Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics A 789 (2007) 94–102

Pairing interactions and vanishing pairing correlations in hot nuclei

E. Khan [a,*], Nguyen Van Giai [a], N. Sandulescu [a,b]

[a] *Institut de Physique Nucléaire, Université Paris-Sud, IN_2P_3-CNRS, 91406 Orsay cedex, France*
[b] *Institute for Physics and Nuclear Engineering, PO Box MG-6, 76900 Bucharest, Romania*

Received 18 December 2006; received in revised form 1 March 2007; accepted 5 March 2007

Available online 15 March 2007

Abstract

Finite temperature Hartree–Fock–Bogoliubov calculations are performed in Sn isotopes using Skyrme and zero-range, density-dependent pairing interactions. For both stable and very neutron-rich nuclei the critical temperature at which pairing correlations vanish is independent of the volume/surface nature of the pairing interaction. The value of the critical temperature follows approximatively the empirical rule $T_c \simeq 0.5\Delta_{T=0}$ for all the calculated isotopes, showing that the critical temperature could be deduced from the pairing gap at zero temperature. On the other hand, the pairing gap at temperatures just below T_c is strongly sensitive to the volume/surface nature of the pairing interaction.

PACS: 21.30.Fe; 21.60.-n; 21.60.Jz

1. Introduction

The competition between the temperature and pairing correlations in hot nuclei has been studied for more than four decades. The first studies were based on the BCS approximation [1] but later on more involved calculations based on the Bogoliubov approach have been performed [2,3]. More recently the Bogoliubov approach has been employed together with self-consistent Hartree–Fock mean fields in order to study the pairing properties of hot nuclei. One of the first finite-temperature HFB (FT-HFB) calculations was based on a finite-range force of Gogny type, which is used for describing both the mean field and the pairing properties of hot nuclei [4]. FT-

* Corresponding author.
E-mail address: khan@ipno.in2p3.fr (E. Khan).

0375-9474/$ – see front matter
doi:10.1016/j.nuclphysa.2007.03.005

HFB calculations using zero-range forces have been done for hot nuclei [5] and for the inner crust matter of neutron stars [6]. In the latter case the mean field is obtained by using a Skyrme force while the pairing correlations are calculated with a density-dependent delta interaction. Also, shell-model approaches [7,8] have been used in order to probe the impact of the temperature on both pairing and deformation degrees of freedom.

The interplay between temperature and pairing correlations was also studied intensively in nuclear and neutron matter [9,10]. Typically, the pairing gaps are calculated in the BCS approximation and using single-particle states determined by self-consistent Brueckner–Hartree–Fock or Green's function methods (see [11,12] and references therein). In more fundamental approaches, which go beyond BCS approximation, is still unclear how much the pairing correlations are affected by the medium dependence of the nucleon–nucleon interaction (see [13,14] and references therein).

One open issue in current HFB calculations is how much the form of the pairing interaction affects the properties of nuclei, especially when one approaches the drip lines. It is also not clear yet if one really needs to introduce an explicit density dependence in the pairing interaction in order to enforce a pairing field evenly distributed in the nucleus ("volume type pairing") or strongly localized in the surface region ("surface type pairing"). Since a realistic pairing force derived from first principles is missing, one hopes to disentangle between various types of pairing forces by analyzing their consequences on measurable quantities. However, up to now these studies are not conclusive. For instance, in Ref. [15] a mixed surface-volume pairing interaction is considered to better explain the odd–even mass differences of some isotopic chains, whereas in Ref. [16] the surface or the volume type of the pairing interaction is found to be not so relevant for the neutron separation energies. It is also worth stressing that the pair density, which gives indications upon the localization of pair correlations in finite nuclei, is not strongly correlated to the surface or volume character of the pairing force but rather to the localization of the single-particle states close to the chemical potential [17].

Apart from the effects mentioned above, the type of the pairing force could also affect the vanishing of pairing correlations in hot nuclei. Besides constant G studies there have not been such systematic studies with effective density-dependent pairing interactions. It is known that, in a simple BCS approach with a constant pairing G, the vanishing of pairing correlations is expected to occur at $T_c \simeq 0.5\Delta_{T=0}$ [2]. The aim of the present work is to analyze if the volume or surface character of the pairing force could significantly influence vanishing pairing correlations using density-dependent pairing interactions. It should be noted that experimentally, the critical temperature could be extracted from the change of the specific heat in the vanishing pairing correlations region, using level densities measurements, as shown in Refs. [18,19].

2. Finite-temperature Hartree–Fock–Bogoliubov with Skyrme interactions

In this work we employ the FT-HFB approach with zero-range forces. Details can be found elsewhere [5,6], and we recall only the main equations. The FT-HFB equations, in coordinate representation, have the following form:

$$\begin{pmatrix} h_T(r)-\lambda & \Delta_T(r) \\ \Delta_T(r) & -h_T(r)+\lambda \end{pmatrix} \begin{pmatrix} U_i(r) \\ V_i(r) \end{pmatrix} = E_i \begin{pmatrix} U_i(r) \\ V_i(r) \end{pmatrix}, \tag{1}$$

where E_i is the quasiparticle energy, U_i, V_i are the components of the radial FT-HFB wave function and λ is the chemical potential. The quantity $h_T(r)$ is the thermal averaged mean field