

TEMPERATURE DEPENDENCE OF THE EFFECTIVE INTERACTION IN NUCLEAR MATTER

M. BALDO, G. GIAN SIRACUSA and U. LOMBARDO

Dipartimento di Fisica dell'Università di Catania and Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Corso Italia 57, I-95129 Catania, Italy

Résumé- Les propriétés de la matière nucléaire ont été étudiées dans le cadre de la théorie de Brueckner a température finie. L'énergie d'une particule a été calculée en manière autoconsistante utilisant une représentation separable du potentiel de Paris. Les résultats à une température donnée sont comparés avec ceux obtenues à la même température en congelant la matrice G à $T = 0$. En reproduisant nos résultats par une interaction du type de Skyrme on a estimé les paramètres correspondantes a différentes températures.

Abstract- The properties of hot nuclear matter are investigated in the framework of the finite temperature Brueckner theory. The single-particle energy has been self-consistently evaluated using a separable representation of the Paris N-N potential. The results at a given temperature are compared with those obtained at the same temperature with the G-matrix frozen at $T = 0$. Fitting these results with a Skyrme-like interaction the corresponding parameters have been estimated at different temperatures.

1. Introduction

The equation of state (EOS) of nuclear matter is currently a subject of great interest either in relation with heavy ion collision experiments at intermediate energies, and for models of supernovae explosions.

Unfortunately a complete microscopic many-body theory, even at zero temperature, which is able to reproduce the empirical data, is not yet available. Brueckner-Hartree-Fock (BHF) calculations do not give the correct saturation properties. Estimates of the contribution due to three-body correlations /1/ seem not to be able to remedy the situation. Till now semi-phenomenological three-body effective interaction have been used in order to reproduce the correct saturation properties at zero temperature.

At finite temperature the situation is even more uncertain and only a few microscopic calculations have been presented in the literature /2/. On the other hand, semi-phenomenological forces, mainly the so-called Skyrme forces, had a great success in reproducing the ground state

properties of finite nuclei as well as of nuclear matter. The calculation of EOS with these phenomenological forces is readily extended to finite temperature if one assumes that they are temperature independent.

It has been noted however that any effective interaction must be temperature dependent, because of the disappearance at higher temperature of the many body correlations. A first attempt to estimate the temperature dependence of the Skyrme forces (SF) has been presented in ref./3/, where a schematic first order calculation has been performed. According to the conclusions of this work the chemical potential and the pressure are the main quantities which are affected by the temperature dependence of the SF, while the energetics is essentially unaffected. As a consequence the critical temperature is lowered by about 3 Mev.

In this contribution we present the results of a BHF calculation at finite temperature for the properties of symmetric nuclear matter. These results are then used to try an estimate of the temperature dependence of SF, following the analogous procedure already introduced at zero temperature /4/.

2.- Description of the Method.

A complete self-consistent BHF calculation at finite temperature can be performed by extending in a straightforward way the zero-temperature formalism, as discussed in detail in ref./5/. The use of realistic two-nucleon interaction makes the numerical calculations rather cumbersome. To simplify the numerical effort we decided to adopt separable nucleon-nucleon interactions, which are now able to reproduce quite accurately /5/ the free nucleon-nucleon (N-N) t-matrix of realistic interaction, like the Paris one, both on and off-shell. In any case these interactions can be considered as realistic as any other available in the literature inasmuch as they reproduce the experimental N-N scattering and deuteron data. Moreover straightforward procedure to get a separable expansion of a given N-N realistic interaction have been recently presented in ref /6/.

The use of separable interactions greatly simplify the numerical computations and their accuracy has been checked already in calculations for zero temperature nuclear matter.

The separable N-N potential in a given channel C can be written

$$V_{LL'}^c(p, p') = \sum_i \sum_j g_i^{cL}(p) \lambda_{ij} g_j^{cL'}(p') \quad (1)$$

where $c = (JST)$, $L L'$ are the corresponding partial waves and g_i denotes the form factors. The G-matrix appearing in the BHF formalism, with the interaction (1), has also a separable form

$$G_{LL'}^c(z, q, q'; P) = \sum_{ij=1}^{N_c} g_i^{cL}(p) \tau_{ij}^{cLL'}(z, P) g_j^{cL'}(p') \quad (2)$$

where

$$\tau_{ij}^{cLL'}(z, P) = [\lambda^{-1} - \gamma^c(z, P)]_{ij}^{-1} \quad (3)$$

$$\gamma_{ij}^c = \sum_L \langle g_i^{cL} | \frac{Q}{z - H_0} | g_j^{cL} \rangle \quad (4)$$

and Q is the angular averaged Pauli operator at finite temperature and H_0 the angular averaged self-consistent two-nucleon energy operator. It must be self-consistently calculated together with the single-particle potential

$$U(k) = \sum_L \int G_{LL}^c(z, q, q; P) f(k') \frac{k'^2 dk'}{4\pi^2} \quad (5)$$

$$q = |k - k'| \quad P = \frac{1}{2}|k + k'| \quad (6)$$

$$z = \bar{\epsilon}(P + \frac{q}{2}) + \bar{\epsilon}(P - \frac{q}{2}) \quad \bar{\epsilon}(k) = \frac{k^2}{2m} + U(k)$$

a bar means averaging on the angle between q and P vectors and $f(k)$ is the Fermi function.

We have used the separable representation of the Paris potential given in ref./5/.

At finite temperature the standard gap choice in the single-particle spectrum cannot be used, because any distinction between particle and hole is meaningless. We have then followed the continuous choice for the potential $U(k)$ by extending the self-consistent procedure up to a momentum where the kinetic energy can be considered dominant. This momentum turns out to be around $k = 3.5 fm^{-1}$.

3.-Results and Discussion

In our calculations we included the following N-N channels which are expected to be the dominant ones: 1S_0 , $^3S_1 - ^3D_1$, 3P_0 , 3P_1 , 1P_1 , 1D_2 , 3D_2 , $^3P_2 - ^3F_2$

In fig.1 is reported the single-particle potential $U(k)$ obtained through the above described self-consistent procedure, at four different densities and at the temperature $T = 2$ Mev. A convergency for $U(k)$ within 10^{-2} Mev was obtained after 5 iterations. The total binding energy per particle was then evaluated to the first order of the hole-line expansion. As expected, the saturation density ρ_0 results to be too large ($\rho_0 = 0.29 fm^{-3}$) with respect to the empirical one ($\rho_0 = 0.17 fm^{-3}$). The corresponding binding energy is $BE = -14.2$ Mev. These results are comparable with recent similar calculations /7/. In fig.2 is reported the total energy per particle as a function of the total density at different temperatures. The main effect included in these results is due to the gradual disappearance of the g.s. correlations as the temperature increases. In order to single out this effect the same calculation has been repeated for the same values of the temperature using the G-matrix frozen at $T = 0$. Both results for the single-particle energy and the "saturation" density are compared in fig.3. The deviation between the two results increases very slightly up to $T = 10$ Mev in agreement with a previous calculation /3/, but it can be estimated within about 25% at $T = 18$ Mev.

To get more insight in the temperature dependence of the effective force the s.p. energy curves have been fitted around the minimum with a Skyrme-like force

$$E_A = K_A \frac{m}{m^*} + \alpha \rho + \beta \rho^2$$

Where K_A is the kinetic energy per nucleon and m^* is the effective mass. In tab.1. the variations of the Skyrme parameters with respect to their values at $T = 0$ are reported as a function of the temperature. While the effective mass seems not to depend on temperature both α and

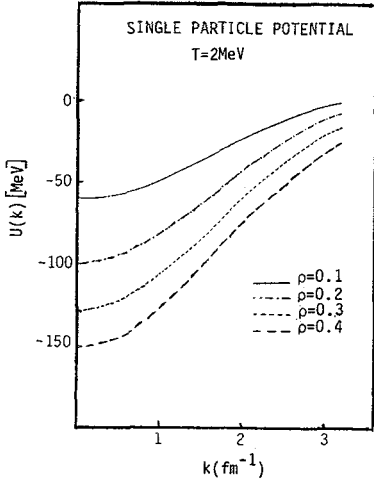


Fig. 1

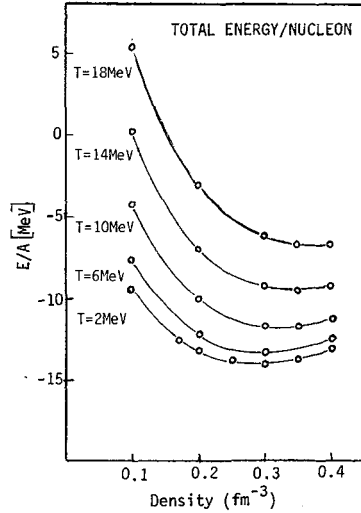


Fig. 2

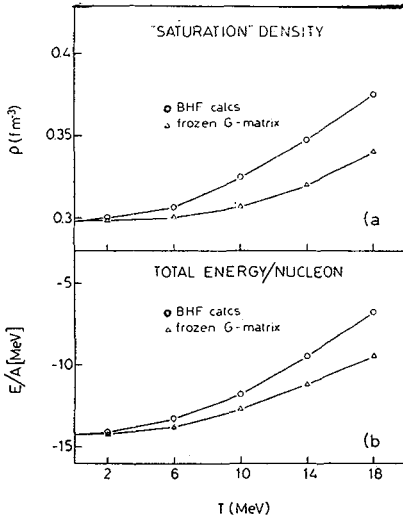


Fig. 3

Table 1

T (MeV)	m/m*	α (MeVfm ³)	β (MeVfm ⁶)
2	1.663	273.9	133.7
6	1.664	267.5	120.9
10	1.667	254.8	91.5
14	1.671	239.4	59.5
18	1.676	223.4	30.3

β exhibit strong variations. Even if these variations have a large compensation around the "saturation" density, their effect is expected to increase when the mechanical equilibrium density is concerned at a given temperature. This is due to the strong enhancement of the entropy release produced by the weakening of the p-p correlations at higher temperature, according to the conclusions of the ref./3/.

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