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IPNO DRE 83-22

MASS AND EXCITED LEVELS OF THE NEUTRON-RICH NUCLEI ^{73}Zn AND ^{74}Zn STUDIED WITH ^{76}Ge(^{14}C, ^{16}O) AND (^{14}C, ^{17}O) REACTIONS

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Abstract : The ^{76}Ge(^{14}C,^{16,17}O)^{74,73}Zn reactions have been studied at 72 MeV bombarding energy. The mass excesses of ^{73}Zn and ^{74}Zn were determined to be - 65.41 ± .04 and - 65.62 ± .04 MeV, respectively. In addition previously unknown excited levels were identified in both nuclei. The structure of ^{73}Zn is discussed in terms of H.F.B. calculations.

NUCLEAR REACTIONS ^{76}Ge(^{14}C,^{16}O)^{74}Zn and ^{76}Ge(^{14}C,^{17}O)^{73}Zn, E = 72 MeV measured ^{74}Zn and ^{73}Zn mass excess and excited state energies.

1. INTRODUCTION

Besides its basic interest in the field of nuclear physics, the knowledge of binding energies of neutron rich nuclei is crucial for calculations of the neutron-capture processes. Those processes are responsible for the nucleosynthesis of elements heavier than iron in the universe. To a large extent, informations on heavy neutron rich species have been obtained from studies of fission products. However, for elements with $Z \lesssim 30$ the fission yields become negligeable. For lighter nucleides the fragmentation or spallation reactions were used to generate exotic nuclei. But they have until now hardly been applied for the production of elements with $20 \leqslant Z \leqslant 30$; thus, in this mass region, direct transfer reactions are indeed appropriate for precise mass measurements and for the observation of excited levels in neutron rich isotopes.

We report here on a spectroscopic investigation of the ${}^{74}_{30}Zn_{44}$ and ${}^{73}_{30}Zn_{43}$ nuclei. Ground state and excited states were populated by two proton (${}^{14}C$, ${}^{16}O$) and two-proton, one-neutron (${}^{14}C$, ${}^{17}O$), pick-up reactions on a ${}^{76}Ge$ target, respectively. Masses and a few excitation energies were deduced from this first direct measurement.

The measured level structure of ${}^{73}Zn$ is compared with the recently observed /1/ β-delayed γ-ray from the decay of ${}^{73}Cu$ and discussed in term of Hartree-Fock-Bogoliubov (H.F.B.) calculations of ${}^{73}Zn$.

2. EXPERIMENTAL PROCEDURE

2.1. Set-up

The 72-MeV ${}^{14}C$ beam of 20 pnA from the Orsay MP Tandem was used to bombard a germanium target of 130 μg/cm^2 thickness. The enriched germanium (93.5% ${}^{76}Ge$) was evaporated on a 30 μg/cm^2 backing of ${}^{12}C$. The particles emerging from the target were analysed by the $n = 1/2$ double-focusing spectrometer "Bacchus" /2/. The magnetic rigidity and the trajectory angles of the emitted particles were determined from the measurement of their intersection with two resistive wire proportional counters (Fig. 1). An accuracy of 0.2° is achieved for the emission angle within a total solid-angle of 4 msr /2/. The particles were identified with an ionization chamber (ΔE_1, ΔE_2, E) where the azimuthal coordinate is also measured /3/. Very small angle measurements were performed with a device set in the vacuum chamber of the spectrometer and designed so as to catch the incident beam with a minor increment of background /4/.

2.2. Calibration of the results

On figures 2a and 2b are reported the ^{16}O and ^{17}O associated with the ^{74}Zn and ^{73}Zn final nuclei for two angle settings of the magnet. The spectra are corrected for kinematical effects for the germanium target. Therefore the reactions on the light target-contaminants, integrated over a few degrees, give broader peaks because of the differences in kinematics. For angles smaller than 6° lab those peaks overlap the excited state peaks of the Zn nuclei and prevent from following the angular distributions in this area.

The mass excess of the residual nuclei were deduced from the magnetic rigidity of the associated ejectiles ^{16}O and ^{17}O. In order to optimize the accuracy a special care was devoted to calibration.

1) On the ^{76}Ge target, the ^{16}O and ^{17}O particles of interest can be recorded with the same field setting of the magnet, therefore the spectra of ^{73}Zn and ^{74}Zn were measured simultaneously, yielding an accurate relative calibration.

2) The reactions on the ^{74}Ge target, leading to the ^{72}Zn and ^{71}Zn nuclei whose masses are known have also been measured for the same magnetic setting providing precise reference points.

3) Within a one degree aperture - set on the computer - the peak due to target contaminants are narrow providing other reference points. However the reaction angle has to be carefully determined since an angle shift of 0.1° at 6° introduces a relative energy shift of $\approx$ 20 keV between the germanium and oxygen contributions.

Finally, a calibration curve of the magnetic rigidity $B\rho$ as a function of the channel number (cl) was approximated by a second order polynomial. The dispersion of the values quoted above are compatible with a 40 keV accuracy.

3. RESULTS AND DISCUSSION

3.1. Nuclear masses

The mass excesses of ^{73}Zn and ^{74}Zn derived here are given in Table 1. The earlier tabulated values /5/ resulting from β end-point determination

/6/ are reported too and they are discussed further with some details. But since they were deduced from single spectra, and no information on the decay scheme were available at this time, only lower limits of Q_β were given.

Hence the present measurements represent the first direct determination of these masses.

The values extrapolated or calculated with the recently developped mass formulae are shown on the last part of the Table 1.

For ^{73}Zn the M.E. limit obtained by combining the data of ref. /5/ with the mass of the daughter nucleus ^{73}Ga /6/ does not agree with our result. However this β-end point was derived on the basis of a plot $(N/pWF)^{1/3}$ versus E_β and not from a normal Fermi-Kurie plot. A 1/3 power was applied instead of the conventional 1/2 power because a statistical feeding of several levels in the daughter nucleus was assumed due to the high value of the Q_β. A recent study /1/ of the β-decay of ^{73}Zn have shown that, on the contrary, almost 90% of the β-transitions are leading directly to the ^{73}Ge ground-state, thus indicating that the Fermi-Kurie plot should yield a more realistic value. This would then correspond to an end point energy lower by ≈ 200 keV, (See Table 1). If the 200 keV uncertainty is maintained, both results become compatible.

The M.E. of ^{74}Zn quoted by Wapstra and Bos /5/ is based also on the Q_β measurement /6/ with the assumption that the β-decay of ^{74}Zn is predominantly feeding a level at 250 keV in ^{74}Ga (See Ref. /8/). A more detailed study of the ^{74}Zn decay /1/ showed that the main β-transitions are leading to levels at 110 keV (~ 32%), 253 keV (~ 44%) and 895 keV (~ 17%). The excellent agreement of the value derived by Wapstra and Bos with the present one seems explainable by the proximity of the weighted value of the three transitions given above with the assumed dominating one.

For both nuclei the measured values agree well with the predictions of Liran and Zeldes /7/ (Semi-empirical shell-model calculation), of Jänecke, Garvey and Kelson /7/ (extrapolation formula) and of Uno and Yamada /8/ (liquid-drop formula with empirical shell corrections), while the five parameters calculation of Möller and Nix /9/ provides slightly less-bound nuclei (See Table 2).

In addition to the Ground-State (G.S.) lines used for the mass determination, the spectra shown in figure 2, exhibit a few peaks associated with excited levels of ^{73}Zn and ^{74}Zn.

3.2. Excited states of ^{74}Zn populated with the (^{14}C, ^{16}O) reaction

The excitation energy of the first level in ^{74}Zn was determined to be

$E_x = 0.67 \pm 0.03$ MeV. It is very similar to the energy of the 2_1^+ level in ^{72}Zn ($E_x = 0.65$ MeV) and considering the level systematics of even zinc and germanium isotopes it is almost certain, that the 0.67 MeV line is connected with the 2_1^+ level of ^{74}Zn. However the spin assignment could not be confirmed by the very forward angular distribution as in Ref. /11/.

For the sake of reference we have also investigated /4/ the ^{74}Ge(^{14}C,^{16}O) ^{72}Zn reaction ; in addition to the G.S. and 2_1^+ level, a third peak was observed corresponding to either the 0_2^+ at 1.505 MeV, to the 2_2^+ level at 1.657 MeV or to both of them. In ^{74}Zn a third peak was also observed at an excitation energy of 1.84 ± 0.05 MeV ; the spin of this state was not determined ; already small at 6° compared to the oxygen contaminant line, this peak would become difficult to follow at smaller angles, because of the larger rise of the contaminant cross sections.

The measured angular distributions for the ^{74,76}Ge(^{14}C,^{16}O) reactions are reported on figure 3 and figure 4. The curves are calculated from an Exact Finite Range - Distorted Waves Born Approximation (EFR - DWBA) performed with the code Saturn-Mars /12/. The optical parameters of the entrance and exit channels were taken from Ref. /13/.

For the reaction on ^{74}Ge (Fig. 3), even with the low statistic of the very forward angles in case of $0_1^+ \rightarrow 2_1^+$ transition the datas are well reproduced by this calculation. For the reaction on ^{76}Ge (Fig. 4), the diffractive oscillations are somewhat washed out and the slope of the data points is smaller than the enveloppe of the calculated curves. This type of divergence, already observed in the Mg and Si study, is likely due to channel coupling effects /14/ and suggests the occurence of stronger deformations in the target or in the residual nuclei.

The normalizing factors $N = d\sigma/d\Omega_{exp}/d\sigma/d\Omega_{DWBA}$ are reported on figure 3 and figure 4. Their order of magnitude is the same than for the (^{14}C,^{16}O) reaction on the series of even Nickel and Zinc targets ; however, for the G.S.→G.S. transitions, the N value related to the more neutron rich target transition $^{76}\mathrm{Ge} \rightarrow {}^{74}\mathrm{Zn}$ is larger by a factor of two than for $^{74}\mathrm{Ge} \rightarrow {}^{72}\mathrm{Zn}$, inversely to the variation of N in the Zn and Ni series. This indicates either that the overlap of target and residual nuclei would be better for $^{76}\mathrm{Ge} \rightarrow {}^{74}\mathrm{Zn}$ G.S. configurations or that couple-channel effects would be larger, as already mentionned on the basis of the shape of angular distributions.

3.3. The (^{14}C,^{17}O) reaction and the excited states of ^{73}Zn

Before discussing the ^{73}Zn levels, we wish to point out general properties of the reaction (^{14}C,^{17}O) reported here for the first time.

First it is interesting to observe that the cross section for the (^{14}C,^{17}O) reaction is not so much smaller than for (^{14}C,^{16}O) in the studied angular range. This indicates that the former reaction is proceeding by a simple quasi-^{3}He pick-up.

Secondly, the first excited state of ^{17}O at 0.87 MeV is not significantly populated. This feature is in contrast with other pick-up reactions as e.g. (^{18}O,^{20}Ne) where the population of levels in ^{20}Ne prevents the observation of excited levels in the residual nuclei /10/.

Both properties make the reaction suited for further spectroscopic studies.

Few peaks are observed on the ^{73}Zn spectra (Fig. 2) but the present energy resolution is not good enough to identify each of the levels. For the two angular ranges, two levels or group of levels can be identified at excitation energies of 0.28 ± 0.04 MeV and 0.50 ± 0.04 MeV. At 1.14 ± 0.03 MeV excitation energy an other level is clearly predominant.

Those informations can be related with the energy and relative intensity of the ^{73}Zn γ-rays following the β-decay of ^{73}Cu /1/. The first group of levels observed here (0.28 - 0.50 MeV) may include few levels decaying to the G.S. by the γ-ray transitions of 306, 449 and 502 keV.

For the state shown here at 1.14 MeV energy, the decay mode could combine the 674 keV γ-line with either the 449 or the 502 keV, no peak can be connected with the 199 keV γ-line. Further studies are required for the construction of the ^{73}Zn level scheme.

In the angular range measured here, the cross sections are not showing significant structures which could be applied for the spin determination of the corresponding levels. Their average values are given in Table 2.

Related with the odd Zn spectroscopy, Hartree-Fock-Bogoliubov (H.F.B.) calculations of ^{71}Zn and ^{73}Zn were performed with the D1 interaction /16/ in the following way ; using the blocking procedure /17/ for each quasi particle state successively, the potential energy surface has been calculated as a function of the deformation parameter β.

The curves representing this energy versus the deformation parameter are reported on figure 5b. In principle, the deepost minimum obtained would be associated to the quasi-particle state responsible for the G.S.. The other minima-corresponding to different quasi particle states would describe the low-lying excited states. However this picture is somewhat modified as for a deformed nucleus the true G.S. is represented by a weighted superposition of various blocked states projected subsequently. Thus this calculation can only give the odd nucleon configurations which are expected within the first 500 keV excitation energy.

For ^{71}Zn, the level scheme of which is known, a probable deformation of $\beta \simeq -0.1$ would suggest for the spin of the deeper quasi particle subshells : $9/2^+$, $1/2^-$, $7/2^+$ and $5/2^+$ to compare with the following sequence $1/2^-$, $9/2^+$ and either $3/2^+$ or $5/2^+$ reported /18/, thus confirming the validity of this approach.

For ^{73}Zn, the addition of a neutron pair induces a change in the more probable deformation. The changing of shape between those two nuclei was already suggested /19/ on the basis of the study of ^{73}Ge and ^{75}Ge - isotones nuclei of ^{71}Zn and ^{73}Zn respectively and relying upon the ^{73}Zn β-decay scheme known at this time /6/.

The expected spin of the first few levels would then be $1/2^-$, $5/2^+$, $5/2^-$ and $3/2^+$. Therefore, within the first few hundred keV, the occurence of a $9/2^+$ level as suggested by the odd Zn systematic, or of a $7/2^+$ as suggested by the N = 43 isotones systematic, would be excluded.

But, which of this four expected spins would correspond to the G.S. remains an open question.

First a spin value of $1/2^-$ was attributed to the ^{75}Ge G.S. isotone of ^{73}Zn, and as already mentionned /19/ the two nuclei show obvious similarities.

However, the logft measurements for the β decay of ^{73}Zn G.S. indicated a strong feeding of the ^{73}Ga $5/2^-$ state (logft < 6.6). But in the recent study /1/ a logft of 7.6 was measured for this transition and hence the G.S. spin of $1/2^-$ for ^{73}Zn becomes compatible with the ^{73}Zn-β decay scheme.

Thus the H.F.B. calculations, the N = 43 systematics, and the ^{73}Zn, β-decay are all converging on a ^{73}Zn G.S. spin value of $1/2^-$.

4. CONCLUSION

We have measured for the first time the masses of the two neutron rich Zn nuclei ^{73}Zn and ^{74}Zn with a significant accuracy by using the quasi-elastic reactions (^{14}C,^{16}O) and (^{14}C,^{17}O). Two excited states were observed on ^{74}Zn. Concerning ^{73}Zn, and relying on H.F.B. calculations, some features of the level scheme are proposed, as for example the ground state spin value of $1/2^-$.

The relatively large $(^{14}C,^{17}O)$ cross-sections and the absence of ^{17}O excited states in the exit channel, make this reaction useful for a spectrocopic investigation.

REFERENCES

/1/ E. RUNTE, W.D. SCHMIDT-OTT, P. TIDEMAND-PETERSSON, R. KIRCHNER, O. KLEPPER, W. KURCEWICZ, E. ROECKL, N. KAFFRELL, P. PEUSER, K. RYKACZEWSKI, M. BERNAS, Ph. DESSAGNE and M. LANGEVIN, Nucl. Phys. A399 (1983) 163

/2/ P. ROUSSEL, M. BERNAS, F. DIAF, F. NAULIN, F. POUGHEON, G. ROTBARD and M. ROY-STEPHAN, Nucl. Instr. and Meth. 153 (1978) 111

/3/ F. NAULIN, M. ROY-STEPHAN and E. KASHY, Nucl. Instr. 180 (1981) 647

/4/ Ph. DESSAGNE, Thèse de 3ème cycle, Université d'Orsay-Paris XI (1982)

/5/ A.H. WAPSTRA and K. BOS, At. Nucl. Data Tables 19 (1977) 175

/6/ B.R. ERDAL, L. WESTGAARD, J. ZYLICZ and E. ROECKL, Nucl. Phys. A194 (1972) 449

/7/ The 1975 Mass Predictions, ed. S. MARIPUU, At. Nucl. Data Tables 17 (1976) 476

/8/ P. MOLLER and R. NIX, At. Nucl. Data Tables 16 (1981) 165

/9/ M. UNO and M. YAMADA, Report INS-NUMA-40 (University of Tokyo), 1982

/10/ H.P. ROTHER, W. HENNING, H.J. KORNER, R. MULLER, K.E. REHM, M. RICHTER and H. SPIELER, Nucl. Phys. A269 (1976) 511

/11/ M. BERNAS, Ph. DESSAGNE, M. LANGEVIN, J. PAYET, F. POUGHEON and P. ROUSSEL, Phys. Lett. 113B (1982) 279

/12/ T. TAMURA and K.S. LOW, Comput. Phys. Commun. 8 (1974) 349

/13/ J.C. PENG, N. STEIN, J.W. SUNIER, D.M. DRAKE, J.D. MOSES, J.A. CIZEWSKI and J.R. TESMER, Phys. Rev. Lett. 43 (1979) 675

/14/ J.C. PENG, M. BERNAS and N. STEIN, to be published.

/15/ M. BERNAS, J.C. PENG, H. DOUBRE, M. LANGEVIN, M.J. LEVINE, F. POUGHEON and P. ROUSSEL, Phys. Rev. 24 (1981) 756

/16/ J. DECHARGE and D. GOGNY, Phys. Rev. C21 (1980) 1568

/17/ M. GIROD and P.G. REINHARD, Phys. Lett. 117B (1982) 1

/18/ D. VON EHRENSTEIN and J.P. SCHIFFER, Phys. Rev. 164 (1967) 1374

/19/ M.N. VERGNES, G. ROTBARD, E.R. FLYNN, D.L. HANSON, S.P. ORBESEN, F. GUILBAULT, D. ARDOUIN and C. LEBRUN, Phys. Rev. C19 (1979) 1276

/20/ Nucl. Data Sheets B32 (1981) 211

FIGURE CAPTIONS

Fig. 1.- Experimental set-up ; double particle identification is achieved in the ionization chamber. The two Position-Sensitive Proportional Counters (P.S.P.C.) provide the emission angle and magnetic rigidity of the particles.

Fig. 2a and 2b.- Spectra of ^{16}O and ^{17}O for two different angular ranges but at the same magnetic field in the spectrometer

Fig. 3.- Angular distributions for the $^{76}Ge(^{14}C,^{16}O)^{74}Zn$. The EFR DWBA calculations are reported as well as the corresponding normalisation factor N.

Fig. 4.- Angular distributions for the $^{74}Ge(^{14}C,^{16}O)^{72}Zn$. The EFR DWBA calculations are reported as well as the corresponding normalisation factor N.

Fig. 5.- Results from the complete H.F.B. calculations.

on part a) is represented the H.F.B. single nucleon energy versus the deformation.

on part b) the potential energy of each nucleus has been followed for each quasi-particle state, versus the deformation parameter β.

Nuclei	Experimental			Predicted			
	this work	values from Ref. /6/		L.Z. [a]	J.G.K. [a]	M.N. [b]	U.Y. [c]
			revised (see text)				
^{73}Zn	-65.41 ± 0.04	- 65.03 ± 0.20	- 65.23 ± 0.20	- 65.76	- 65.21	- 65.11	- 65.427 ± 0.562
^{74}Zn	- 65.62 0.04	- 65.67 0.14		- 65.84	- 65.70	- 65.41	- 65.842 0.349

[a] Ref. /7/

[b] Ref. /9/

[c] Ref. /8/

TABLE 1 : *Mass excess of* ^{73}*Zn and* ^{74}*Zn in MeV.*

Ex (MeV)	dσ/dΩ (mb/sr) for $11° < \theta_{cm} < 17°$
0.	0.020 ± 0.004
0.28 ± 0.04	0.028 ± 0.003
0.50 ± 0.04	0.026 ± 0.003
1.14 ± 0.04	0.030 ± 0.006

TABLE 2 : *Average cross-sections for the* ^{76}Ge(^{14}C,^{17}O)^{73}Zn *reaction.*

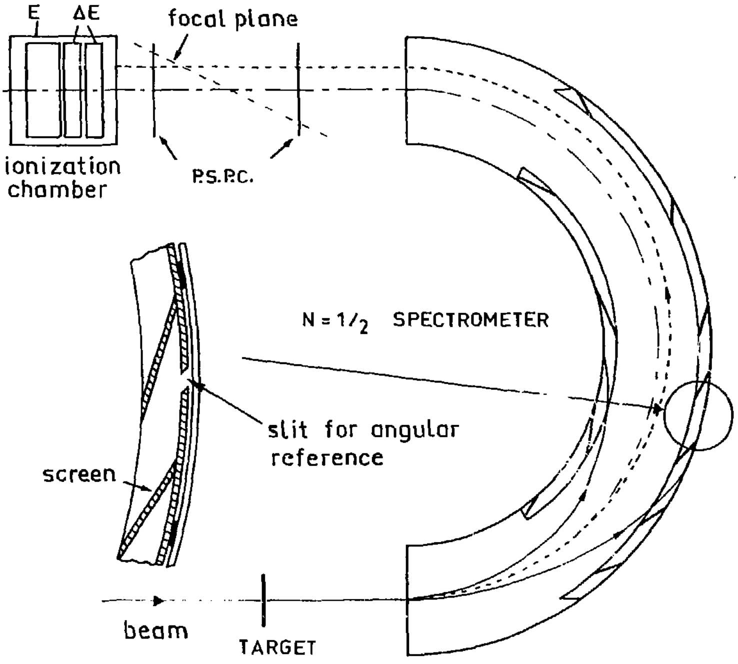

E
ΔE
focal plane
ionization chamber
P.S.P.C.
N = 1/2 SPECTROMETER
slit for angular reference
screen
beam
TARGET

Fig. 1

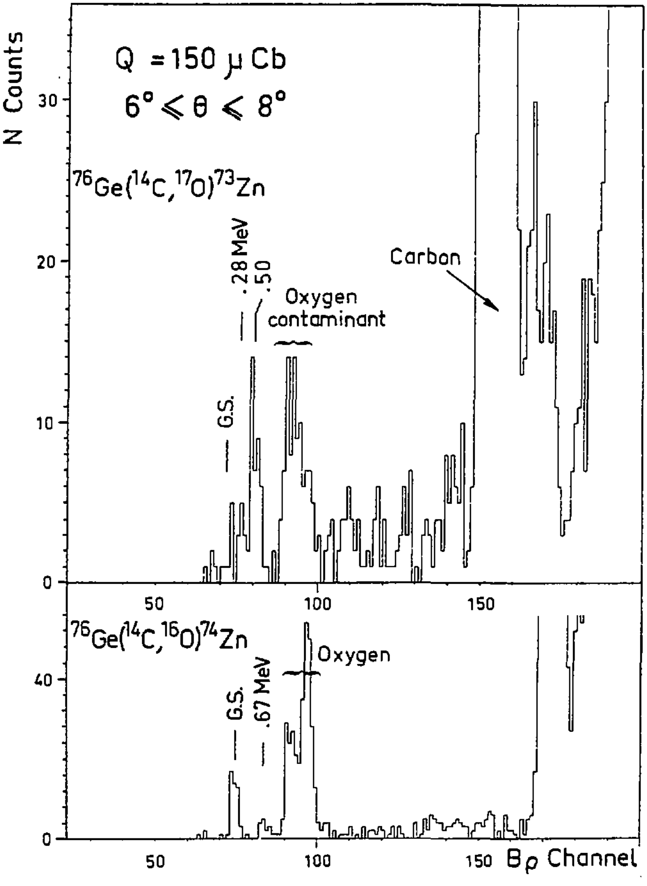

N Counts
Q = 150 μCb
6° ≤ θ ≤ 8°
^{76}Ge(^{14}C,^{17}O)^{73}Zn
G.S.
.28 MeV
.50
Oxygen contaminant
Carbon
0
10
20
30
50
100
150
^{76}Ge(^{14}C,^{16}O)^{74}Zn
G.S.
.67 MeV
Oxygen
0
40
50
100
150
Bρ Channel

Fig. 2a

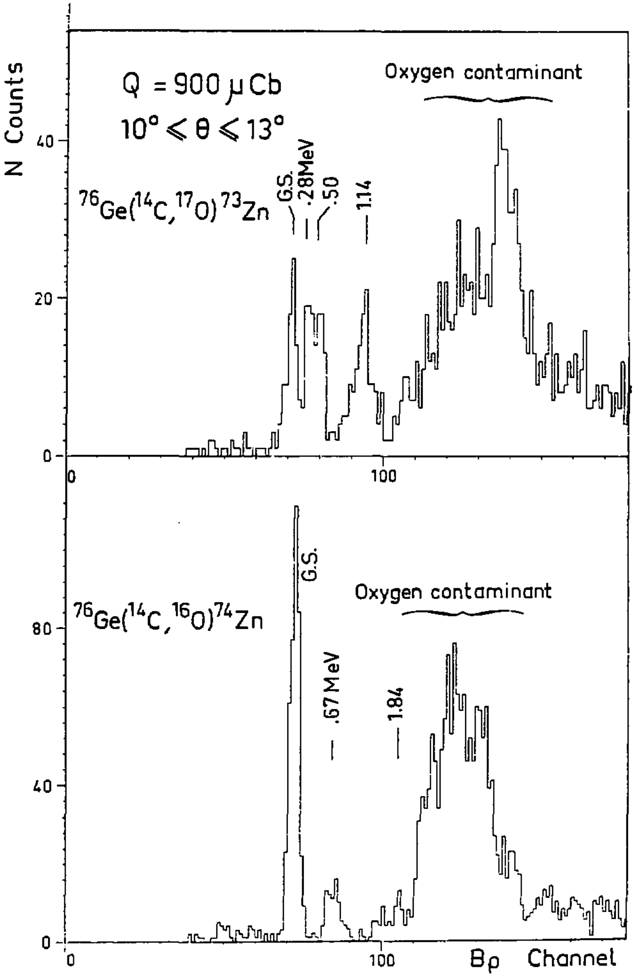
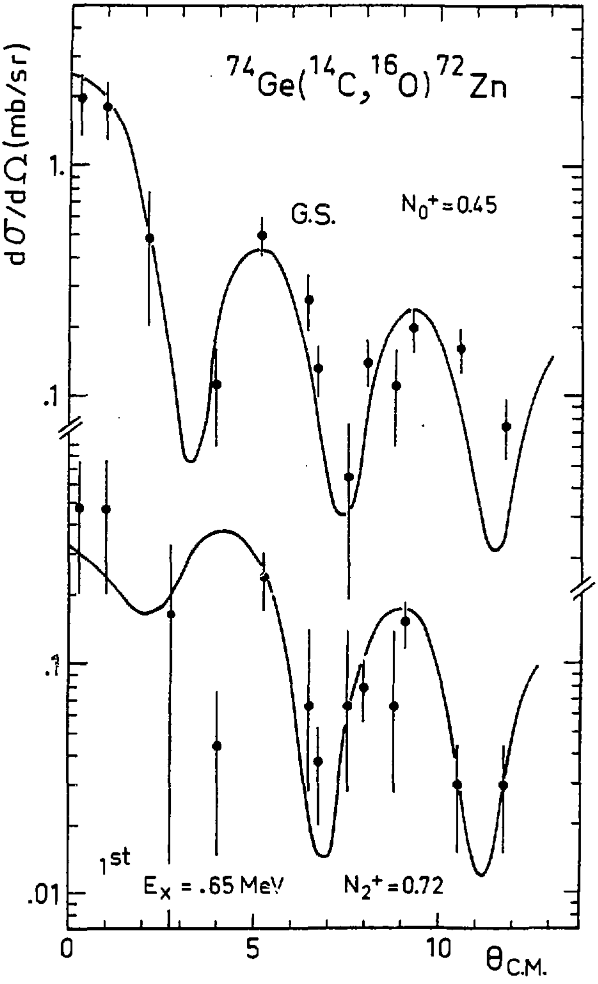
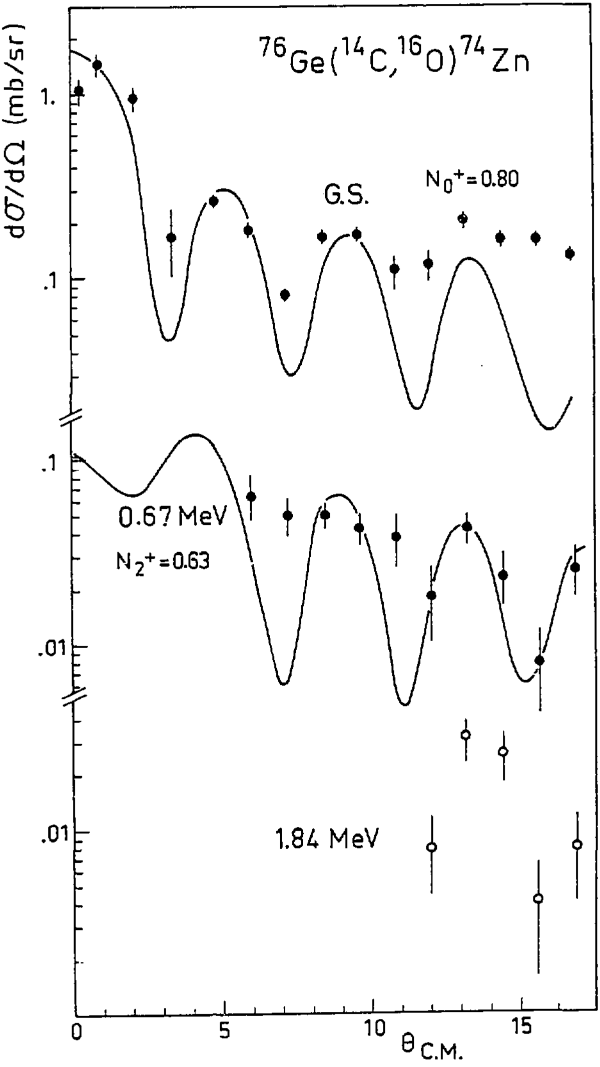

N Counts
Q = 900 μCb
10° ⩽ θ ⩽ 13°
76Ge(14C,17O)73Zn
G.S.
.28MeV
.50
1.14
Oxygen contaminant
0
20
40
0
100
76Ge(14C,16O)74Zn
G.S.
.67MeV
1.84
Oxygen contaminant
0
40
80
0
100
Bρ Channel

Fig. 2b



$^{74}Ge(^{14}C,^{16}O)^{72}Zn$
$d\sigma/d\Omega$ (mb/sr)
1.
.1
.1
.01
G.S.
$N_0^+=0.45$
1^{st}
E_x = .65 MeV
$N_2^+=0.72$
0
5
10
$\theta_{C.M.}$

Fig. 3



$^{76}Ge(^{14}C,^{16}O)^{74}Zn$
$d\sigma/d\Omega$ (mb/sr)
1.
.1
.1
.01
.01
G.S.
$N_{0^+}=0.80$
0.67 MeV
$N_{2^+}=0.63$
1.84 MeV
0
5
10
15
$\theta_{C.M.}$

Fig. 4

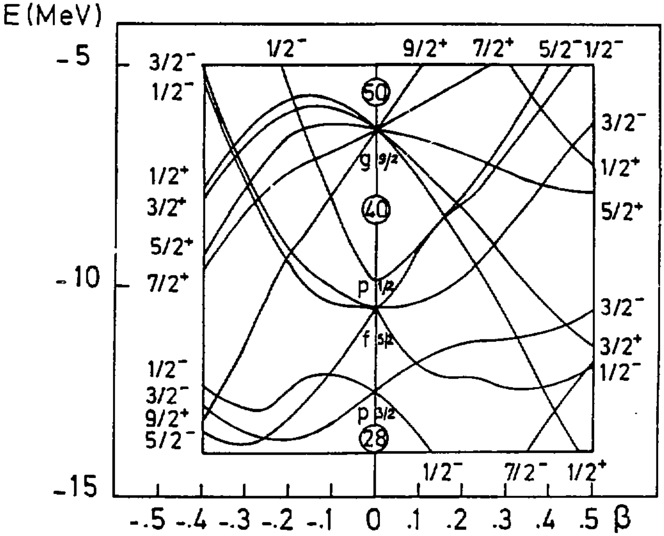

E (MeV)
-5
-10
-15
-.5 -.4 -.3 -.2 -.1 0 .1 .2 .3 .4 .5 β
3/2⁻
1/2⁻
1/2⁺
3/2⁺
5/2⁺
7/2⁺
1/2⁻
3/2⁻
9/2⁺
5/2⁻
1/2⁻
9/2⁺
7/2⁺
5/2⁻
1/2⁻
3/2⁻
1/2⁺
5/2⁺
3/2⁻
3/2⁺
1/2⁻
1/2⁻
7/2⁻
1/2⁺
50
g 9/2
40
p 1/2
f 5/2
p 3/2
28

Fig. 5a

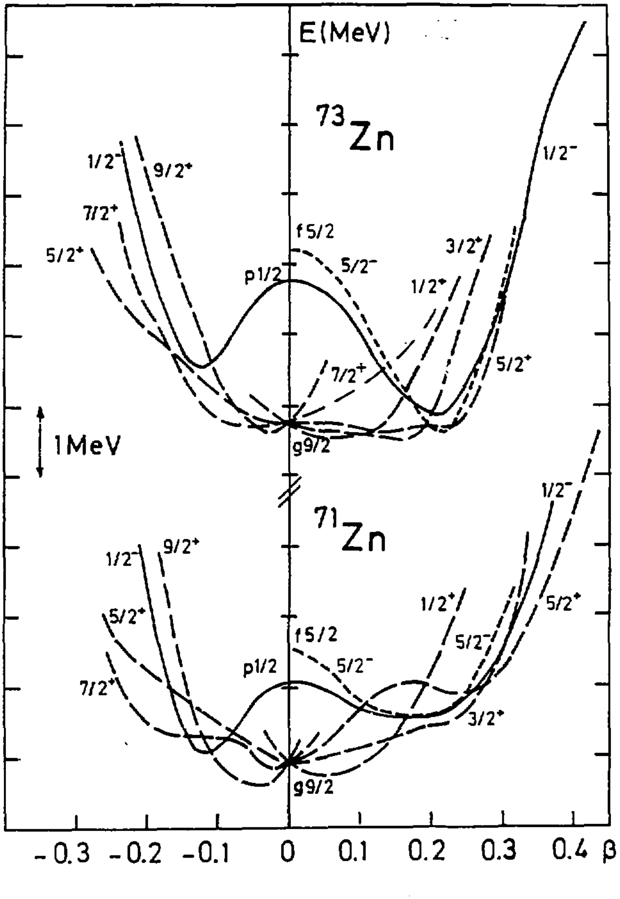

E(MeV)
^{73}Zn
1/2⁻
9/2⁺
7/2⁺
5/2⁺
p1/2
f5/2
5/2⁻
3/2⁺
1/2⁺
7/2⁺
5/2⁺
1/2⁻
g9/2
1MeV
^{71}Zn
1/2⁻
9/2⁺
5/2⁺
7/2⁺
p1/2
f5/2
5/2⁻
1/2⁺
5/2⁻
1/2⁻
5/2⁺
3/2⁺
g9/2
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4
β

Fig. 5b