Study of Pairing Deformations by Means of Two-Particle Transfer Reactions

O. Dragun¹, R. J. Liotta, and T. Vertse²
Research Institute of Physics, Stockholm, Sweden

Received May 15, 1987

The macroscopic approach for two-particle transfer reactions is applied in normal spherical nuclei and pairing deformation parameters $\beta_p$ are estimated. For Ni isotopes the macroscopic approach works reasonably well while for the lead region strong energy dependence of the $\beta_p$ values has been observed. It is shown that alpha-transfer reactions can also be treated within this formalism as couplings of the two-neutron and two-proton channels.

PACS: 24.10.Eq; 24.50.+g; 27.50.+e; 27.80.+w

1. Introduction

The description of nuclei in terms of macroscopic degrees of freedom has been of great importance to understand the dynamics of nuclei [1, 2]. Processes apparently so disparate as nuclear fission, giant resonances, nuclear vibrations and rotations (even at very high spin) can be analysed within a common theoretical framework. This not only has an elegant appeal but also greatly simplifies the calculations. The convenience of the macroscopic approach lies mainly in its capacity to account for a vast amount of nuclear properties by using only a few parameters. For instance, one extracts values of deformation parameters from nuclear spectra and with these values one can calculate inelastic scattering cross sections. The validity of this macroscopic description can be tested by using different experimental conditions (e.g. different projectiles or bombarding energies). One may however extract values for the deformation parameter $\beta_2$ which differ from each other considerably [3]. One usually attributes these differences to the presence of higher order deformations or to the influence of the opening of new channels in the reaction.

The description of inelastic scattering is one of the fields where the macroscopic approach has been very successful. But the closely related field of two-particle transfer reactions could, up to recently, be studied only within microscopic models. However, two-particle excitations are for most purposes formally equivalent to particle-hole excitations [4] and, therefore, one may have expected that inelastic scattering and two-particle transfer reactions may be treated formally in the same way. It was realized only recently that in two-particle transfer reactions the number of particles may be chosen to play the role of a macroscopic variable [5]. In this case collective motion is not related to coordinates in the ordinary space but rather to motions (vibrations and rotations) in an abstract space, the so-called gauge space [1]. The recognition of this collective motion allows one to approach two-particle transfer reactions in the same way as inelastic scattering reactions [5]. In fact, the form factors for two-particle transfer reactions become proportional to those used for inelastic scattering and by using the analogy between the two formalisms a pairing "deformation" parameter can be introduced. However, so far no systematic study of these deformations has been done and also the limits of the applicability of this approximation has not been checked. Therefore it seems to be necessary to explore the limitations of the theory by analysing different

¹ Permanent address: Dto. de Fisica, CNEA, Av. Libertador 8250, RA-1429 Buenos Aires, Republica Argentina
² On leave from: Institute of Nuclear Research of the Hungarian Academy of Sciences, H-4001 Debrecen, Pf. 51, Hungary
reactions at several values of the bombarding energy. As in inelastic scattering, one would like to establish that the pairing deformation parameter does not depend too much upon the reaction used to probe a given state and the bombarding energy applied.

The purpose of this paper is to carry out such an analysis in normal spherical nuclei, where only pairing vibrations are important. The formalism is reviewed in Sect. 2, the applications are presented in Sect. 3 and a summary and conclusions are left for Sect. 4.

2. Formalism

Macroscopic studies in nuclei are based in the collective character of electromagnetic transition probabilities of the nuclei concerned. The large value of the transition probabilities can be interpreted as shape oscillations and rotations. This interpretation was introduced in nuclear physics rather early [7], no doubt due to the easy visualization of the collective motion in the three dimensional physical space. Later, pairing collective modes were identified in nuclei and they were also interpreted in terms of vibrations and rotations in the abstract gauge space [1].

In the ordinary space spherical systems can only vibrate while rotations occur in statically deformed nuclei. Similarly, gauge-spherical nuclei can only vibrate, giving rise to pairing vibrations while superfluid systems, which are gauge-deformed, can also rotate.

Collective vibrations can be understood within a microscopic framework. Vibrations in ordinary space correspond to a collective superposition of particle-hole excitations while vibrations in gauge space are coherent superpositions of two-particle (or two-hole) excitations. Although these similarities were known for a long time, only recently a macroscopic description of two-particle transfer reactions has been introduced [5]. The form factors obtained in this way are very similar to those obtained within a microscopic description [6]. In order to show the analogy between inelastic scattering and two-nucleon transfer let us briefly review the formalism corresponding to vibrations in the ordinary space.

A density vibration of multipole \( \lambda \) produces a variation of the nuclear potential which, to first order in the deformation, is of the form

\[
\delta V = -k_\lambda(r) \sum_\mu Y^\mu_\lambda(\theta, \varphi) \alpha_\lambda r. \tag{2.1}
\]

Assuming the potential to be distorted in the same way as the nuclear density, i.e.

\[
\rho(r, \alpha_\lambda) \approx \rho_0(r) - R_0 \frac{\partial \rho_0}{\partial r} \sum_\mu Y^\mu_\lambda \alpha_\lambda r. \tag{2.2}
\]

one can write

\[
k_\lambda = R_0 \frac{\partial V}{\partial r}. \tag{2.3}
\]

In a similar way, the form factors corresponding to inelastic scattering are usually written [2] in terms of the derivative of the complex optical potential, i.e.

\[
f_\lambda(r) = - \beta_\lambda R_0 \frac{\partial V_{AA}}{\partial r}, \tag{2.4}
\]

where \( V_{AA} \) is the ion-ion potential and \( \beta_\lambda \) is the deformation parameter.

For the case of monopole pairing vibrations one assumes that the change in particle number, \( \Delta A \), is a macroscopic variable. Relaxing the number of particles as a discrete, conserved quantity, the pairing transition density can be written as [5]

\[
\Delta \rho^{(0)} = \frac{\partial \rho}{\partial A} \Delta A \tag{2.5}
\]

on the nuclear surface (where the reaction takes place) one can write \( R_0(A) = r_0 A^3 \) and

\[
\frac{\partial \rho}{\partial A} = - \frac{1}{3} R_0(A) A^{-1} \frac{\partial \rho}{\partial r}. \tag{2.6}
\]

Using eq. (2.6) one can construct macroscopic form factors for two-particle transfer reactions just following the familiar prescription for inelastic scattering. Introducing a pairing deformation parameter \( \beta_p \) the monopole pairing interaction term becomes

\[
\Delta V_p = - \beta_p k_p(r) \frac{\partial \rho}{\partial A}. \tag{2.7}
\]

The expression equivalent to eq. (2.4) is

\[
f_p(r) = - \beta_p \frac{R_0}{3 A} \frac{\partial V_{AA}}{\partial r}. \tag{2.8}
\]

Because of the proportionality between the radial parts of Eqs. (2.4) and (2.8) one can calculate two-particle transfer cross sections using available computer codes for inelastic scattering [8]. But the distorted waves for the entrance and the exit channels may be very different from each other (especially in light ion reactions) and one might need to calculate them separately. This is not a computational problem since computer codes usually contemplate this possibility [9].

One important use of inelastic scattering reactions has been to evaluate deformation parameters in nuclei. In principle, one expects that the deformation parameters would be independent upon the specific reaction used to probe the nucleus, e.g. bombarding