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PROTON INELASTIC SCATTERING BY THE EVEN-Ge ISOTOPES AT E_p = 22 MeV

P.AVIGNON, L.H.ROSIER, R.TAMISIER and B.RAMSTEIN
Institut de Physique, 2, rue de la Houssinière, F-44072 Nantes Cédex, France
Institut de Physique Nucléaire, Orsay, France
J.P.DELAROCHE
SPNN, CE Bruyères-le-Châtel, BP 561, F-92542 Montrouge Cédex, France

ABSTRACT

The even-Ge(p,p') inelastic scattering has been studied at 22 MeV with an overall energy resolution of 10 keV using a tandem Van de Graaff and a split pole magnetic spectrometer. Angular distributions have been obtained for about 40 levels in each isotope. DWBA, vibrational and asymmetric rotor model CC calculations have been made. Spin and parity assignments have been deduced. Possible unnatural parity levels have been populated.

1. INTRODUCTION

The present paper reports the main results of a systematic survey [1] of proton inelastic scattering from the even isotopes of Ge. This study has been undertaken to obtain more information on the collective part of the structure of these nuclei. Indeed as results of studies of these nuclei via the (p,t), (t,p) and (6Li,d) transfert reactions it became apparent that the structure of these nuclei has both a collective aspect and a single-particle one [2].

Furthermore, except for the 3^+;1697 keV state of 74Ge, all the known levels of even Ge isotopes have natural parity in so far as the (p,t) and (t,p) reactions are the main sources of information on spin and parity. It can be expected that the (p,p') scattering gives rise to unnatural parity states.

Our experimental differential cross sections have been compared to DWBA calculations [3] and to Coupled Channel (CC) calculations [4] in the frameworks of the Vibrational Model (VM) and the Asymmetric Rotor Model [5].

2. EXPERIMENTAL TECHNIQUE AND RESULTS

The even-A Ge(p,p') measurements were performed at 22 MeV using the MP tandem Van de Graaff and the split pole magnetic spectrometer of the IPN (Orsay).

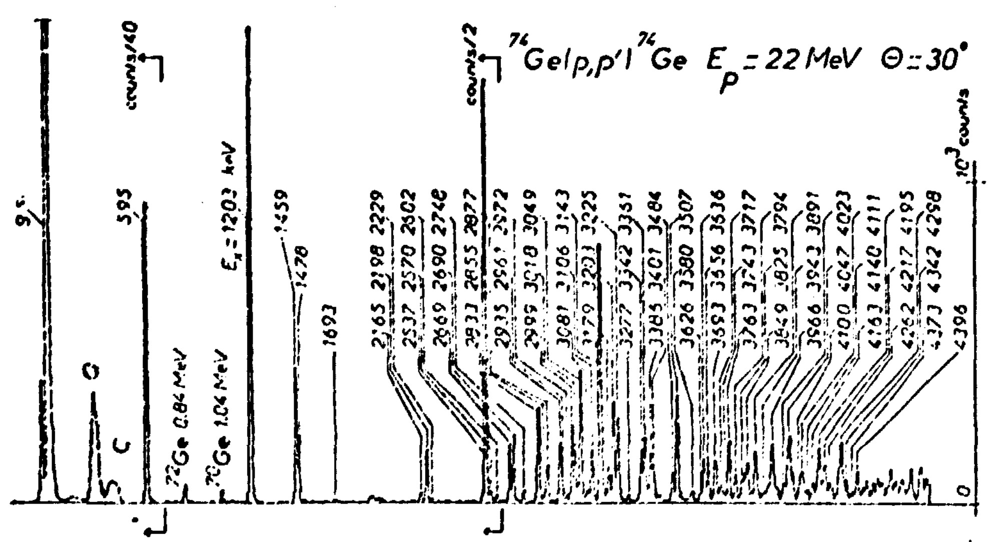

Fig.1 Spectrum of the 74Ge(p,p') scattering at θ = 30°. The excitation energies have been indicated.

The targets were selfsupporting metallic foils of 100 $\mu g/cm^2$. Their isotopic abundances were 96.2, 98.2, 98.8 and 95.5% for A = 70, 72, 74 and 76 respectively. The outgoing particles were detected along the spectrometer focal plane using position-sensitive silicon detectors for 74Ge and an high resolution position-sensitive proportional counter for the other isotopes.

Fig.1 presents a typical proton spectrum ; the energy resolution was 10 keV FWHM. About ninety states were excited in each isotope up to Ex going from 4.4 to 5 MeV. Our determinations of the excitation energies are in good overall agreement with those of the literature [6]. New levels appear for the four isotopes. They are especially numerous in the 72 and 76 Ge excitation spectra.

3. DATA ANALYSIS

In order to achieve comparable analyses of the inelastic data for the four isotopes we used the same kind of optical potential in all the cases, i.e. the "best" proton potential of Becchetti and Greenlees [7]. Applying its A and (N-Z) dependences we got the parameter values used in the DWBA and CC calculations without further adjustements. As can be seen in figs. 2,3 this optical potential leads to a good description of the elastic scattering cross sections.

The most part of the inelastic experimental differential cross sections can be explained by DWBA calculations leading to $J = L, L\pm1; \pi = (-)^L$ for the final state and giving a large amount of new spectroscopic informations. In some cases our results combinated with the previous one of the literature allow us to propose unnatural parity [1].

In this paper we present mainly our results concerning the $2_1^+, 0_2^+, 2_2^+, 4_1^+$ and 3_1^- states. The agreement between the data and the DWBA calculations can be judged in fig.2 for 74 and 76Ge, the conclusions being the same for the other isotopes : the distributions for the $0_1^+, 2_1^+$ and 3_1^- states are well fitted by the DWBA curves but the DWBA calculations fail to explain the data for the other low lying states. The following list gives the values of the β2 and β3 parameters for each A-value :

A;β2;β3 = 70;0.21;0.25 72;0.24;0.22 74;0.25;0.14 76;0.24;0.14

From the excitation energy spectra of 74 and 76Ge we made the assumption that the $0_2^+, 2_2^+$ and 4_1^+ states form the 2-quadrupolar phonon triplet built from the 2_1^+ state considered as the 1-quadrupolar phonon state of the VM. The 3_1^- state could be then the 1-octupolar phonon state. The fig.2 shows that the CC calculations based on the VM improve slightly the agreement with the data for the $0_1^+, 2_1^+$ and 3_1^- states but that for the "triplet" the simple 2-phonon picture is poor. We performed then new CC calculations taking for the wave functions of the 2_2^+ and 4_1^+ states a mixing of 1-and 2-phonon wave functions in the form

$$|2_2^+\rangle \text{ or } |4_1^+\rangle = \cos\phi \; |1\text{-phonon}\rangle + \sin\phi \; \left[|2_1^+\rangle \otimes |2_1^+\rangle \right]_{2^+ \text{ or } 4^+} \quad (1)$$

where ϕ is a mixing parameter and $|2_1^+\rangle$ represents the VM wave function of the 2_1^+ state. The CC calculations were performed taking as basis the $0_1^+, 2_1^+$ and 3_1^- states and with the following 1-phonon amplitudes :

74Ge	β21 = 0.29	β31 = 0.16	β22 = 0.07;	ϕ = 60°	β41 = 0.02;	ϕ = 50°
76Ge	0.26	0.15	0.085	55°	0.02	50°

One can see that the CC β21 and β31-values are not very different from the DWBA β2 and β3-values. For the 2_2^+ and 4_1^+ states of 74Ge a fairly good agreement can be obtained in this way. Furthermore for most of the other 4^+ states of 74Ge such a mixing also improves the fits. In a similar way for the most

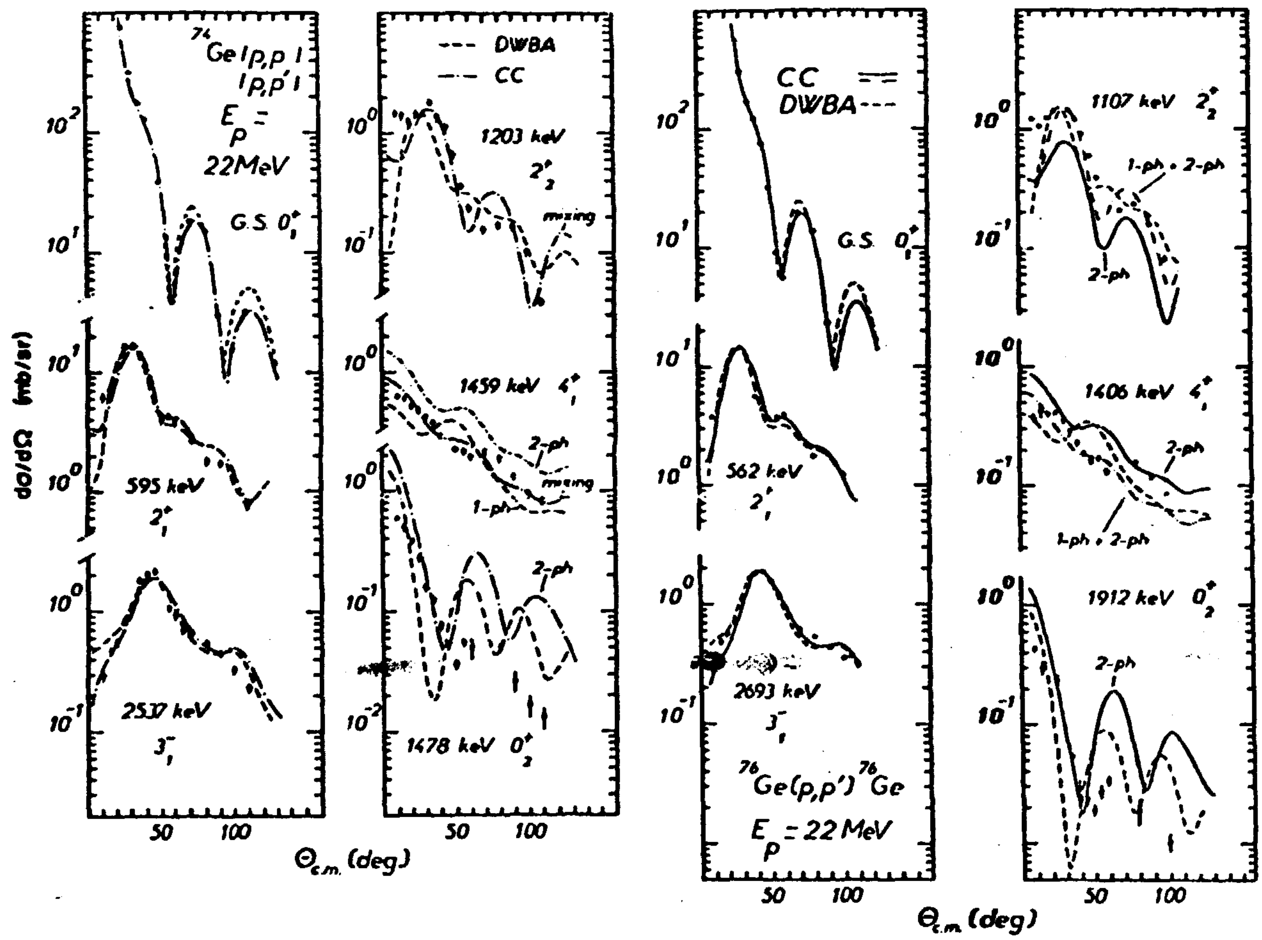

Fig.2 Vibrational model CC and DWBA fits to the experimental distributions of the $0_1^+, 2_1^+, 3_1^-, 2_2^+, 4_1^+$ and 0_2^+ states of 74Ge and 76Ge.

part of the 5^- states of 74Ge a rather strong 2-phonon component built from the VM$|2_1^+\rangle$ and $|3_1^-\rangle$ states was needed in order to fit the data [1]). For 76Ge the description grounded on eq.(1) is not sufficient ; in particular it does not lead to an acceptable fit for the 4_1^+ data which are out of phase with the CC curve.

Finally a VM description seems to be roughly valid only for 74Ge so that we attempted to describe the $0_1^+, 2_1^+, 2_2^+$ and 4_1^+ states of all the even Ge isotopes by the ARM. The values of the deformation parameter γ were extracted from the experimental values [8]) of the ratio $B(E2;2_1^+ \rightarrow 0_1^+)/[Q(2_1^+)]^2$. The values of the parameter β were obtained in normalizing the CC calculated curves to the 2_1^+ experimental angular distributions. The β and γ-values were the following for each A-value :

$A;\beta;\gamma$ = 70;0.25;30.5 72;0.25;28. 74;0.275;26.5 76;0.26;27.3

It can be seen in the fig.3 that the overall agreement is very good. Beside a slight improvement of the fit to the 2_1^+ data, the CC curves are now in phase with the 4_1^+ data and the A-dependence of the experimental data for the 2_2^+ states is qualitatively very well reproduced (and quantitatively in the case of 70Ge).

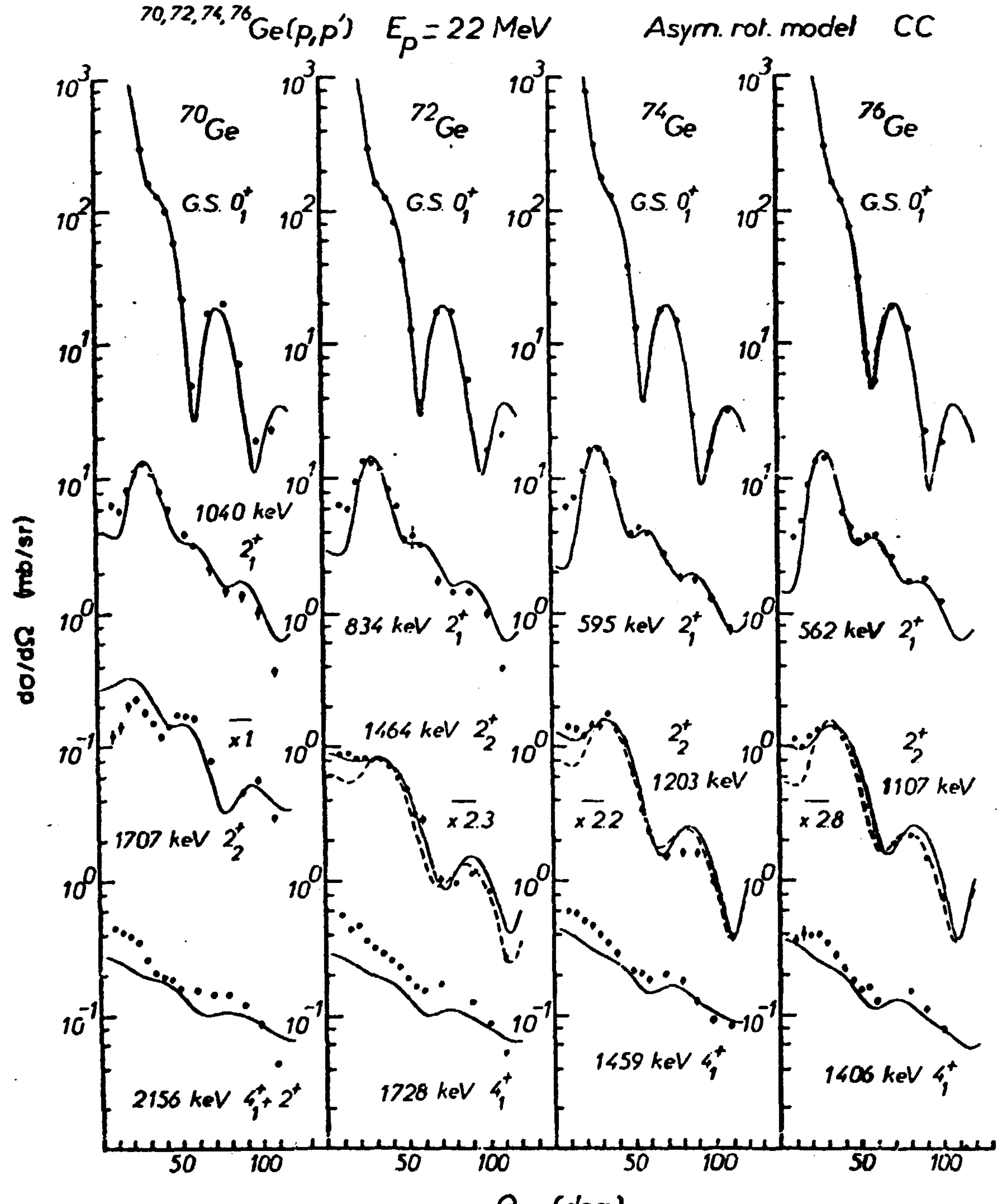

Fig.3 Asymmetric rotor model CC fits to the experimental distributions of the $0_1^+,2_1^+,2_2^+$ and 4_1^+ states of the even Ge's

However in order to reproduce the magnitudes of the cross sections for the 2_2^+ states we propose now a tentative way. Since a good agreement has been obtained between the data for the $0_1^+,2_1^+$ and 4_1^+ levels and the CC predictions based on the ARM, this model was presumed to be still valid for these states. Therefore the previous β and γ-values were assigned to them as well as to the potential form factors. For the 2_2^+ states we used an ARM-type wave function but calculated with a value, γ', of the nonaxial deformation parameter different from the one, γ, used for the other states. γ' was varied until the best fit to the 2_2^+ data was achevied, this variation having a negligible effect on the other states. The resulting CC curves are shown in fig.3 as dotted lines and the corresponding γ'-values are 26.,24. and 24.5° for A =72,74 and 76 respectively. It must be noticed that the effect of the nonorthogonality between the 2_1^+ and 2_2^+ wave functions is not taken into account in the present calculations. In so far as the value of their scalar product is at most 0.15, we think that the above calculations are significant.

4.CONCLUSION

The even-Ge(p,p') inelastic scattering at 22 MeV has allowed us to populate many levels, a lot of which for the first time, of the even Ge nuclei with an energy resolution of 10 keV. A large amount of new spectroscopic informations has been deduced from our DWBA analysis of the higher excited states. In several cases unnatural parity could be proposed.

For the low lying states the DWBA is not sufficient. From our VM and ARM CC analyses, it can be concluded that :

(i) For 74Ge both these collective models give equivalent agreement with the data

(ii) The angular patterns of the data for the 2_2^+ states of 70,72Ge and for the 4_1^+ state of 76Ge agree only with the ARM CC calculations. The magnitude of the cross sections of the 2_2^+ states are underestimated by the ARM apart for 70Ge. In the cases of 72,74,76Ge these magnitudes can be retrieved in using a γ-value different from the one used for the other levels.

About the 0_2^+ states both the DWBA and the vibrational CC calculations fail to reproduce the data. However it can be underlined that their differential cross section patterns are almost identical for all the isotopes suggesting a similar reaction mechanism.

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