NUCLEAR STRUCTURE CALCULATIONS FOR THE 2p-1f NUCLEI: ^{56}Fe, ^{57}Fe, ^{58}Ni, ^{59}Ni

G. Vanden Berghe
Seminarie voor Wiskundige Natuurkunde,
Rijksuniversiteit Gent, Gent, Belgium

Many authors have tried to explain the structure of the 2p-1f nuclei in terms of the nuclear shell model |1|. All these investigations mainly differ in the type of interaction used. They are all able to reproduce to a certain extent the position of the levels, but they practically all fail to account for the electromagnetic properties and in particular for the E2 enhancements in the doubly-even nuclei. So we propose in this paper to describe these nuclei within the particle-cluster core coupling model |2|. The valence neutrons are assumed to move in the (2p-1f) shell. We use the parametrization taken in a very simple-minded way directly from experiment. The experimental energies of the first excited states in ^{57}Ni are taken as single-particle energies. The energy of the first excited 2^+ state in ^{56}Ni (or ^{54}Fe) has been used as phonon energy of the core. The pairing strength is assumed to be $G = 27/A$ MeV. A value for the particle-vibrator coupling strength has been derived from the following expression |3|

$$a = \sqrt{4\pi}/(3Ze\ R_o^2)\ \langle k \rangle |B^{vibr}(E2; 2_1^+ \rightarrow 0_1^+)|^{1/2}$$

where the nuclear radius is denoted by $R_o = 1.2\ A^{1/3}$ fm and $\langle k \rangle$ is taken to be 50 MeV. A value for B^{vibr} is taken either from ^{56}Ni or from ^{54}Fe. In this parametrization without an adjustable parameter, we have diagonalized the Hamiltonian in the corresponding basis $|(j_1 j_2)J, NR; I\rangle$ for ^{56}Fe, ^{58}Ni and $|(j_1 j_2)J_1, j_3 J; NR; I\rangle$ for ^{57}Fe and ^{59}Ni.

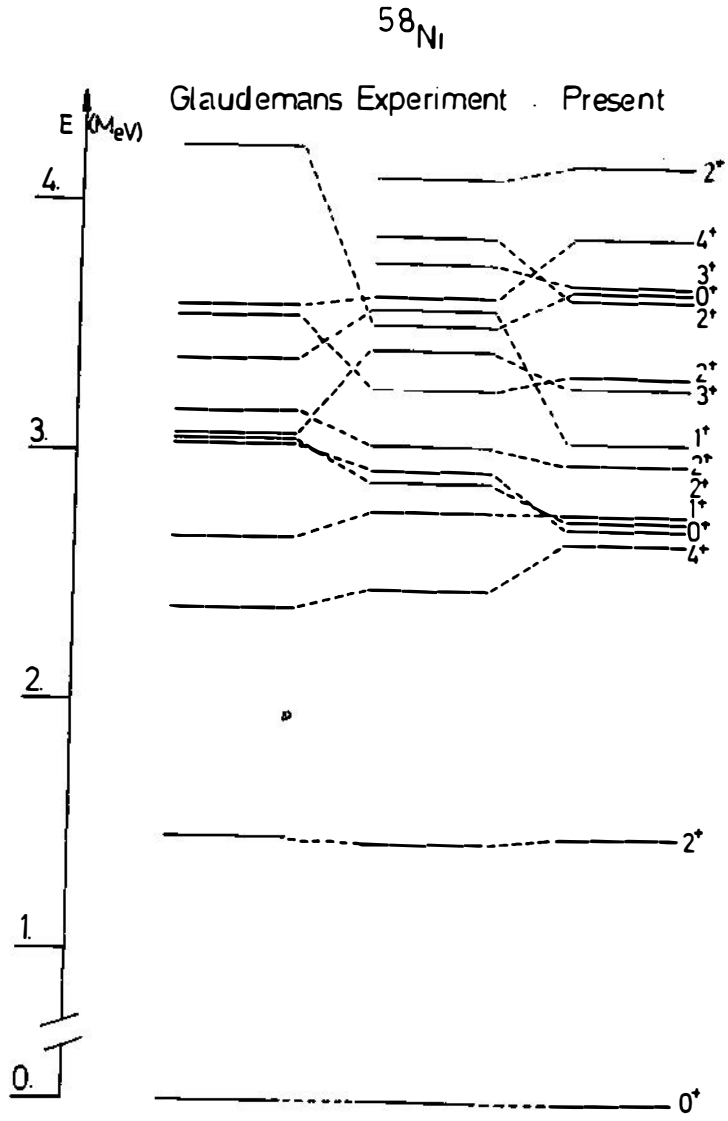

Fig. 1

In fig. 1, as an example for the doubly-even isotopes, we compare the theoretical level scheme of ^{58}Ni up to 4.2 MeV with the experimental data |4,5| and the results of a shell-model calculation by Glaudemans et al. |1| where only the theoretical counterparts of the experimental levels up to 3.62 meV are given. The present

TABLE 1

Transition	B(E2) (e^2fm^4) Exp. |4,5|	B(E2) (e^2fm^4) (theory) Ref. |6| e_n^{eff}=1.05e	Ref. |1| e^{eff}=1.70e	Present e_n=1.0e e^{vibr}=1.4e
$2_1^+ \rightarrow 0_1^+$	140^{+10}_{-11}	136	131	149
$2_2^+ \rightarrow 0_1^+$	$0.36^{+0.12}_{-0.10}$	7.43	9	0.60
$4_1^+ \rightarrow 2_1^+$	<560	-	113	135
$2_2^+ \rightarrow 2_1^+$	199^{+61}_{-63}	14.66	24	17
$2_3^+ \rightarrow 2_1^+$	20^{+10}_{-8}	-	53	6
$4_2^+ \rightarrow 4_1^+$	40^{+100}_{-40}	-	-	5
$0_2^+ \rightarrow 2_2^+$	231 ± 29	100.2	211	199

model describes all experimentally observed levels. The average absolute deviation between calculated and experimental data for the 15 levels considered is 0.15 MeV. Analogous results have been obtained for ^{56}Fe. In order to make a comprehensive test for the proposed model, in table 1 we compare some calculated reduced E2 transition probabilities |4,5| with experimental data and results of shell model calculations |1,6|. The values used for the effective charges (the neutron charge and the vibrator charge) are also indicated. The data of Shimizu and Arima |6| are those obtained by including core excited states of the type 3p-1h and 4p-2h into a shell model calculation. They explain the enhanced E2 transition from the 2^+ state to the ground state due to core polarization effects. Anyway, the agreement for the other B(E2) values is still poor. Glaudemans et al. |1| can only obtain fair agreement between theory and experiment by introducing a very large effective neutron charge. The satisfactory results of the present model can be understood by the fact that in most of the calculated B(E2) values the particle cluster and core vibrational contributions add coherently, resulting in quite large reduced E2 transition probabilities. The observed inhibited $2_2^+ \rightarrow 0_1^+$ cross-over transition is better reproduced by the present calculations than by all previous treatment. We want to remark that most of these results can be explained by means of the generalized vibrational intensity and selection rules (GVISR) |7|.

As an example for an odd-A nucleus, in fig. 2 we compare the experimental |8,9| and theoretical level schemes of ^{59}Ni up to 3 MeV. The several groups of levels (around 1 MeV, 1.8 MeV and 2.6 MeV) are nicely reproduced. It is obvious that the $I^\pi = 7/2^-$ state at 2.640 MeV, which clearly shows a $\ell=3$ distribution in a (d,p) reaction work

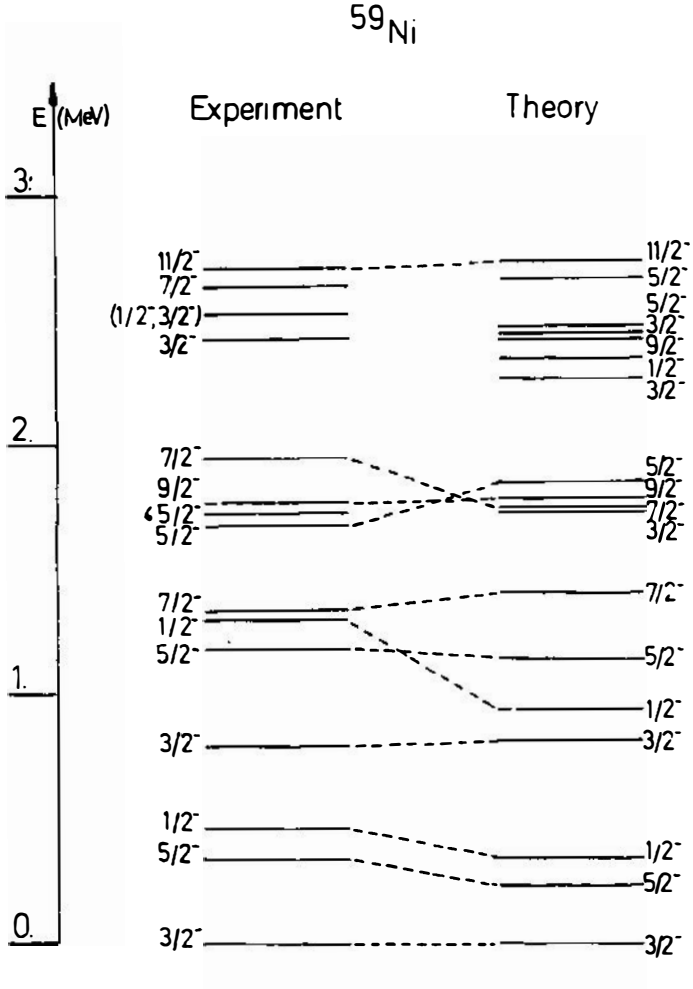

Fig. 2

|10|, cannot be reproduced by the present model, where the $1f_{7/2}$ single-particle state has not been taken into account. Analogous results have been obtained for ^{57}Fe.

In table 2 we compare the theoretical and experimental spectroscopic factors |11,12| for the following one particle transfer reactions: $^{56}Fe(d,p)^{57}Fe$ and $^{58}Ni(d,p)^{59}Ni$. We want to remark that too small a

TABLE 2

	^{57}Fe		^{59}Ni	
I^π	exp |11|	present	exp |12|	present
$1/2^-_1$	0.143	0.069	0.63	0.48
$3/2^-_1$	0.415	0.575	0.69	0.64
$5/2^-_1$	0.594	0.530	0.76	0.71
$3/2^-_2$	0.253	0.010	0.08	0.003
$5/2^-_2$	-	0.005	-	0.004
$1/2^-_2$	0.371	0.222	0.27	0.13
$3/2^-_3$	0.025	0.020	-	-
$3/2^-_4$	0.044	0.112	-	-
$5/2^-_3$	0.039	0.040	0.10	0.05

spectroscopic factor for the $I^\pi=3/2^-_2$ has been theoretically found in ^{57}Fe as well as in ^{59}Ni. Nevertheless, the other data are nicely reproduced.

We can conclude that these preliminary results obtained for some 2p-1f nuclei in the framework of the particle-cluster core coupling model clearly show that further calculations in that mass region are desirable.

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