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Time Evolution of Fast Particles During the Decay of Hadronic Systems

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Abstract

A phenomenological model is presented based on the formation of nuclear thermodynamic system during the collision of heavy ions in the regime of intermediate and high energy regions. The formulation and the dynamic picture are determined by solving the Vlasov equation. The solution is dressed in the form of a power series. The first term of which is the equilibrium distribution in phase space. The rest, are time dependent perturbation terms due to the multiple strong interactions inside the system. The temperature gradient and the derivatives of the phase function are calculated. The time dependence of the angular emission of the produced particles is studied. It is found that particles emitted in the forward direction are produced in the early stage of the reaction, far from the equilibrium. Backward production comes in a later stage when the system constituents undergo multiple cascade collisions.

1- Introduction.

The particle production in heavy ion collisions was considered by the fireball models at medium energy range (Gosset, 1977),(Myers, 1978),(Aichelin,1985). As the energy increases more, it is expected that collision time becomes small enough so that particles emitted in the early stage of the reaction possess non-equilibrium characteristics. In this work a method is developed to solve the Vlasov equation (Kruse, Jacak & Stocker 1985) with reasonable approximations in a frame of a time dependent thermodynamic model, which leads to the calculation of light and heavy particle spectra on the different reaction stages.

2-The model

Let us consider the collision between a target and a projectile nucleus at a given impact parameter $\bar{b}$. The nuclear matter in the overlap region is then treated as a heterogeneous thermodynamic system. Multiple nuclear collisions run inside the system which increases the energy density and allows the formation of quark gluon plasma state (Hussein, 1995), (Muller&Tragonov,1992). This leads to the creation of new particles and expansion of the system, which gradually approaches the equilibrium state. Particle emission from the system is allowed at different points on the time scale of the reaction. Light created particles are expected to be emitted on the early stage at narrow forward cone angle, i.e. due to the first few collisions. The higher order collisions draw the system towards the equilibrium state producing particles in isotropic distribution in phase space. It is then convenient to consider the state of equilibrium as a time reference of the reaction. Hadronic matter inside the system is partially formed by the fast projectile nucleons and the slow target ones. The relative projectile density (r,b), at a given distance r inside the fireball matter and a given impact parameter b, is given by:

$$\eta(r,b) = \frac{\rho_p(\bar{r}-\bar{b})}{\rho_p(\bar{r}-\bar{b})+\rho_t(\bar{r})} \qquad (1)$$

The local equilibrium momentum distribution of the system nucleons in the center of mass system is given by:

$$\frac{d^2N}{p^2 apd\Omega} = \frac{N}{4\pi\, m^3}\, \frac{\exp(-E/T)}{2(T/m)^2 K_1(m/T)+(T/m)K_0(m/T)} \qquad (2)$$

Since particles emission is allowed before approaching the equilibrium state, then it is convenient to use the Vlasov equation to deal with the particle energy spectra at any time of the reaction. The Vlasov Eq. has the form,

$$\frac{d\,f}{d\,t} = \frac{\partial f}{\partial\, t} + \frac{\bar{P}}{m}.\bar{\nabla}_r f - \bar{\nabla} U.\bar{\nabla}_p f \qquad (3)$$

Where U(r) is a scalar potential acting among the particles. Eq.(3) may be solved under some approximations. First, we shall consider a pre-equilibrium state where the time derivative $\partial f / dt$ may be approximated as $(f - f_o)/t_c$, and f_o is the equilibrium distribution. It is convenient to consider that the rate of change of the function f is approximately equal to that of f_o. So we replace f by f_o in the RHS of Eq.(3). Moreover, let us consider the particles as almost free so that we neglect the potential U in this stage of approximation. Eq.(3) then becomes,

$$f_1 \approx f_o + t_c \frac{\bar{P}}{m}.\bar{\nabla}_r f_o = f_o + t_c \frac{p}{m}\cos\theta \frac{\partial\, f_o}{\partial\, r} \qquad (4)$$

f_1 is the first order approximation of the particle spectrum, t_c is the time interval required by the system to approach the equilibrium state f_o and θ is the scattering angle. A second order approximation is obtained by using f_1 instead of f in the RHS of Eq.(9), so that,

$$f_2 = f_o + t_c \frac{p}{m}\cos\theta \frac{\partial\, f_o}{\partial\, r} + (t_c \frac{p}{m}\cos\theta\ )^2 \frac{\partial^{\,2} f_o}{\partial\, r^2} \qquad (5)$$

By analogy we get the recursion relation for the nth order approximation as;

$$f_n = f_o + \sum_{i=1}^{n} (t_c \frac{p}{m}\cos\theta\ )^i \frac{\partial^i\, f_o}{\partial\, r^i} \qquad (6)$$

3- Results and discussion

The predictions of the pre equilibrium model are applied to the Ne-U collisions at 400 and 2100 A MeV. In Fig.(1) we demonstrate $\overline{\eta}(\overline{r})$ averaged over the whole range of impact parameter. This shows a peak value at a distance where the projectile and the target have equal densities. The parameter η has a main role in evaluating the temperature and its gradient inside the nuclear matter. Fig.(1) also shows the temperature as a function of η for the reactions at 400 and 2100 MeV incident kinetic energy per nucleon. The maximum temperature is found to be 55 and 230 MeV respectively. The solution of the Vlasov equation is calculated to the fourth order approximation. The result is integrated over the effective range with a geometrical weight factor W(η), depends on the size of the nuclear matter. Assuming azimuthal symmetry of the system then the Lab energy spectra is calculated at emission angles θ = 30, 60, 90, 120 and 150°.

$$f_L^n(E) = \int f^n(E,r) W(\eta(r)) 4\pi \ r^2 dr \qquad (7)$$

Fig.(3) shows the lab energy spectra of protons produced in Ne-U at 400 A MeV corrected to the second order, compared with the experimental data. The emission time parameter is found by fitting method to be -12, -12, 8, -4.5 and -2 (GeV)-1 (in units where h=c=1) corresponding to the emission angles θ = 30, 60, 90, 120 and 150° respectively. A global fair agreement is obtained by the second order corrected solution of the Vlasov equation at energy 400 MeV A.

4- Conclusive remarks

i- The pre-equilibrium model with reasonable approximations may fit the experimental data of heavy ion collisions within the regime of few hundreds A MeV. In this case, a power series is presented to describe the nuclear density function in the frame of a thermodynamic picture.

ii- The relative projectile density plays an important role in determination of the hadronic matter temperature and its gradient.

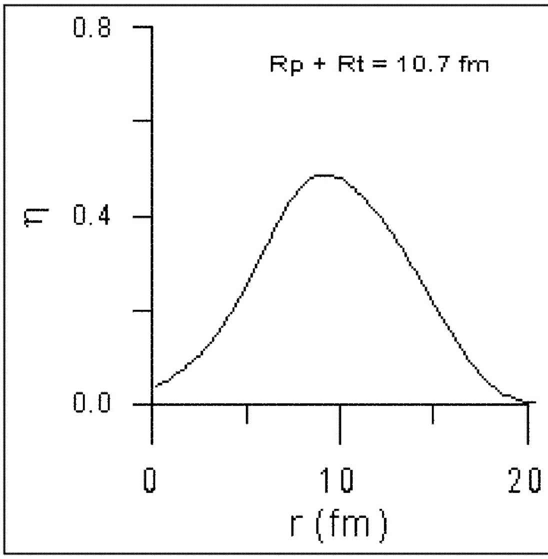
iii- The temperature has minimum values around the center and near the end of the effective range of the nuclear matter. These regions are responsible for the emission of low energy particles, while fast particles are produced in the bulk region characterized by ~0.5 and high temperature.

iv- Particles emitted in the forward direction are produced in the early stage of the reaction, far from the equilibrium. Backward production comes in a later stage when the system constituents undergo multiple cascade collisions.

References

Gosset J.et al,Phys.Rev C(1977)16,629.
Myers W.D,Nucl.Phys.A (1978) 296,177.
Aichelin J.and F.Bertsch G., Phys.Rev. C (1985) 31,1730

Kruse H., Jacak B.V.and Stocker H., Phys.Rev.Lett. (1985) 54, 289.
Hussein M.T., et al, Prog.Theor.Phys. (1995) 93 ,585.
Muller B.and Tragonov A., Phys.Rev. Lett. (1992) 68,3387.



Fig(1)

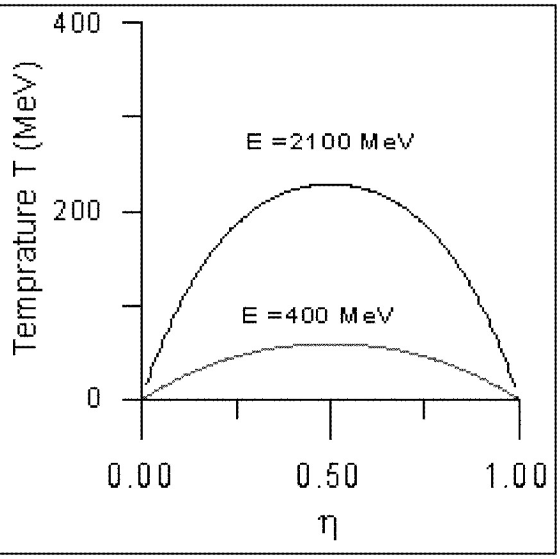
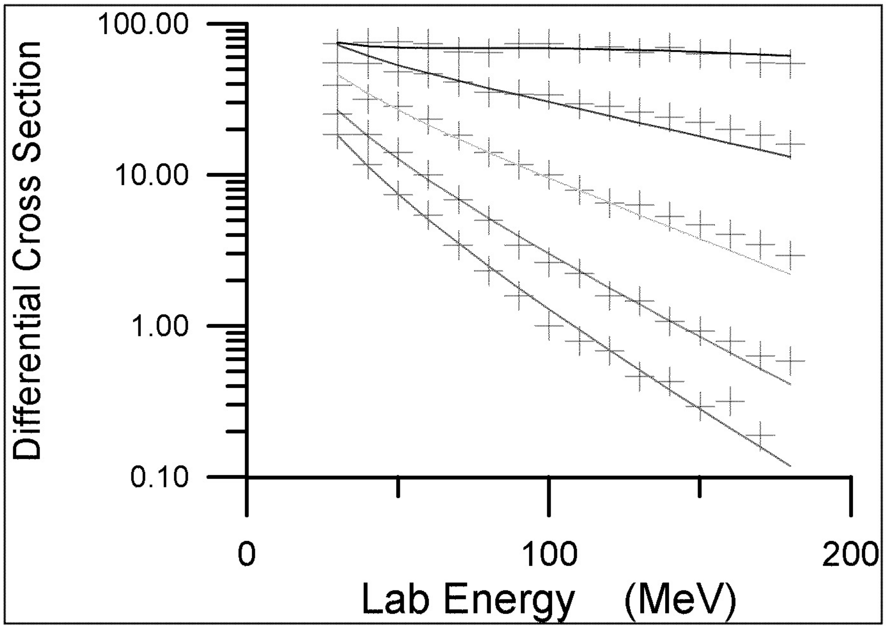


Fig.(2)



Fig(3)