Revista Brasileira de Física, Vol. 2, N.° 1, 1972

The Pairing Deformation in Isospace and Gauge Space

D. R. BÈS*
Comisión Nacional de Energia Atómica, Buenos Aires, Argentina

Today I would like to inform you about the present state of an attempt to describe the $J^\pi = 0^+$ states around a closed shell nucleus. The description is made m terms of collective states which are specifically generated by a pairing force carrying isospin $T = 1$[1,2,3]. This program was started in 1965 at the Niels Bohr Institute[4]; it was continued at the University of Minnesota[5,6] and, presently, at the Los Alamos Scientific Laboratory[7,8] (New Mexico), the Niels Bohr Institute[7,8] (Copenhagen) and the Comisión Nacional de Energia Atómica[9,10,11,12] (Buenos Aires). The names of the persons involved in this program can be found in the references[4-12].

The description of nuclear states in terms of elementary excitations (phonons) is not only useful but very essential in order to understand the properties of many-body systems. These elementary excitations carry some definite quantum numbers like angular momentum, spin, isospin, transfer quantum number, etc. The relevance of this last quantum number among the properties of the phonons was first recognized by A. Bohr[1] in 1964 and leads to the treatment of the corresponding collective states in the following way[6,7]: the expectation value of the operator creating a pair of particles (coupled to $J^\pi = 0+$) will in general be a complex number d,

$$d = \langle 0 | \sum_j [c_j^\dagger c_j^\dagger]_J^{J=0} | 0 \rangle. \tag{1}$$

By performing a gauge transformation, we obtain

$$d = S^{-1} d' S = e^{2i\phi} d',$$

---

*Fellow of the *Consejo Nacional de Investigaciones Científicas y Técnicas,* Buenos Aires, Argentina
On leave of absence from the Universitv of Minnesota School of Physics and Astronomy, Minneapolis, Minnesota, USA.

where $S = e^{iA\phi}$. We choose ϕ such that $d' = A$, a real number. A change in the phase angle ϕ corresponds to a rotation in gauge space. The wrresponding conjugate momentum is the number of particles A. The collective treatment of the A – and ϕ – degrees of freedom is equivalent to the treatment of a two-dimensional deformable rotor. In particular, the corresponding Hamiltonian[6],

$$H = -\frac{\hbar^2}{2B}\frac{\partial^2}{\partial\Delta^2} - \frac{\hbar^2}{4B}\left(\frac{1}{\mathscr{F}}\frac{\partial\mathscr{F}}{\partial\Delta} - \frac{1}{B}\frac{\partial B}{\partial\Delta}\right)\frac{\partial}{\partial\Delta} + \frac{\hbar^2}{2\mathscr{F}}(M - M_0)^2 + V, \qquad (2)$$

depends on three functions of Δ, the potential energy surface V and the two inertial parameters B and $\mathscr{F}$. Here M is the number of pairs of particles. The BCS or superconducting solution corresponds to the case in which the potential V has a sharp minimum at $A, \neq 0$ (Ref. 13). Thus, the only low energy degree of freedom is a rotation in gauge space. Most of the non-closed shell nuclei are in this situation[7].

In the harmonic approximation around the equilibrium value $A, = 0$ ($V = \frac{1}{2}C\Delta^2$; $B = \frac{\mathscr{F}}{4A^2}$ = constant) the A– and ϕ – degrees of freedom have the same frequency. If the ground state of Pb^{208} is considered to be the vacuum state, the ground states of Pb^{206} and Pb^{210} are the one-phonon states carrying transfer quantum number ∓ 2, respectively[4]. The state at 4.87 MeV in Pb^{208} is very well described by the superposition of the two one-phonon states. This state is probably the most pure two-phonon state that is known in nuclear physics. In fact, a detailed study of the possible anharmonicities indicates that the total admixture of other states is less than 15% (Ref. 14).

Using (2), we have also treated the transition region in which neither the harmonic nor the superwnducting approximations are valid. The application of the crancking formalism to the determination of the parameters B and $\mathscr{F}$ yields excellent results when compared with an exact diagonalization of the pairing force in a two-level mode1[6].

Since the effective nuclear interaction is isospin invariant (but may be for terms of order T_z/A), the previous formalism was generalized[2,3,17] to include all the components of a T = 1 pairing interaction. In such case, there are three complex numbers of the form (1) corresponding to the three possible T_z projections,

$$d_{T_z} = \langle 0 \,|\, \sum_j [c_j^\dagger c_j^\dagger]_{T_z}^{J=0,\,T=1} \,|\, 0 \rangle. \qquad (3)$$

In addition to the gauge angle ϕ, there are now three angles O, corresponding to rotations in isospace. Under rotation in gauge ande isospace, the collective coordinates (3) transform according to

$$d_\mu = e^{2i\phi} \sum_\nu D^1_{\mu\nu}(\theta_i)\, d_\nu . \tag{4}$$

Let us assume an "irrotational" kinetic energy of the form

$$T = \frac{1}{2} B \sum_\mu |\dot{d}_\mu|^2, \tag{5}$$

with B = constant. The transformation (4) to an intrinsic system is chosen[g] such as to diagonalize the expression (5) of the kinetic energy. The three non-diagonal terms containing two time derivatives of θ_i are proportional to the vector product $a \times \beta$ of the real (a) and imaginary (β) components of d in the intrinsic frame; thus, we eliminate two[18] non-diagonal components of (5) by aligning the i-intrinsic axis in the direction of $a \times \beta$. Since the vector product is invariant under a rotation in gauge space, the diagonalization of the tensor of inertia corresponding to rotations in isospin is maintained when ϕ is changed. In contrast to that, the scalar product $a \cdot \beta$ changes with 4 and the value of 4 defining the orientation of the intrinsic system is chosen such that $\alpha \cdot \beta = 0$. In this way, we insure the vanishing of terrns containing one angular velocity $\dot{\phi}$, $\dot{\theta}_i$ and one time derivative of d_ν. It is convenient to choose the two remaining intrinsic axis (j – and k-axis) along the direction of the real and imaginary components, respectively (Fig. 1).

There remains in (5) a coupling term containing $\dot{\phi}$ and the isospin angular velocity along the direction of the cross product $a \times \beta$. In general, this cannot be eliminated since the corresponding rotations in gauge and isospace take place in the same plane. Therefore, in the intrinsic system, there remain two parameters describing the deformation of the system, namely α_j and β_k. We introduce two new variables[5]:

$$\Delta \equiv (\alpha_j^2 + \beta_k^2)^{1/2},$$

$$\Gamma \equiv \tan^{-1}(\alpha_j/\beta_k), \tag{6}$$

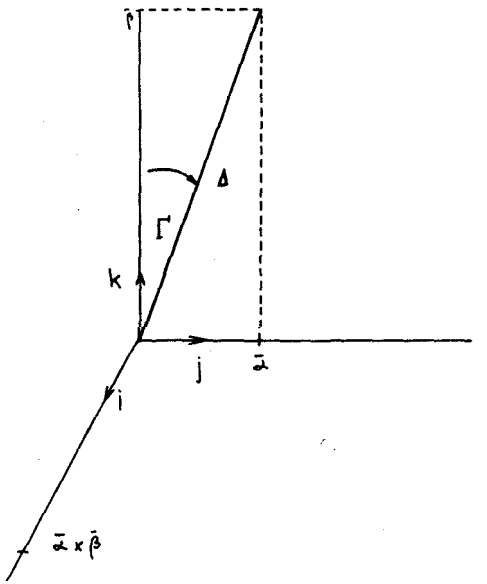


Figure 1 - The real $\bar{\alpha}$ and imaginary $\bar{\beta}$ collective vectors in the intrinsic system. The total (complex) debrmation vector has a modulus A and is oriented in the j-k plane making an angle Γ with the *k-axis.*

which play a similar role to β and γ in the case of the quadrupole deformations. In terms of these variables, the Hamiltonian reads

$$H = Z_{vib} + Z_{rot} + V(\Delta, \Gamma),$$

$$Z_{vib} = -\frac{\hbar^2}{2B}\left[\frac{1}{\Delta^5}\frac{\partial}{\partial\Delta}\Delta^5\frac{\partial}{\partial\Delta} + \frac{1}{\Delta^2 \sin 4\Gamma}\frac{\partial}{\partial\Gamma}\sin 4\Gamma\frac{\partial}{\partial\Gamma}\right],$$

$$Z_{rot} = \frac{1}{2B\Delta^2}\left[\frac{T_i^2}{\cos^2 2\Gamma} + \frac{T_j^2}{\cos^2\Gamma} + \frac{T_k^2}{\sin^2\Gamma} + \frac{2\sin 2\Gamma}{\cos^2 2\Gamma}(M - M_0)T_i + \frac{(M-M_0)^2}{\cos^2 2\Gamma}\right], \qquad (7)$$

where T is the angular momentum operator in isospace. The volume element is

$$dv = \frac{1}{4}B^5\Delta^5 |\sin 4\Gamma| d\theta\, d\phi\, d\Delta\, d\Gamma \qquad (8)$$

and the variables are used in the intervals

$$0 \le \phi \le \pi, \quad 0 \le \Gamma \le \frac{\pi}{4}, \quad 0 \le \Delta. \qquad (9)$$

Within our scheme, the operator corresponding to the two particle transfer process is

$$P^{\pm} = \pm i\, e^{\pm 2i\phi}\, \Delta \left[\cos\Gamma\, D^{1}_{\mu o}(\theta_i) \mp \frac{\sin\Gamma}{\sqrt{2}} \left(D^{1}_{\mu 1}(\theta_i) + D^{1}_{\mu -1}(\theta_i) \right) \right], \qquad (10)$$

while the operator associated with an α-transfer is

$$S^{\pm} = e^{\pm i4\phi}\, \Delta^2 \cos 2\Gamma. \qquad (11)$$

We are now in a similar position as nuclear physicists were after Bohr's paper[15] of 1952. We may apply here similar techniques as those used in order to solve Bohr's collective Hamiltonian[15, 16]. For instance, symmetry considerations associated with permutation of the intrinsic axes determine the most general form of the wave function,

$$\psi_{MTT_z}(\theta_i, \phi, \Delta, \Gamma) = \left(\frac{2T+1}{16\pi^3} \right)^{1/2} e^{2Mi\phi} \times$$

$$\times \sum_{K \geq 0} \frac{g^{TM}_{K}(\Delta, \Gamma)}{(1+\delta_{Ko})} \left[D^{T}_{T_z K}(\theta_i) + (-1)^{T+M} D^{T}_{T_z -K}(\theta_i) \right], \qquad (12)$$

where the quantum numbers corresponding to the motion in A and Γ remain yet unspecified.

We also note that there are only two independent quantities that are scalars both in gauge and isospace, namely A^2 and $\Delta^4 \cos^2 2\Gamma$. They play the same role as β^2 and $\beta^3 \cos 3\gamma$ in the case of the quadrupole deformation[16]. In particular, the potential energy surface is expressible as a power series in these two invariants.

We may discuss now some limiting cases''

a) If the system stabilizes at $A_{\alpha} \neq 0$ and Γ_o, we have rigid rotations. Moreover, if $\Gamma_o = 0$ or $\pi/4$, the deformation has axial symmetry and thus the energies are proportional to T(T + 1). If $\Gamma_o = 0$, only K = 0 and only T values with the same parity as M subsist[2]. No $\Delta T = 0$ two-body transfer processes are allowed, and thus the transition pattern is practically identical to the one arising from the usual pairing force acting between identical particles. If $\Gamma_o = \pi/4$, then T ≥ M and the a-transfer is forbidden.

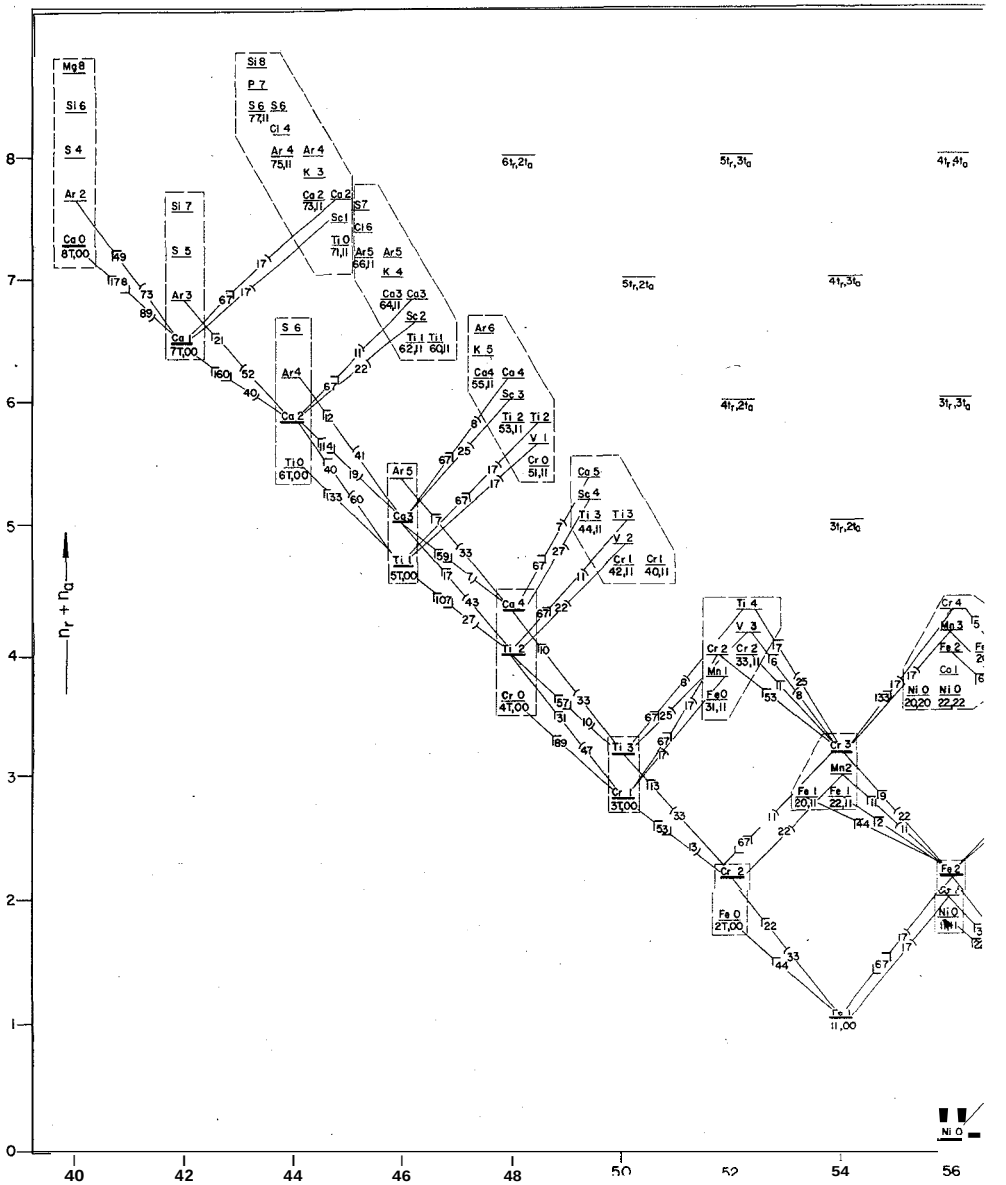
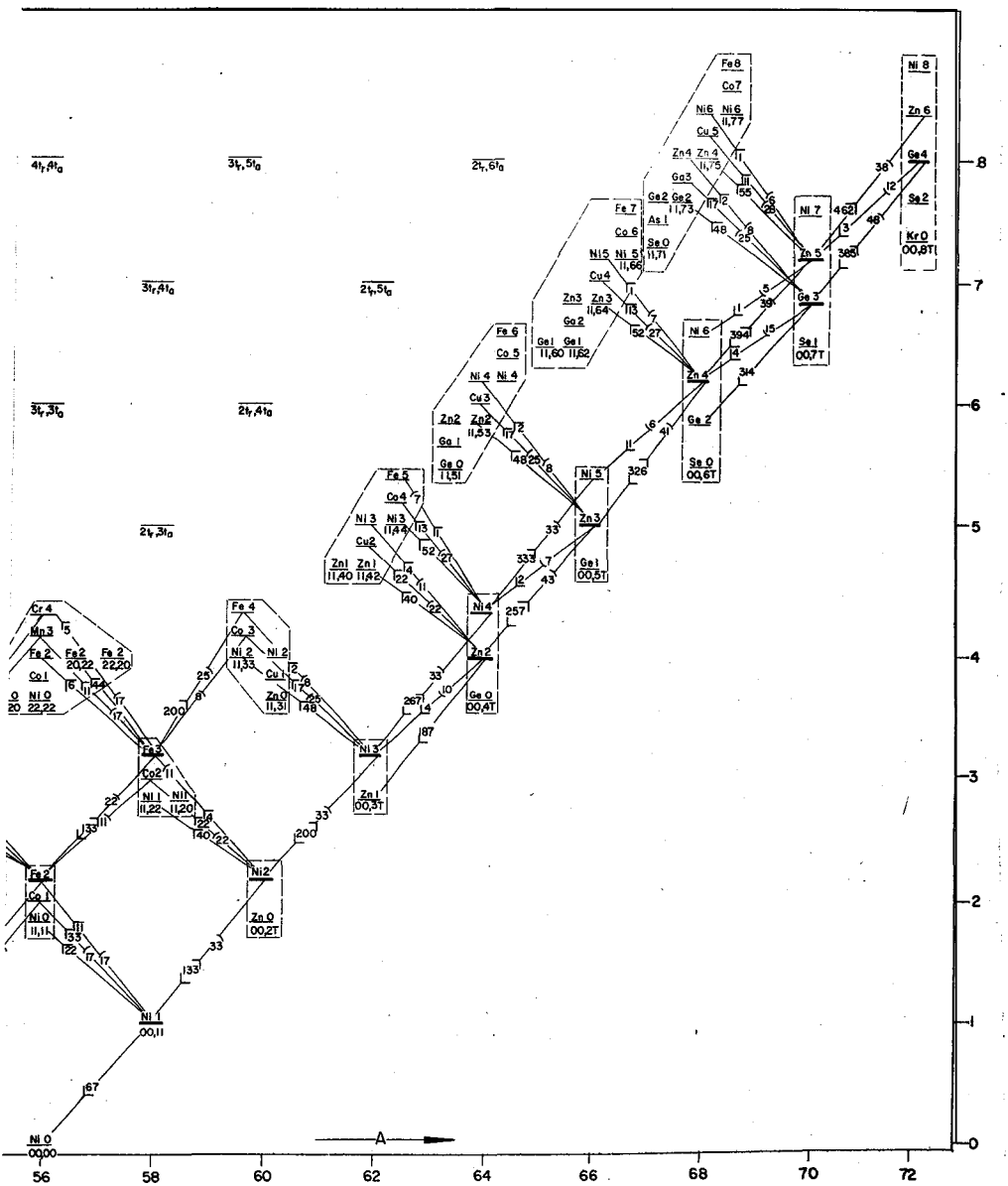


Figure 2 - The collective levels in the vibrational limit. The levels are labelled by (n, t_r, n_a t,) where n, and t, are the number and isospin of the removal quanta, respectively, and (n_a, t_a) are the corresponding quantum numbers for the addition quanta The total isospin is written to the right of each state. The chemical symbol corresponds to the nucleus with $T_z = T$. (Their isobaric analogues are not represented explicitly). Levels represented by a thicker



line correspond to the stable cases, which may be used as targets. Square brackets ((t, *p*) or (*p*, *t*)) and round brackets ((*h*, p) and (p, *h*)) point the direction of the possible reactions The adjoining numbers are given by expression (I) of Ref. 5 and are roughly proportional to the respective intensities.

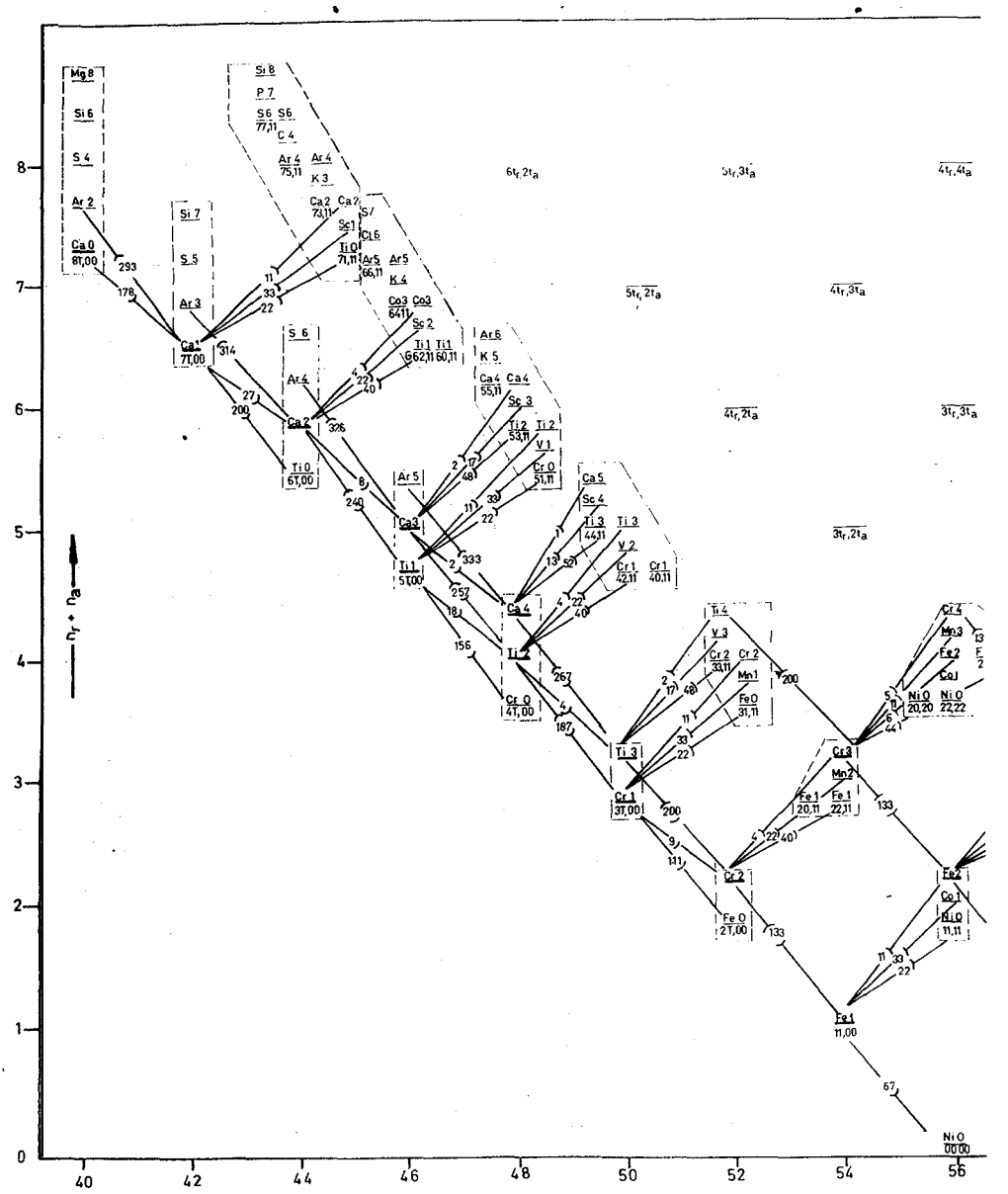
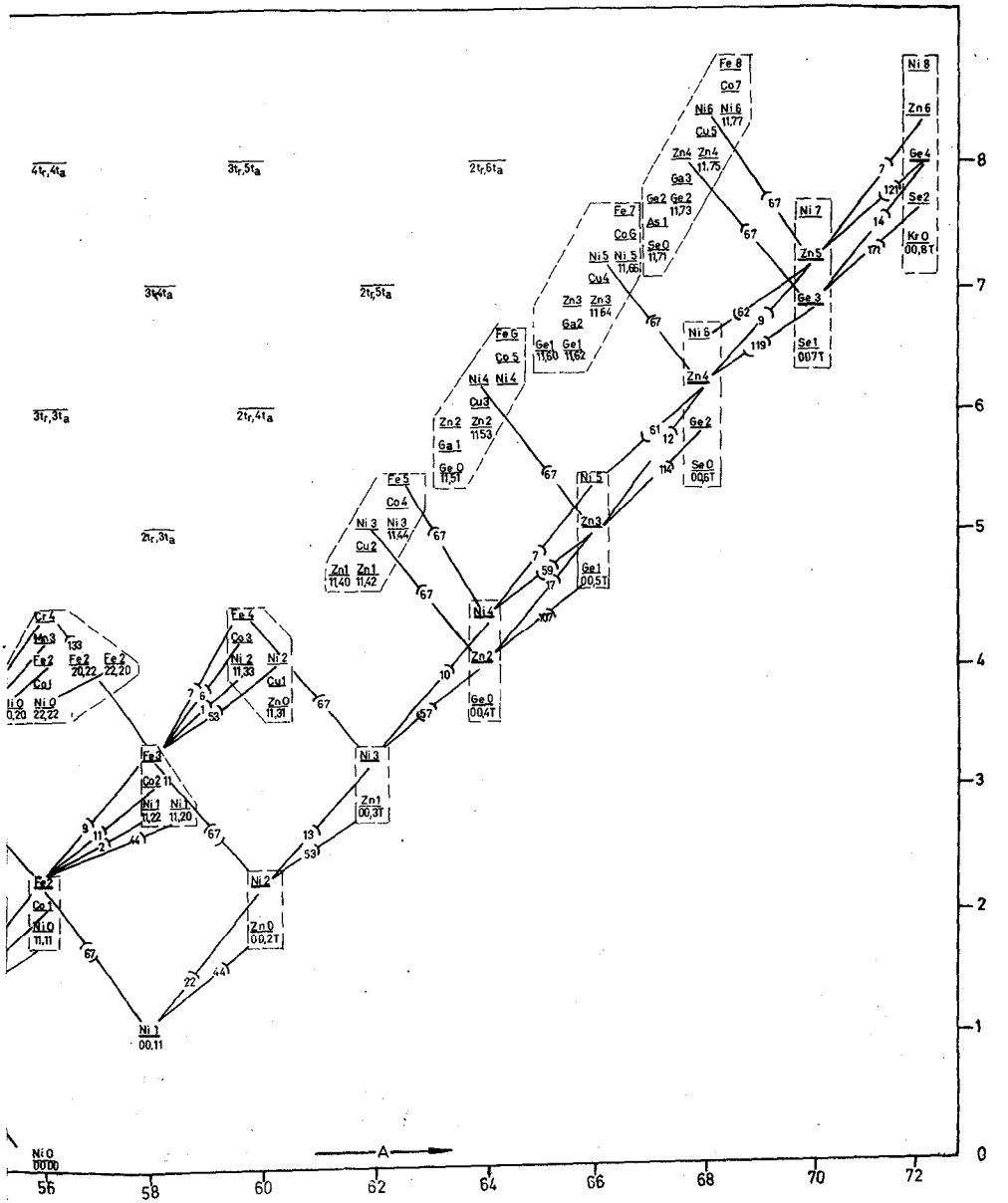


Figure 3 - Similar to Fig. 2, showing the possible *(h,* n) and (n, *h)* reactions.


4t,4t
3t,5t
2t,5t
3t,4t
2t,5t
3t,3t
2t,4t
2t,3t
A
0
1
2
3
4
5
6
7
8
56
58
60
62
64
66
68
70
72

b) Another interesting case of rigid rotations occur for $\Gamma_o \sim 23°$ in which case there are two excited states (T = 1, 2) for M = 0, a low T = 1 and an excited triplet (T = 1, 2, 3) for M = 1, a low doublet (T = 0, 2) for M = 2, etc. This spectrum ressembles the vibrational one around $\Delta = 0$ (Figs. 2 and 3), but for the fact that a few states are missing (like a T = M = 0 excited state).

If we allow small departures, for instance, from an equilibrium position A, with $\Gamma_o = 0$, symmetry considerations allow[5] for the A- vibrations (K = 0) and Γ- vibrations (K = 1) which also have their counterpart in the theory of quadrupole deformations. In this case, T = 0 transitions may occur between the ground state and a Γ- band.

The lowest terms in an expansion of the potential energy surface in terms of the elementary scalars are

$$V = V_o + \frac{1}{2} C \Delta^2.$$

The resulting harmonic spectrum[2, 3, 5] is also characterized by the number of phonons[19] N. If M = 0, there is a triplet of two-phonon states (T = 0, 1, 2); a one-phonon T = 1 and a three-phonon quadruplet ($T = 1, 2^2, 3$) for M = 1; a two-phonon doublet (T = 0, 2) for M = 2, etc. The transition spectrum for two-body transfer processes has obviously the selection rule $\Delta N = 1$ (Figs. 2 end 3).

The more general situation can be solved by diagonalizing anharmonic terms within a large but finite set of phonon states. This has been done[11] for a model potential energy surface, which reproduces the main features of the results of a pairing force. Fig. 2 represents the probability distribution for the ground state and first A-vibrational state, for a value of a pairing force strength which is 1.75 times the critical value.

We want to turn now our attention to real nuclei and try and determine how much of the previous discussion is useful. The most favourable region for the applicability of the present coupling scheme lies around Ni^{56} (from about Ca^{42} to Ge^{70}). Earlier analysis of the experimental data, in terms of the vibrational[3,5] and axially symmetric rotations[5], lead to values which, in many cases, lie between those two limits. Moreover, an optimum fit of a shell model calculation[12] including the $f_{7/2}, f_{5/2}$ and $p_{3/2}$ single particle levels yields a value for the strength of the T = 1 pairing force very close to the one corresponding to the phase transition between normal and superconducting systems. Therefore, it is apparent that we have to use a method which is able to deal with intermediate situations like the one that we have just developed.

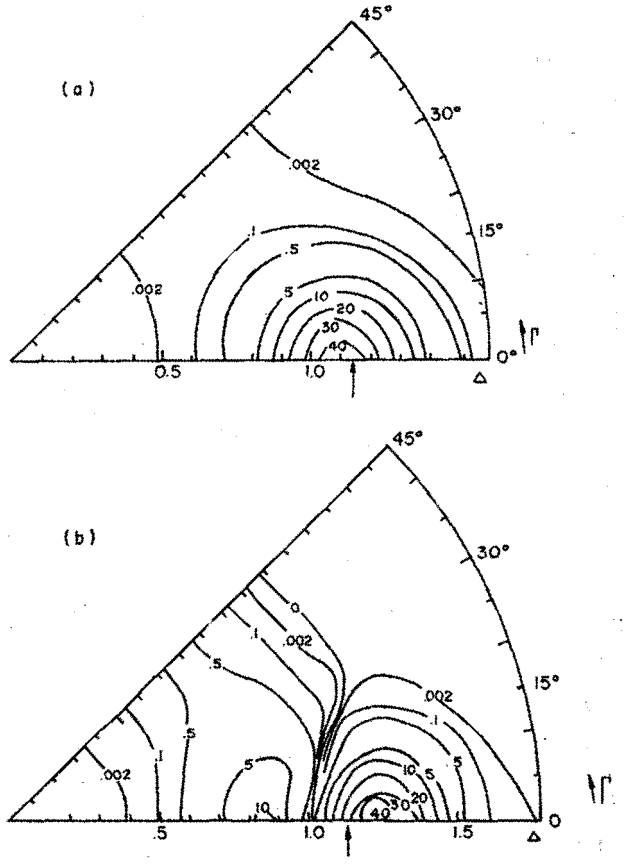


Figure 4 - The probability distribution for the ground state and first Δ-vibrational state, for a value of a pairing force strength which is 1.75 times larger than the critical value.

In order to study the experimental energies we must sort out from rhe nuclear spectrum states with $J^{\pi} = 0^{+}$, which are strongly populated in two-body transfer processes. We subtract from the empirical binding energies the contribution from the Weizsácker mass formula (without the pairing term) and the resulting spectrum has to be compared with the eigenvalues of (7). There is some ambiguity in the amount of the symmetry term which must be subtracted. We have left only 1/2 of the usual value in the Weizsácker formula[20], since the contribution from the single-particle T = 1 field is not taken into account in (7), but the "kinetic" term should in principle be included there.

In this region, there are about 60 experimental states which may be considered to be members of the collective band[8]. If we try to fit the energy of these states using a vibrational or a rigid rotational description, we obtain[12] least square deviations of order 2.5 MeV to 5 MeV, which has to be compared with an average excitation energy of about 10 MeV. The fit improves if either anharmonicities are included in the vibrational motion or a calculation with variable moments of inertia[21] is performed. With 7 anharmonic terms or 5 parameters in the VMI model, the least squares deviation is reduced to 0.8 MeV. No attempt has yet been made to fit the energies using the full complication of (7) plus, for instance, the constraints implied by the shell model in the construction of the potential energy surface.

A more significant test for the model is probably given by two-body and alpha-transfer processes. The data up to 1969 on the former experiments is discussed in reference[5]. Since then, a significant contribution has been performed at Los Alamos[22] where absolute cross sections which allow the comparison of the results corresponding to different nuclei were measured. The main conclusion from Ref. 22 is that, from Ni^{36} to Ca^{48}, the ground state to ground state cross sections increase, with the number of phonons, at a higher rate than is predicted by the harmonic approximation (the rotational scheme would predict practically no increase at all for these transitions).

Another important experimental requirement concerning the nature of the anharmonicities are the $\Delta T = 0$ transitions which, in the region below Ni, may proceed only via (τ, p) reactions if we are close to the vibrational limit. The experimental results[23] indicate that these $\Delta T = 0$ transitions are considerably weaker than expected on the basis of known $\Delta T = 1$ strengths. Within the model, this effect may be explained by moving from the harmonic limit in the direction of a vibrating rotor with more stiffness in the Γ- restoring force than in the A- restoring force.

In this case, the corresponding levels should start to be also populated by the inverse (p, *h*) reaction. Moreover, the unique role played by the (h, p) reaction in nuclei below Ni, is played by the inverse (p, *h*) process for mass number larger than 56, where there is anyhow very little experimental information. Probably the most important information yet to come concerns these (p, *h*) transfers. These reactions require a very good energy resolution (since they populate states in odd-odd nuclei) and a proton energy 25 - 30 MeV, in order to overcome the effects of a negative Q value and the Coulomb energy. Therefore, the Pelletron will be in a very convenient position to obtain these data.

The $Zn^{68}(d,Li^6)Ni^{54}$ reaction has been performed[24] at the *Ciclotrón* de Energia *Atómica* at Buenos Aires, showing good evidence for a direct reaction mechanism. A systematic study of ground state to ground state transitions in this region is on the way. This project wuld also most conveniently be extended making use of the Pelletron to study, for instance, excited $J^\pi = 0^+$ states.

We may sumarize the present state of the problem by saying that we can treat now the collective T = 1 pairing degree of freedom within the adiabatic approximation The formalism is similar to the one corresponding to the quadrupole degree of freedom. By comparing the two formalisms, we understand better which properties are inherent to a collective treatment of the many-body problem and which are inherent to the particular symmetry.

The applicability of the present scheme to real nuclei is not yet finished. Empirically, there is one collective band but with many more states than in any known quadrupole band. Some more experimental data and/or theoretical calculations of the collective parameters will be needed to decide if we have the correct treatment for the *T*-dependence of the $J^\pi = 0^+$ degree of freedom around Ni^{56}.

References and Notes

1. A. Bohr, *Compt. Rend. du Con. Int. de Physique Nucléaire,* Paris, 1964, Ed Centre National de la Recherche Scientifique (Paris 1964) p. 487.
2. A. Bohr, *Proc. Int.* Symp. *on Nuclear Structure,* Dubna, 1968, IAEA (Vienna 1968) p. 179.
3. O. Nathan, *Proc. Int. Symp. on Nuclear Structure,* Dubna, 1968, IAEA (Vienna 1968) p. 191.
4. D. R Bès and R A. Broglia, Nucl. Phys. 80, 289 (1966).
5. B. Bayman, D. R. Bès and R. A. Broglia, Phys Rev. Lett. 23, 1299 (1969).
6. D. R. Bbs. R. A. Broglia, R. P. J. Perazzo and K. Kumar, Nuc Phys. A143, 1 (1970).
7. R. A. Broglia, O. Hansen and C. Riedei, to be published in *Advances in Nuclear Physics*
8. D. R. Bès. R A. Broglia and O. Hansen, priyate communication
9. G. G. Dussel, E. Maqueda and R P. 1. Perazzo, Nucl. Phys. A153, 469 (1970).
10. G. G. Dussel, R P. J. Perazzo, D. R Bès and R A. Broglia, to be published
11. G. G. Dussel, R. P. J. Perazzo and D. R Bès to be published.
12. D. R. Bès, G. G. Dussel, E. Maqueda and R P. J. Perazzo, private communication.
13. The meaning of A is here somewhat different from the usual ones. It corresponds to the sum $\sum U_\nu V_\nu$ in the BCS solution.
14. R. A. Broglia, V. Paar and D. R Bès, to be published in Physics Letters.
15. A. Bohr, Mat. Fys. Medd. Dan. Vid. Selsk. 26, N." 14 (1952).

16. M. Baranger and K. Kumar, Nucl. Phys. **A110**, 490 (1968). 490 G. G. Dussel and D. R. Bès, Nucl. Phys. **A143**, 623 (1970).
17. J. Ginocchio and J. Weneser. Phys. Rev. **170,** 859 (19681.
18. The third Euler angle θ_i can be chosen such as to eiiminate the third non-diagonal term.
19. Another quantum number that may be introduced is the seniority (see [10]).
20. A. Bohr and B. R. Mottelson, Nuclear Structure, Vol. 1, W. A. Benjamin Inc. (1969) New York, p. 142.
21. M. A. Mariscotti, G. Scharff-Goldhaber and B. Buck, Phys. Rev. 178, 1864 (1969).
22. R. F. Casten, E. R. Flynn, O. Hansen and T. J. Mulligan, Physical Review **C4**, 130 (1971).
23. O. Hansen and O. Nathan, private communication.
24. A. Ceballos. H. Erramuspe, A. Ferrero, M. Sametband and J. Testoni, Physical Review **C4,** 1959 (1971).

List of Participants

Argentina

D. Bès	Comisión Nacional de Energia Atómica
H. Bosch	Universidad de Buenos Aires
E. Maqueda	Comisíon Nacional de Energía Atómica
M. Mariscotti	Universidad de Buenos Aires
R. Perazzo	Comisión Nacional de Energía Atómica
J. Testoni	

Brasil

N. C. Faria	Pontificia Universidade Católica do Rio de Janeiro
W. Owens	
B. Patnaik	
C. M. do Amaral	Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro
S. M. de Barros	
D. Binns	
A. C. M. Gonçalves	
A. Marques	
J. Martins	
L. Tauhata	
R. B. da Costa	Centro Latino Americano de Física
D. V. Ferreira	
W. Huang	Universidade Federal do Rio de Janeiro
L. T. Auler	Instituto de Engenharia Nuclear do Rio de Janeiro.
A. G. da Silva	
I. Baumvol	Universidade Federal do Rio Grande do Sul
G. Jacob	
J. Rogers	
V. H. F. dos Santos	
P. Deichelbohrer	Fundação Universidade de Brasilia
L. C. Gomes	
Y. S. Liu	
J. B. Camargo	Natal RN
H. G. de Souza	Universidade Federal de São Carlos
M. A. Guimarães	Instituto Tecnológico de Aeronáutica

Thereza Borello	Universidade de São Paulo
Hsi-Tseng Chen	
Olacio **Dietzsch**	
Ross A. Douglas	
Carlos Fontenla	
Doracy Fontenla	
José **Goldemberg**	
Iuda D. Goldman	
Amelia I. Hamburger	
Ernst W. Hamburger	
Silvio B. Herdade	
Mahir S. Hussein	
José **Roberto Moreira**	
Giorgio Moscati	
Ivan C. Nascimento	
Antonio F. R. Toledo Piza	
Trentino Polga	
Violeta de J. G. Porto	
M. Narayana Rao	
Wayne M. **Roney**	
Oscar Sala	
Wayne A. **Seale**	
Muhsio Abo-Shaeer	
Elly Silva	
Wiktor Wajntal	
Shigueo Watanabe	
Diogenes R. de Oliveira	Instituto de Física Teórica, SP
Valdir C. **Aguilera Navarro**	
Canada	
A. E. **Litherland**	University of Toronto
Chile	
L. **Birstein**	Universidad de Chile
L. Laroze	Universidad **Tecnica** F. Santa Maria
J. R. **Morales**	Universidad de Chile
J. L. Romero	
Colombia	
J. Herkrath	Universidad Nacional de Colombia
Great Britain	
P. E. **Hodgson**	Oxford University

Mexico

R. Almanza	Comisión Nacional de Energía Nuclear
A. Dacal	Universidad Nacional Autónoma de Mexico
R. Fuller	Instituto Politécnico Nacional
M. E. O. López	Universidad Nacional Autónoma de Mexico
M. Martinez	Instituto Politécnico Nacional

Perú

V. Latorre	Universidad Nacionat de Ingenieria

U.S.A.

D. A. Bromley	Yale University
W. Haeberli R. G. Herb H. T. Richards	University of Wisconsin
E. K. Warburton	Brookhaven National Laboratories

SOCIEDADE BRASILEIRA DE FÍSICA

1. DIRETORIA (1971-1973)

Presidente - Alceu G. de Pinho Filho (PUC-GB)
Vice-presidente - Emst Wolfgang Hamburger (USP)
Secretário Geral - Giorgio Moscati (USP)
Secretario - Carlos A. Dias (UFBa)
Tesoureiro - Olácio Dietzsch (USP)
Secr. p/Assuntos de Ensino - Beatriz Alvarenga (UFMG)
Secr. Adjunto p/Ass. de Ensino - Marw Antonio Moreira (UFRGS)

2. SECRETÁRIOS ESTADUAIS (1970-1972)

Rio Grande do Sul - Victoria E. Herswvitz (UFRGS)
São Paulo - Nelson Jesus Parada (UEC)
Minas Gerais - Manoel Lopes Siqueira (UFMG)
Bahia - Antônio G. Oliveira (UFBa)
Ceará - Homero Lenz Cesar (UFCe)

3. CONSELHO

Jayme Tiomno (Princeton, EUA)
Ross Alan Douglas (USP)
Ramayana Gazzinelli (IPR)
José Leite Lopes (Strasbourg - França)
José Goldemberg (USP)
Shigueo Watanabe (USP)
Erasmo Madureira Ferreira (PUC-GB)
Jorge André Swieca (PUC-GB)
Cesare M. Lattes (UEC)
Francisco A. Germano (UFCe)

Suplentes

Luiz Carlos Gomes (UNB)
Henrique Fleming (USP)
Femando de Souza Barros (UFRJ)
Rogério C. Cerqueira Leite (UEC)
Nelson Jesus Parada (UEC)

Enderêços

PUC - Instituto de Física
Pontificia Universidade Católica
Rua Marquês de São Vicente, 209
20000 - Rio de Janeiro GB

USP - Instituto de Fisica
Universidade de São Paulo
Caixa Postal 20516
01000 - São Paulo SP

UFBa - Instituto de Física
Universidade Federal da Bahia
Federação
40000 - Salvador BA

UFMG - Instituto de Ciências Exatas
Universidade Federal de Minas Gerais
30000 - Belo Horizonte MG

UFRGS - Instituto de Física
Universidade Federal do Rio Grande do Sul
Av. Luiz Englert s/n
90000 - Pôrto Alegre RS

UEC - Instituto de Física
Universidade Estadual de Campinas
Cidade Universitária
13100 - Campinas SP

UFCe - Instituto de Física
Universidade Federal do Ceará
Caixa Postal 1262
60000 - Fortaleza CE

IPR - Instituto de Pesquisas Radioativas
Universidade Federal de Minas Gerais
Caixa Postal 1941
30000 - Belo Horizonte MG

UNB - Departamento de Física
Universidade Nacional de Brasília
70000 - Brasília DF

UFRJ - Instituto de Física
Universidade Federal do Rio de Janeiro
Ilha do Fundão
20000 - Rio de Janeiro GB

ESTA OBRA FOI COMPOSTA EM TIMES ROMAN
PELO SISTEMA DE FOTO-COMPOSIÇÃO (*Monophoto)* E IMPRESSA EM *Off-Set* PELA
DISTRIBUIDORA PAULISTA DE JORNAIS,
REVISTAS, LIVROS E IMPRESSOS LTDA.
RODOVIA PRESIDENTE DUTRA, KM 387
GUARULHOS — ESTADO DE SÃO PAULO