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The in-medium nucleon–nucleon cross section and BUU simulations of heavy-ion reactions

T. Alm [a], G. Röpke [a], W. Bauer [b], F. Daffin [b], M. Schmidt [c]

[a] *Arbeitsgruppe der Max-Planck-Gesellschaft "Theoretische Vielteilchenphysik" an der Universität Rostock, Universitätsplatz 1, 18051 Rostock, Germany*

[b] *Department of Physics and Astronomy and National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI 48824, USA*

[c] *Institut für Ostseeforschung, Seestr. 15, 18119 Rostock-Warnemünde, Germany*

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Abstract

The in-medium nucleon–nucleon cross section is calculated microscopically starting from the thermodynamic T-matrix at finite temperatures. We find pronounced deviations from the elementary free-space NN cross section. The sources of these deviations, Pauli blocking and self-energy contributions, are discussed separately. We present a Boltzmann–Uehling–Uhlenbeck computer simulation of heavy-ion reactions at intermediate energies where the in-medium cross section is incorporated into the collision term. The solution of the BUU equation at different beam energies gives an estimate of how the number of collisions during the heavy-ion reaction is changed by medium corrections to the NN cross section. The influence of these medium corrections on the number of collisions in the heavy-ion reaction is discussed.

1. Introduction

The complicated dynamics of a heavy-ion reaction at intermediate energies can be simulated on the basis of kinetic equations such as the Boltzmann–Uehling–Uhlenbeck (BUU) equation [1–5]. These simulations are capable of determining observable quantities of the heavy-ion reaction such as the collective flow [1] and in particular the balance energy [6–10]. This balance energy is the energy of the beam at which the transition between attractive and repulsive mean field interaction occurs and the nuclear collective flow disappears, an effect predicted by the BUU model [11].

BUU calculations require the NN cross section as an input. With increasing accuracy of the measurements, in particular of the collective flow, it became clear that the use

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of the free NN cross section is not sufficient to reproduce the data for the balance energy [10,12]. Therefore it is necessary to incorporate medium modifications of the NN cross section, due to the surrounding nucleons in the hot source, into BUU simulations. The question, to what extent the results of such simulations depend on the modification of the two-particle scattering properties is of considerable current interest [13]. The in-medium NN cross section depends on the center-of-mass energy of the colliding pair as well as on the density and the temperature of the nuclear medium (assuming local equilibrium), as well as the velocity of the pair relative to the medium.

First results for the in-medium modifications of the mean free path of a nucleon in hot dense matter were obtained by Cugnon et al. [14], by Schmidt et al. [15] and by Köhler [16], and substantial modifications compared to the use of the free cross section were observed.

The in-medium NN cross section at zero temperature has been calculated by Faessler et al. [18,19] in the framework of Brueckner theory based on the Reid potential. In order to account for the situation in a heavy-ion reaction these authors modified the usual Pauli operator using two overlapping Fermi spheres. They found strong modifications of the free NN cross section with increasing density. In particular, their calculations showed a non-monotonous behaviour of the cross section with the density. Ter Haar et al. [20] determined the in-medium cross section in the framework of the relativistic Dirac–Brueckner approach at $T = 0$, also showing strong deviations from the free cross section. Using the Bonn NN potential within the Dirac–Brueckner approach Li et al. [21] calculated the in-medium NN cross section in nuclear matter at zero temperature. In Refs. [20,21] a substantial reduction of the in-medium cross section, particularly for low energies, was found. Within the framework of quantum hadrodynamics the in-medium nucleon–nucleon cross section has been discussed by Schönhofen et al. [22] and by Mornas [23]. The behaviour of the in-medium NN cross section at low temperatures has been investigated by Alm et al. [17] within a T-matrix approach based on Matsubara Green functions. A critical enhancement of the in-medium NN cross section at low temperatures was found, which could be interpreted as a precursor effect of the superfluid phase transition in nuclear matter.

Using the formalism of Ref. [17] in the present paper a discussion of the in-medium NN cross section at finite temperatures will be given with special emphasis on the topics relevant for heavy-ion reactions at intermediate energies. We discuss the dependence of the in-medium NN cross section on thermodynamic variables, i.e. density and temperature, and on the total momentum of the pair. These were selected in a range relevant for intermediate energy heavy-ion reactions. It will be shown that the low temperature behaviour discussed in Ref. [17] resulting in a resonance like structure of the in-medium cross section at low energies is a consequence of the Pauli blocking. With increasing temperature the Pauli blocking becomes less important and the behaviour of the in-medium cross section is dominated by the self-energy contributions (effective mass). In particular, it will be demonstrated that for high temperatures and high energies a suppression of the in-medium cross section which is proportional to the square of the effective mass is found. The results of this calculation are then incorporated into the collision term of the Boltzmann–Uehling–Uhlenbeck (BUU) equation. Results for the number of collisions, and the motion of colliding nuclear systems through the density/temperature plane are presented and compared to results obtained with free NN cross sections as well as earlier parametrizations of the medium dependence of the nucleon–nucleon cross sections.

2. Discussion of the in-medium nucleon–nucleon cross section

The in-medium nucleon–nucleon cross section at finite temperatures has been derived using Matsubara Green-function techniques in Ref. [17]. We refer to this reference for details of the definition of the microscopic calculation.

The in-medium differential cross section for an unpolarized system is defined via the on-shell thermodynamic T-matrix [17] ($|\boldsymbol{k}| = |\boldsymbol{k}'| = k$) as

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(k) = \frac{N(k)^2}{(2s_1+1)(2s_2+1)} \sum_{S,M_S,S',M'_S} \frac{(2\pi)^4}{k^2} |T(\boldsymbol{k}SM_S, \boldsymbol{k}'S'M'_S)|^2. \tag{1}$$

with the generalized density of states

$$N(k) = \frac{k m^*_{12}(k,K)}{2(2\pi)^3\hbar^2}. \tag{2}$$

The thermodynamic T-matrix obeys the corresponding Bethe–Salpeter equation

$$T(121'2') = K(121'2') + \int \mathrm{d}3\ \mathrm{d}3'\ \mathrm{d}4\ \mathrm{d}4'\ K(1234) G_1(33') G_1(44') T(3'4'1'2'), \tag{3}$$

1 denotes wavenumber k_1, spin σ_1 and isospin τ_1 of the nucleons. The ladder approximation for the thermodynamic T-matrix is obtained replacing the four-point interaction K in (3) by the bare nucleon–nucleon interaction V. Within the quasiparticle approximation [24] the product of the two one-particle Greens functions G_1 in (3) yields

$$G^0_2(k_1,k_2,z) = \frac{1 - f(\epsilon(k_1)) - f(\epsilon(k_2))}{z - \epsilon(k_1) - \epsilon(k_2)}, \tag{4}$$

where $f(\epsilon)$ is the Fermi distribution function and $\epsilon(k_1), \epsilon(k_2)$ are the quasiparticle energies. They are defined in terms of the self-energy as

$$\epsilon(k) = \frac{\hbar^2 k^2}{2m} + v(k), \qquad v(k) = \mathrm{Re}\Sigma(k,\omega)\,|_{\omega=\epsilon(k)}, \tag{5}$$

where the self-energy $\Sigma(k,\omega)$ was calculated as described in Ref. [15].

Within these approximations two medium effects are contained in the quantity G^0_2. One of these effects is the phase space occupation Q (Pauli blocking) of the surrounding nucleons given by the $Q(k_1,k_2) = 1 - f(\epsilon(k_1)) - f(\epsilon(k_2))$ in Eq. (4). This form of the Pauli operator takes hole–hole-scattering into account, that is neglected in the usual Brueckner theory taking the Pauli operator as $Q_B(k_1, k_2) = [1 - f(\epsilon(k_1))] \times [1 - f(\epsilon(k_2))]$ [24]. The possibility for the Pauli operator to change its sign turns out to be crucial for the onset of superfluidity (see discussion below). The second medium contribution is the renormalization of the quasiparticle energies (5) entering Eq. (4). Assuming local equilibrium the in-medium differential cross section (1) depends on the temperature T and the chemical potential μ of the medium as well as on the total momentum K of the pair of nucleons. In the low-density limit $\mu/T \to -\infty$ the thermodynamic T-matrix approaches the scattering T-matrix describing the isolated elastic NN-scattering. Correspondingly, the in-medium differential cross section (1) in this limit approaches the free NN differential cross section. Integrating Eq. (1) over the angles, one arrives at the total cross section in the medium

$$\sigma(k) = \sum_{J,L,L'} \frac{(2J+1)2\pi^3 N(k)^2}{(2s_1+1)(2s_2+1)k^2} |T_\alpha^{LL'}(k,k)|^2. \tag{6}$$

Eq. (6) gives the NN cross section with Pauli blocking in the intermediate states only; i.e. without correction for Pauli blocking in the outgoing channel [20].

For the numerical evaluation of $T_\alpha^{LL'}$ and the cross section (1, 6) we use a separable approximation of the Paris nucleon–nucleon potential [29] (see Ref. [17] for details). The features of the Paris interaction mentioned above, in particular the reliable description of the empirical two-nucleon scattering data, are preserved in the separable approximation by Plessas et al. [29]. This separable approximation was applied in nuclear matter calculations too [15,30].

The in-medium total nucleon–nucleon cross section (6) depends on the relative energy $E = \hbar^2 k^2 / m_{12}^*(k, K)$ (or the energy in the laboratory-frame $E_{\rm lab} = 2E$, where one nucleon is at rest), on the thermodynamic variables characterizing the medium, namely the density n (in units of the saturation density $n_0 = 0.17$ fm^{-3}), the temperature T, and via the Pauli blocking and the self-energy shifts on the total momentum K of the pair. The dependence of the in-medium cross section $\sigma = \sigma_{\rm np} + \sigma_{\rm nn}$ on temperature and density is illustrated in the following 2 figures. For comparison the free total NN cross section, as calculated from (6) neglecting all medium effects, was also plotted in Figs. 1 and 2 (dotted line). Taking into account partial waves up to $L = 2$ we were able to reproduce the experimental free NN cross section.

In Fig. 1 the in-medium cross section as a function of $E_{\rm lab}$ is given at a fixed density $n = 0.5 n_0$ for two temperatures $T = 10$ and 35 MeV. For both temperatures we compare the results of the calculation with both Pauli blocking and self-energy corrections included with a calculation when the Pauli blocking is omitted $Q(k_1, k_2) = 1$ in Eq. (4). The in-medium cross section shows a pronounced temperature dependence.

In the $T = 10$ MeV curve the cross section is suppressed compared to the free one for low energies $0 < E_{\rm lab} < 50$ MeV. This behaviour is mainly due to the Pauli blocking reducing the available phase space for scattering.

Within the energy range $50 < E_{\rm lab} < 130$ MeV the cross section is drastically enhanced compared to the free one. This enhancement is especially pronounced for

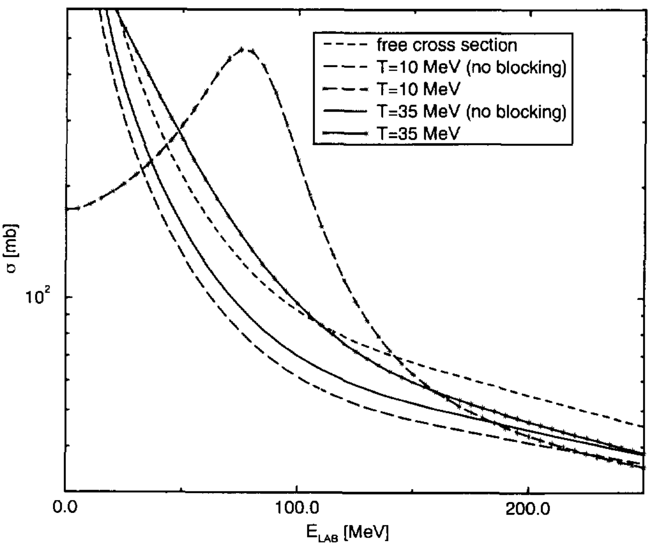

Fig. 1. The in-medium total nucleon–nucleon cross section σ as a function of $E_{\rm lab}$ at a given density $n = 0.5n_0$ and total momentum $K = 0$ for two values of the temperature T = 10 MeV (long-dashed) and T = 35 MeV (solid). The curves with the stars give the results for the calculation with both Pauli blocking and self-energy corrections. The curves without stars give the results with Pauli blocking omitted (see text). The dashed line gives the total free cross section.

low temperatures. This behaviour was discussed in detail in Ref. [17] and could be interpreted as a precursor effect of the superfluid phase transition in nuclear matter. It could be shown, that the critical temperature T_c coincides with the critical temperature for the superfluid phase transition in nuclear matter as given by the Thouless criterion [31]. Comparing with the calculation without Pauli blocking one notes that the enhancement is entirely due to Pauli blocking. The self-energy contributions yield a reduction compared to the free cross section. A resonance like behaviour of the in-medium scattering matrix for neutron–proton scattering at an energy $E = 2\epsilon_F$ has also been found by Vonderfecht et al. [32] in their calculation of the nucleon spectral function and related quantities at zero temperature.

At energies $E_{\rm lab} > 130$ MeV the in-medium cross section is suppressed compared to the free one. With increasing energies the calculations with and without Pauli blocking approach one another, indicating that the high energy behaviour is dominated by the self-energy contributions and Pauli blocking can be neglected for these energies. The suppression at higher energies due to the momentum-dependent effective mass $m^*_{12}(k,K)$, was discussed in Ref. [15]. It was found that at high energies the T-matrix in Eq. (6) can be approximated by the bare potential (Born approximation). In this approximation the only medium modification arises from the effective mass entering the cross section (6) via the generalized density of states (2). Thus, the total in-medium cross section is proportional to the square of the momentum-dependent effective mass occurring in the generalized density of states (2). This turns out to be the only medium correction in Eq. (6) in Born approximation. For still higher energies $E_{\rm lab} > 500$ MeV the free cross

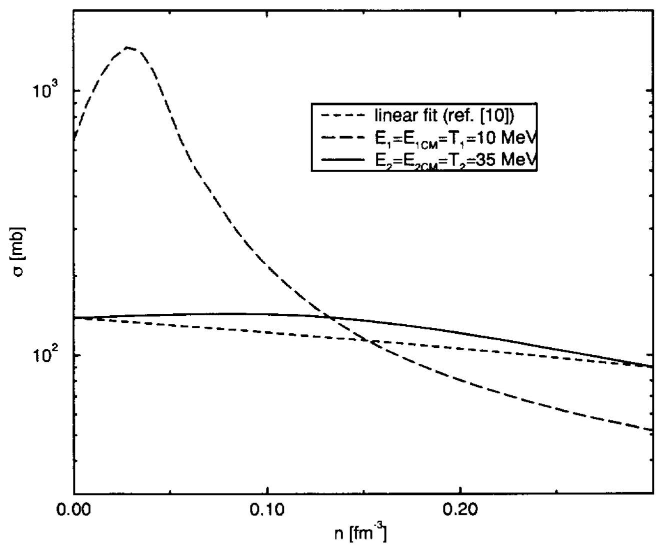

Fig. 2. The total in-medium NN cross section as a function of the density n for two temperatures T_1 = 10 MeV (long-dashed) and T_2 = 35 MeV (solid curve) at fixed relative energies $E_1 = T_1$ and $E_2 = T_2$ and total energies of the pair $E_{1CM} = T_1$ and $E_{2CM} = T_2$. For comparison the parametrization (7) by Klakow et al. [10] was plotted (dashed curve) with $\alpha_1 = -0.2$.

section is approached as the momentum-dependent effective mass becomes equal to the bare mass [15].

For the temperature T = 35 MeV the modification of the in-medium cross section with respect to the free cross section is less pronounced compared to the T = 10 MeV case. One observes some enhancement in the energy range $20 < E_{lab} < 100$ MeV, which has the same origin as the resonance structure at T = 10 MeV although it is much less pronounced because the temperature is much larger than the critical temperature in this case. Outside this range the in-medium cross section is suppressed compared to the free cross section. At high energies the results approach the curve with the Pauli blocking omitted, indicating as in the T = 10 MeV case that at high energies the modification of the cross section are mainly due to the self-energy contributions.

After having discussed the behaviour of the in-medium cross section, $\sigma(E_{lab})$, on only one parameter separately we want to discuss its full parameter dependence, which is very complicated. However, at a given temperature T, values of the relative energy E, close to T are of particular relevance for the dynamical behaviour of the system.

In Fig. 2 the total in-medium NN cross section is plotted as a function of the density for two temperatures, T_1 = 10 MeV and T_2 = 35 MeV, at fixed relative energies, $E_1 = T_1$ and $E_2 = T_2$. The total energies of the pair, E_{1CM} and E_{2CM}, were also fixed at the corresponding values T_1 and T_2, respectively.

In the $T_1 = E_1 = E_{1CM}$ = 10 MeV case one observes an increase of the cross section with increasing density until at $n \approx 0.04$ fm^{-3} a maximum is reached. This maximum is due to the enhancement of the in-medium cross section near the critical temperature for the superfluid phase transition as discussed above. At a density $n \approx 0.05$ fm^{-3}

the cross section reaches its free space value. At higher densities the cross section is monotonically falling with the density.

In the case $T_2 = E_2 = E_{2CM} = 35$ MeV one finds a decrease of the cross section with the density. The variation of the cross section with the density is much less pronounced than in the $E_1 = 10$ MeV case.

A monotonous decrease of the in-medium cross section with the density has been suggested by Klakow et al. [10]. They proposed the following formula

$$\sigma_{\text{medium}} = \sigma_{\text{free}} \left[1 + \alpha_1 (n/n_0) \right], \tag{7}$$

where the dimensionless quantity α_1 represents the first-order coefficient in a Taylor-expansion about $n = 0$,

$$\alpha_1 = n_0 \frac{\partial}{\partial n} \{\ln \sigma_{\text{NN}}\}|_{n=0} \,. \tag{8}$$

In Ref. [10], α_1 was assumed not to depend on energy and temperature, with $\alpha_1 = -0.2$ yielding the best agreement with experimental flow excitation function data.

For comparison with the microscopic calculation of the in-medium cross section the parametrization (7) by Klakow et al. with $\alpha_1 = -0.2$ is also given in Fig. 2 for $E_2 = 35$ MeV.

At high temperatures, our calculations confirm the general form (7) for the density dependence of the in-medium cross section. However, in general α_1 should depend on the temperature.

Thus, the formula (7) seems to yield a reasonable approximation at higher temperatures. However, as expected, the formula (7) is not able to reproduce the more complicated behaviour of the in-medium cross section at low temperatures $T < 20$ MeV.

We conclude this section by summarizing our main results:

(i) For low densities ($n < 0.1\, n_0$), high temperatures ($T > 30$ MeV) and/or high total momenta of the nucleon pair ($K > 400$ MeV/c) the in-medium cross section approaches the free cross section.

(ii) Our calculations show in general a strong dependence on the temperature. At low temperature the modification of the free cross section with density is much more pronounced (see Fig. 1). This is due to the fact that the dominating medium effect, the Pauli blocking, is more pronounced at low temperatures. At low temperatures ($T < 10$ MeV) we observe a characteristic peak structure in the total cross section at energies close to twice the effective chemical potential [15,17]. This behaviour is due to the Pauli blocking in the thermodynamic T-matrix. At high temperatures this effect is reduced compared to the self-energy corrections.

(iii) At relative energies $E \approx 2\mu_{\text{rel}}$ (see Ref. [17] for the definition of the effective chemical potential μ_{rel}) the behaviour of the in-medium cross section is dominated by the Pauli blocking responsible for the peak structure at low temperatures discussed above. At higher energies the dominant medium corrections are the self-energy contributions. These lead to a suppression of the in-medium cross section compared to the free cross section. Within the Born approximation the in-medium cross section is proportional to the square of the effective two-particle mass [15].

(iv) The influence of the medium becomes less important for nucleonic pairs with non-zero total momentum K, indicating that the Pauli-blocking as well as the quasiparticle contributions are considerably reduced with increasing K. Consequently, at sufficiently high total momentum K the medium effects are negligible and the in-medium cross section approaches the free cross section. This behaviour is demonstrated in Ref. [17].

(v) Considering the density dependence of the in-medium cross section at fixed energy one observes a monotonous decrease of the in-medium cross section with increasing density at high temperatures. However, for low temperatures the density behaviour is more complicated, showing an enhancement at low densities ($n < 0.3n_0$) and a suppression compared to the free cross section at higher densities.

3. Solution of the BUU equation with in-medium NN cross sections

In the BUU approach, the collision integral is given by

$$I(k_1) = -\int d^3k_2\, d^3k_3\, d\Omega_4\, v_{12} \frac{d\sigma_{12-34}}{d\Omega} \delta(p_1 + p_2 - p_3 - p_4) \times [f_1 f_2 (1 - f_3)(1 - f_4) - f_3 f_4 (1 - f_1)(1 - f_2)]. \tag{9}$$

In the present approach we obtain the cross section $d\sigma_{12-34}/d\Omega$ from the microscopic expression for the in-medium cross section (1). As can be seen from Eq. (9) the final state Pauli blocking $(1 - f_3)(1 - f_4)$ has already been included in the BUU equation.

In order to incorporate the in-medium NN cross sections into the BUU program code, knowledge of the spatial distribution of the temperature, density and the momentum of the center of mass of the colliding particles relative to the local fermionic matter is needed. The number density is initialized in the program code by randomly distributing the nucleons throughout the volumes of the nuclei using the Woods–Saxon distribution, and then self-consistently propagated in time.

At every time-step in the simulation, the momentum of the center of mass of each occupied cell in configuration space is calculated, stored and then subtracted from the momentum of the individual particles within that cell. This procedure eliminates effects of collective streaming and thus obtains the momentum of each cell due solely to random or thermal motion, and with it the thermal kinetic energy. From the kinetic energy of a given cell, we obtain the local temperature by inverting the Fermi-integral

$$n = \frac{16\pi\sqrt{2}m^{3/2}}{(2\pi\hbar)^3} \int de\, e^{1/2} f(e). \tag{10}$$

Since the momentum of the center of mass of each occupied cell has been calculated, the momentum of the colliding nucleons relative to the matter within that cell is easily obtained. Finally, for each collision the in-medium NN cross section is calculated via

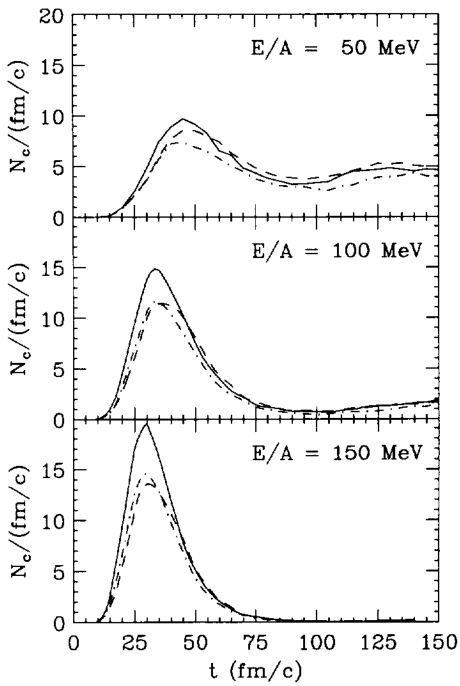

Fig. 3. The number of NN collisions in La on La at different beam energies E/A as a function of time. The solid line is the result of the BUU calculation with the free NN cross section. The dashed curve is the result of the BUU calculation with the in-medium cross section of Alm et al. [17]. The dash-dotted curve is the parametrization of Klakow et al. [10] (see text).

linear interpolation among its tabulated values, obtained from the in medium NN cross section described above.

With these in-medium NN cross sections, we perform simulations of central collisions of ^{132}La on ^{132}La at energies of 50, 100 and 150 MeV per nucleon.

In Fig. 3 the number of nucleon-nucleon collisions per time interval of 1 fm/c are shown as a function of time, where the solid lines represent results from simulations using the free NN cross sections from the particle data group [33], and the dashed line represent results from using the in-medium NN cross sections described above. For comparison we also show (dash-dotted line) the results of the calculations using the medium modifications following Klakow et al., with $\alpha_1 = -0.2$.

One can clearly see that at the two higher beam energies, E/A = 100 and 150 MeV, there are significant deviations of the simulations using in-medium NN cross sections from the simulation using the free ones. The number of collisions is reduced by 30-50%, corresponding to a lower degree of collective stopping. It is again surprising that the simple parametrization of Klakow et al. is in very good agreement with our more involved calculations. The only significant deviation we see for the two in-medium parametrizations is at the 50 MeV beam energy, for which the Klakow parametrization slightly under predicts the number of nucleon-nucleon collisions in the heavy ion

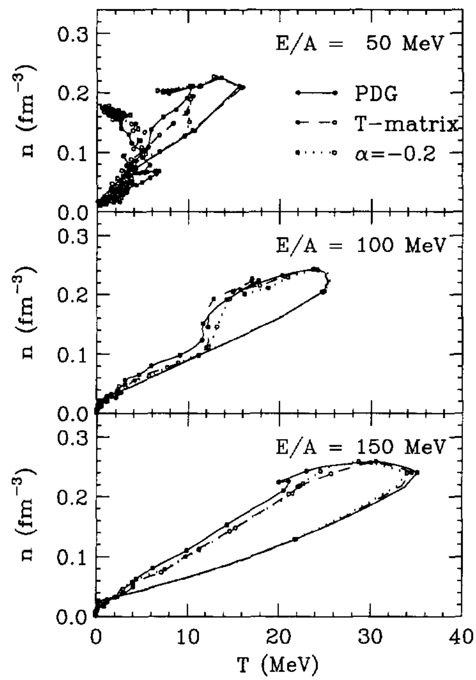

Fig. 4. The path of a volume element of the reaction zone in the temperature-density plane for the reaction La on La at different beam energies. The solid curve is the calculation with the free cross section from the particle data group (PDG). The dashed line is the result with the in-medium cross section of Alm et al. [17] as calculated from the thermodynamic T-matrix. The dotted curve is the parametrization of Klakow et al.[10] (see text).

reaction.

It is instructive to examine the path of the nuclei through the density/temperature plane during the course of the reaction. Doing this, we can determine what features of the medium modifications of the nucleon-nucleon cross section have most influence on the collective nuclear dynamics and are thus most important for studies of the nuclear equation of state.

In Fig. 4, we conduct a study of this kind by displaying the path of a central cube of side length 2 fm through this plane. The small circles on these paths are spaced 5 fm/c apart in time. Initially, the density and temperature in this cube are both 0, as the nuclei are well separated and the central cube is empty. As the nuclei approach each other and start to overlap, the density in the cube quickly rises. The onset of nucleon-nucleon collisions also causes energy to be converted from the collective streaming motion of the two incoming nuclei into thermal excitation, and the temperature rises. After a relatively quick compression phase (lower part of the trajectories) of 10–20 fm/c duration (depending on beam energy) maximum densities and temperatures are reached as indicated in the figure. This behaviour is only slightly changed if the in-medium cross section is used instead of the free cross section The dependence on the particular parametrization of the in-medium nucleon-nucleon cross section is only minor in this respect. One can clearly see from this figure that for the higher beam energy densities up to 1.5 n_0 and temperatures of 25 to 35 MeV come into play, where we have strong in-medium modifications of the cross section. At the lower beam energy, we only reach maximum densities of the order n_0 and temperatures of 15 MeV or less, and there on average the medium modifications are not as strong as in the previous cases.

Remarkable in this figure is also the fact that the density and temperature in the central cube return to 0 for the higher two beam energies. This corresponds to a complete disintegration of the nuclear system. For $E/A = 50$ MeV, we see a return to $T = 0$ and $n = n_0$, corresponding to the formation of a compound nuclear system.

4. Summary and conclusions

Within a dense medium with a density and temperature comparable to that reached in a heavy-ion reaction at intermediate energies, the NN cross section in the medium is considerably modified compared to the free NN cross section.

The microscopic calculation of the in-medium cross section carried out in this paper indicates a complicated dependence of the in-medium cross section as a function of energy on the total momentum of the colliding pair, as well as on the density and on the temperature of the medium.

For low temperatures, low energies and low total momenta the behaviour of the in-medium cross section is dominated by Pauli blocking effects. In particular, these effects strongly suppress the in-medium cross section at very low energies and lead to an enhancement in the in-medium cross section for two particles with opposite momenta near the Fermi surface. This could be interpreted as a precursor signal for the onset of the superfluid phase in nuclear matter [17].

For high temperatures, high energies and high total momenta the Pauli blocking is small and the dominant medium effect are the self-energy contributions. These lead to a general reduction of the in-medium cross section compared to the free cross section. In particular, at energies where the Born approximation holds this reduction is proportional to the square of the effective two-particle mass [15].

By incorporating the in-medium cross section into a BUU calculation we found that the number of nucleon–nucleon collisions during heavy ion collisions, and with it the degree of nuclear stopping, is significantly reduced by using the in-medium cross section. This is not a trivial result, because the total number of collisions in a heavy ion reaction is obtained from a multidimensional integral over the elementary cross section folded with the (time-dependent) nucleon phase space distribution function. Since the medium-modifications yield enhancement in some parts of parameter space and suppression in others, it is not a priori clear what the sign of the overall effect should be.

It was previously found that observable quantities such as the collective flow and correspondingly the balance energy show a sensitive dependence on the in-medium cross section as well. The results for simulations of heavy ion collisions using the in-medium cross sections obtained here and the ones used by Klakow et al. show surprisingly good agreement.

This result validates the study of Klakow et al. on nuclear collective flow. In addition, it indicates that the in-medium nucleon–nucleon cross sections obtained in this paper will also yield quantitative agreement with experimental flow observables, such as the balance energy.

Thus, the experimental results for the collective flow offers a possibility to study the in-medium modifications of nucleonic properties such as the in-medium cross section. We plan to extend our studies to also look at the resulting two-particle correlation functions from heavy ion collisions, observables that previously have been found to be strongly dependent on the in-medium nucleon–nucleon cross section [4]. From this we can obtain further tests of the BUU model with in-medium cross sections included and investigate the information content of two-particle interferometry with respect to in-medium transport properties.

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