}\Delta_{\vec{R}}\Phi(\vec{R},t) + iW(R)\Phi(\vec{R},t) \tag{1}$$

implies

$$\frac{\partial(\Phi^*\Phi)}{\partial t} = -\nabla.\vec{j} + \frac{2}{\hbar}W(\Phi^*\Phi) \ , \quad \vec{j} = \frac{\hbar}{2Mi}(\Phi^*\nabla\Phi - \Phi\nabla\Phi^*) \tag{2}$$

The term $\frac{2}{\hbar}W(\Phi^*\Phi)$ describes for $W < 0$ the absorption of J/ψ . The standard expression for the absorption of J/ψ by collisions with hadrons in HG is

$$\frac{dn_\psi}{dt} = -\rho_h < v\sigma_{abs} > n_\psi \tag{3}$$

where the ρ_h is the density of hadron gas and σ_{abs} is the absorption cross-section. The comparison of the corresponding terms in Eqs. (2) and (3) gives

$$W = -\frac{\hbar}{2}\rho_h < v\sigma_{abs} > \tag{4}$$

In the homogeneous hadron gas ρ_ψ decreases as a consequence of Eq. (3) exponentially $\rho_\psi(t) = \rho_\psi(0)\exp[2Wt/\hbar]$, note $W < 0$. Let us now treat J/ψ in the homogeneous hadron gas again, this time taking into account the internal degrees of freedom. The wave function of the $c\bar{c}$ pair $\chi(\vec{r}_1, \vec{r}_2, t)$ obeys the Schrödinger equation

$$i\hbar\frac{\partial\chi(\vec{r}_1,\vec{r}_2,t)}{\partial t} = [-\frac{\hbar^2}{2m_c}\Delta_1 - \frac{\hbar^2}{2m_c}\Delta_2 + V(\vec{r}_1 - \vec{r}_2) + iW]\chi(\vec{r}_1,\vec{r}_2,t) \tag{5}$$

where $V(|\vec{r}_1 - \vec{r}_2|)$ is the confining potential. The separation of variables $\chi(\vec{r}_1,\vec{r}_2,t) = \Phi(\vec{R},t)\psi(\vec{r},t)$ with

$$\vec{R} = \frac{m_c\vec{r}_1 + m_c\vec{r}_2}{2m_c} \ , \quad \vec{r} = \vec{r}_1 - \vec{r}_2 \ , \quad \mu = m_c/2 \ , \quad M = 2m_c$$

leads to

$$i\hbar\frac{\partial\Phi(\vec{R},t)}{\partial t} = -\frac{\hbar^2}{2M}\Delta_R\Phi(\vec{R},t) \tag{6}$$

$$i\hbar\frac{\partial\psi(\vec{r},t)}{\partial t} = (-\frac{\hbar^2}{2\mu}\Delta_r + V(r) + iW)\psi(\vec{r},t) \tag{7}$$

So far as W is a constant independent of r it can appear either in Eq.(6) or in Eq.(7) leading in both cases to the exponential damping of the product $\Phi(\vec{R},t)\psi(\vec{r},t)$. In a realistic situation $c\bar{c}$ is produced at $t = 0$ as a narrow wave packet with the radius of $< r^2 >^{1/2} \simeq 0.075$fm and as the best guess for the dependence of σ_{abs} on time we have [25]

$$\sigma_{abs}(t) = \sigma^0_{abs}\frac{< r^2(t) >}{< r^2_\psi >} \tag{8}$$

The $< r^2(t) >$ is the time-dependent radius squared of the expanding wave packet and $< r^2_\psi >$ is the same quantity for the J/ψ wave function.

One could also consider other options for the dependence of σ_{abs} on r and t, for instance the one with $< r^2(t) >$ in Eq.(8) replaced simply by r^2. The latter would attenuate different parts of the wave function differently, corresponding to physics of absorption different than that in Eq.(8). It might be interesting to study such an option in more detail, but we shall stick here to the standard option given by Eq.(8).

The real part $V(r)$ of the potential in Eq.(7) is the standard confining potential $V(r) = \sigma r - \alpha/r$, with $\alpha = 0.471$ and $\sigma = 0.192GeV^2$. The numerical values of σ^0_{abs} and ρ_h are estimated from the simplified model of hadron gas used in Ref.[16]. Note that similar absorption follows also from a model of hadron gas containing mesons from scalar octet and vector nonet as well as baryons from the octet and decuplet [26].

The imaginary part of the potential then becomes

$$W = -W_0\frac{< r^2(t) >}{< r^2_\psi >} \tag{9}$$

with $W_0 \sim 40MeV$.

The J/ψ absorption in QGP is described by the same Eq.(7), with parameters obtained in the following way. The real part of the potential $V(r)$ corresponds to the Debye screened potential $V(r) = V_0(r) = \alpha'\exp(-r/r_0)/r$ with $r_0 = 0.2fm$ and

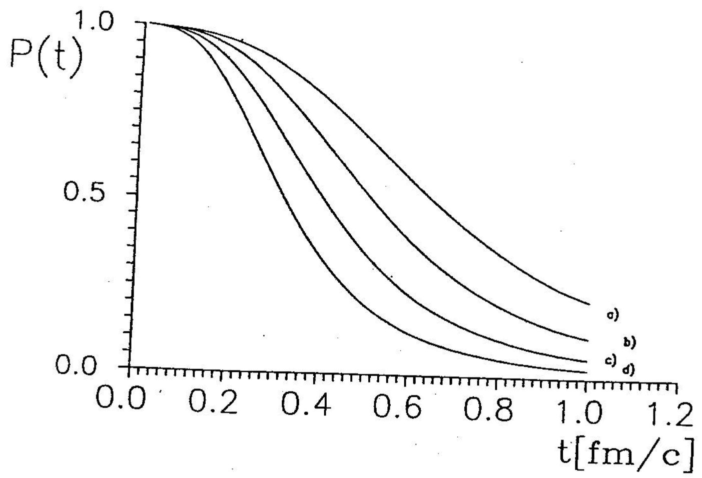

Fig. 1. Probability $P(t)$ to find J/ψ in the expanding wave packet being simultaneously attenuated by HG. The real part of the potential is confining with $\alpha = 0.471$ and $\sigma = 0.192\text{GeV}^2$. The imaginary part is of the form of Eq.(9) with a) $W_0 = 10$MeV, b) $W_0 = 20$ MeV, c) $W_0 = 40$ MeV, d) $W_0 = 80$ MeV.

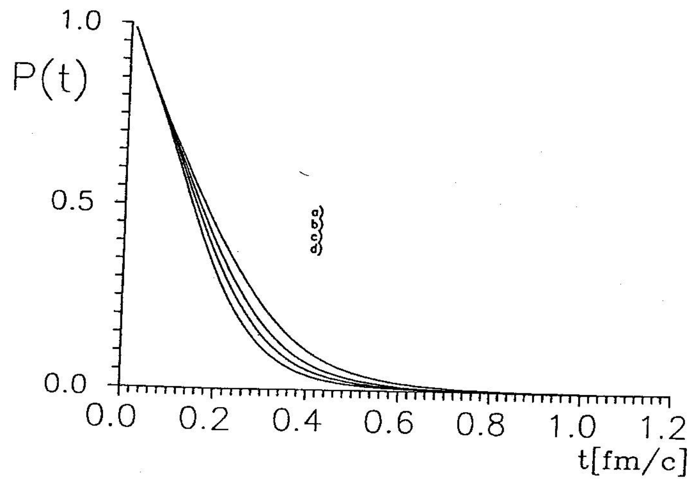

Fig. 2. Probability P(t) to find J/ψ in QGP. The real part of the potential is deconfining Debye screened one with $\alpha' = 0.18$ and $r_0 = 0.2$ fm and the imaginary part is as given in Eq.(9) with a) $W_0 = 60$ MeV, b) $W_0 = 100$ MeV, c)$W_0 = 140$ MeV, d) $W_0 = 200$ MeV.

$\alpha' = 0.18$ [5]. The imaginary part is of the form in Eq.(9) with W_0 estimated from the work by Wittmann and Heinz [14] to $W_0 \sim 140$ MeV. The probability to find J/ψ

in the wave packet which is expanding and being absorbed is given by the expression

$$P(t) = \left| < \varphi_{J/\psi} | \, \psi(t) > \right|^2 \qquad (10)$$

where $\psi(\vec{r}, t) =< \vec{r}|\psi(t) >$ is the solution of the Schrödinger equation (7) with the initial wave function given by the Gaussian wave packet with $< r^2 >^{1/2} = 0.075$fm. Details of the calculation are described in Ref.[5].

As an illustration of results obtained in this way we present in Figs. 1 and 2 probabilities $P(t)$ computed from Eqs (7) and (10) for J/ψ in QGP and in HG.

Most realistic estimates correspond to full lines in both Fig. 1 and 2. As expected the decrease of P(t) is steeper for the case of QGP, what means that experimentally the production of QGP in heavy ion collision should manifest itself by kinks in the dependence of J/ψ suppression on the total transverse energy E_T [27].

Even if both absorption and the effects of medium on the real part of the potential are taken into account by complex potential, one essential ingredient is still missing. The data on charmonium production in hadron-nucleus interactions [21] indicate [28] that $c\bar{c}$ pair is created in the colour-octet state which reaches the colour-singlet state after the emission of a gluon. The next step therefore consists in describing the emission of the gluon from the expanding and absorbed wave packet. The authors are indebted to P. Filip and V. Goloviznin for numerous valuable discussions.

REFERENCES

[1] T.Matsui,H.Satz: *Phys.Lett.* *B* **179** (1986), 416 ;
[2] F.Karsch,R.Petronzio: *Phys.Lett.* *B* **193** (1987), 105 ;
[3] J.-P.Blaizot, Y S.Ollitraut: *Phys.Lett.* *B* **199** (1987), 499 ;
[4] I.Horváth et al.: *Phys.Lett.* *B* **214** (1988), 237 ;
[5] V.Černý et al.: *Z.Phys.* *C* **46** (1990), 481 ;
[6] R.Lietava: *Z.Phys.* *C* **50** (1991), 107 ;
[7] J.Cleymans, R.L.Thews: *Z. Phys.* *C* **45** (1990), 391 ;
[8] S.Hioki et al: *Progr. Theor. Phys.* **84** (1990), 317; E.Quack: *Nucl. Phys.* *B* **364** (1991), 321;
[9] T.Matsui: *Ann. of Phys.(N.Y.)* **196** (1989), 182 ;
[10] J.Cugnon, P.-B.Gossiaux: *Z.Phys.* *C* **58** (1993), 77 ;
[11] J.Cugnon, P.-B.Gossiaux: *Z.Phys.* *C* **58** (1993), 94 ;
[12] G.Röpke, D.Blaschke, H.Shulz: *Phys.Lett.* *B* **202** (1988), 479; and: *Phys.Rev.* *D* **38** (1988), 3589 ;
[13] M.Gazdzicki, S.Mrówczyński: *Z.Phys.* *C* **49** (1991), 569 ;
[14] R.Wittman, U.Heinz: *Z.Phys.* *C* **59** (1993), 77 ;
[15] B.Z. Kopeliovich, B.G. Zacharov: *Phys. Rev.* *D* **44** (1991), 3466;
[16] J.Ftáčnik, P.Lichard, J.Pišút: *Phys.Lett.* *B* **207** (1988), 194 ;
[17] R.Vogt, M.Prakash, P.Koch, T.H.Hansson: *Phys.Lett.* *B* **207** (1988), 263 ;
[18] C.Gerschel, J.Hüfner: *Phys.Lett.* *B* **207** (1988), 253 ;
[19] S.Gavin, M.Gyulassy, A.Jackson: *Phys.Lett.* *B* **207** (1988), 257 ;

[20] C.Baglin et al.(NA-38 Coll.): *Phys.Lett.* *B* **220** (1989), 471; J.Y.Gossiord et al.(NA-38 Coll.): *Nucl.Phys.* *A* **498** (1989), 249c ;
[21] D.M.Alde et al.: *Phys.Rev.Lett.* **66** (1991), 133 ;
[22] J.-P.Bliazot, J.Y.Ollitraut: *Phys.Lett.* *B* **217** (1989), 386 ;
[23] S.Gavin, R.Vogt: *Nucl.Phys.* *B* **345** (1990), 104 ;
[24] R.Vogt, S.J.Brodsky, P.Hoyer: *Nucl.Phys.* *B* **360** (1991), 2285 ;
[25] J.Hüfner, M.Simbel: *Phys.Lett.* *B* **258** (1991), 465 ;
[26] D.Prorok, L.Turko: *Transverse momentum dependence of* J/ψ *suppression in an equilibrium hadron gas* University of Wroclaw preprint, June 1993
[27] J.Ftáčnik,P.Lichard, N.Pišútová, J.Pišút: *Z.Phys.* *C* **42** (1989), 139 ;
[28] G.Piller, J.Mutzbauer, W.Weise: *Z. Phys.* *A* **343** (1992), 247; Regensburg preprint TPR-92-48.