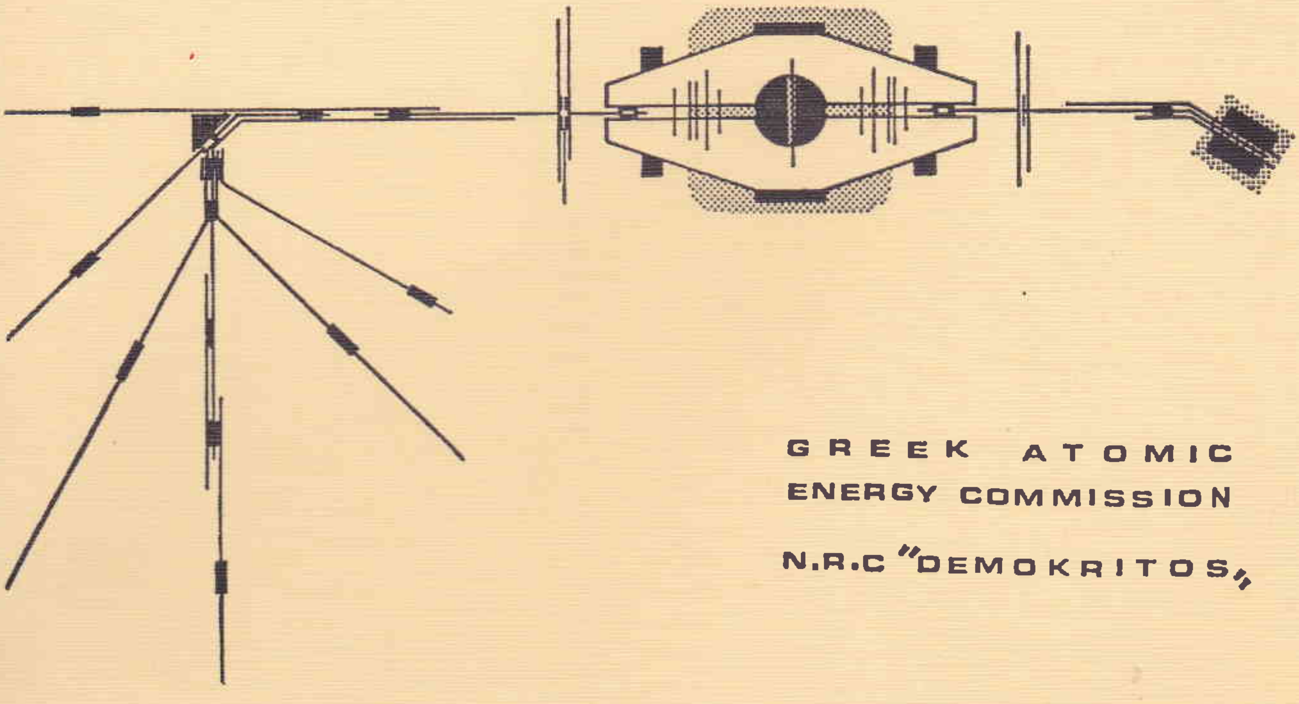
TANDEM ACCELERATOR LABORATORY

ANNUAL REPORT

1979



GREEK ATOMIC ENERGY COMMISSION

N.R.C "DEMOKRITOS"

NUCLEAR RESEARCH CENTER DEMOKRITOS

TANDEM ACCELERATOR LABORATORY

ANNUAL REPORT 1979

Editor: A.C. Xenoulis

I N D E X

INTRODUCTION

During 1979 the research in the laboratory covered heavy-ion reactions, gamma-ray spectroscopy, theoretical nuclear physics and applied atomic and nuclear physics.

In the same year an International Conference on the Structure of Medium-Heavy Nuclei was organized by the laboratory in Rhodos, 1-4 May.

With respect to the instrumentation, a major breakdown of the on-line computer occured which incapacitated this main data collection system for almost two months. On the contrary, no serious problem was encountered in the operation of the accelerator.

Considerable progress has been noted in the investigation of heavy-ion resonances in the s-d shell. In particular , the development of a method for assigning spins to resonances in reactions with non-zero spin in the entrance channel has been carried out.

The study of competition between exit channels such as pn and d, and p2n, dn and t, which has been established in this laboratory in ^{16}O and ^{18}O induced nuclear reactions , has been extended to ^{7}Li induced reactions with the intention of establishing a relation between the magnitude of such competition and the mechanism of the reaction.

Spectroscopic information about the structure and electromagnetic properties of a series of nuclei were established via (p,nγ), (p,p′γ) and (H.I.,x yγ) reactions as well as via off-beam studies of radiactive decay.

In the applied physics the perturbed angular correlation method continued to be succesfully employed to the study of molecules with biological interest. Furthermore in addition to the PIXE and XRF techniques which are routinely employed in this laboratory, spectrometry of prompt γ rays emitted in nuclear reactions has been investigated as a means to obtain the content of light elements in samples of interest.

In theoretical nuclear physics , shell-model studies in the A ~90 mass region have progressed in parallel with corresponding experimental work carried out in this laboratory in order to establish the shell-model nature of the nuclear states in this region.

The isomorphic model has been extended to give a geometrical explanation of the quantization of angular momenta and a symmetry description of the independent particle model.

The influx of visitors from abroad for experiments with our Tandem as well as visits by our scientists to other laboratories, was found again to be very beneficial.

The dedication and quality of our technical and administrative personnel, this hidden variable in the continuous progress of the laboratory, is especially acknowledged.

George Vourvopoulos

I. HEAVY ION REACTIONS

Spin Assignments of Resonances in the ^{9}Be + ^{12}C System

X. Aslanoglou, G. Vourvopoulos, G. Andritsopoulos+,
E. Holub++ and D. Pocanic++.

The study of $^{9}Be+^{12}C$ system was continued in order to assign spins to the resonances found at energies E_{CM}=7.4, 9.73 and 11.4 MeV (1). The usual methods of fitting the square of a Legendre polynomial ($P^2_\ell(\cos\theta)$)or a series of Legendre polynomials to the angular distribution data with the purpose of extracting spin values does not apply in the $^{9}Be+^{12}C$ system. This is due to the existence of non zero spins in the entrance and outgoing channels. A new technique therefore was developed based on Blatt and Biedenharn's formalism.

Angular distributions were measured for the reaction $^{12}C(^{9}Be,\alpha)$ ^{17}O at the energies E_{CM}= 7.4, 9.7, 11.4 MeV (on resonances) and E_{CM}=8.0, 9.14 MeV (off resonance).

The shape of the angular distribution of alpha particles populating the E_X=0.871 keV ($1/2^+$) state of ^{17}O at the resonance energy E_{CM}=7.4 MeV (Fig1) is best reproduced by the calculated shape of the angular distribution for a J^{res} =17/2. Also the shapes of the angular distributions of alpha particles populating the same state of ^{17}O at the resonance energies E_{CM}= 9.73 and 11.4MeV agree with the calculated shapes of angular distributions for resonance spins J^{res}=15/2 and 17/2 respectively (Fig.2 and 3).

Hence , we propose the spins J^{res}=17/2, 15/2 and 17/2 for the resonances located at energies E_{CM}= 7.4, 9.73 and 11.4MeV in the ^{9}Be + ^{12}C system. DWBA calculations for a ^{5}He cluster transfer in the $^{9}Be+^{12}C\rightarrow\alpha+^{17}O$ reaction give qualitative agreement with the off resonance angular distribution data.

+ University of Ioannina
++ R. Boskovic Institute, Zagreb, Yugoslavia

(1) TANDEM ACCELERATOR LAB "Annual Report 1978, p.5

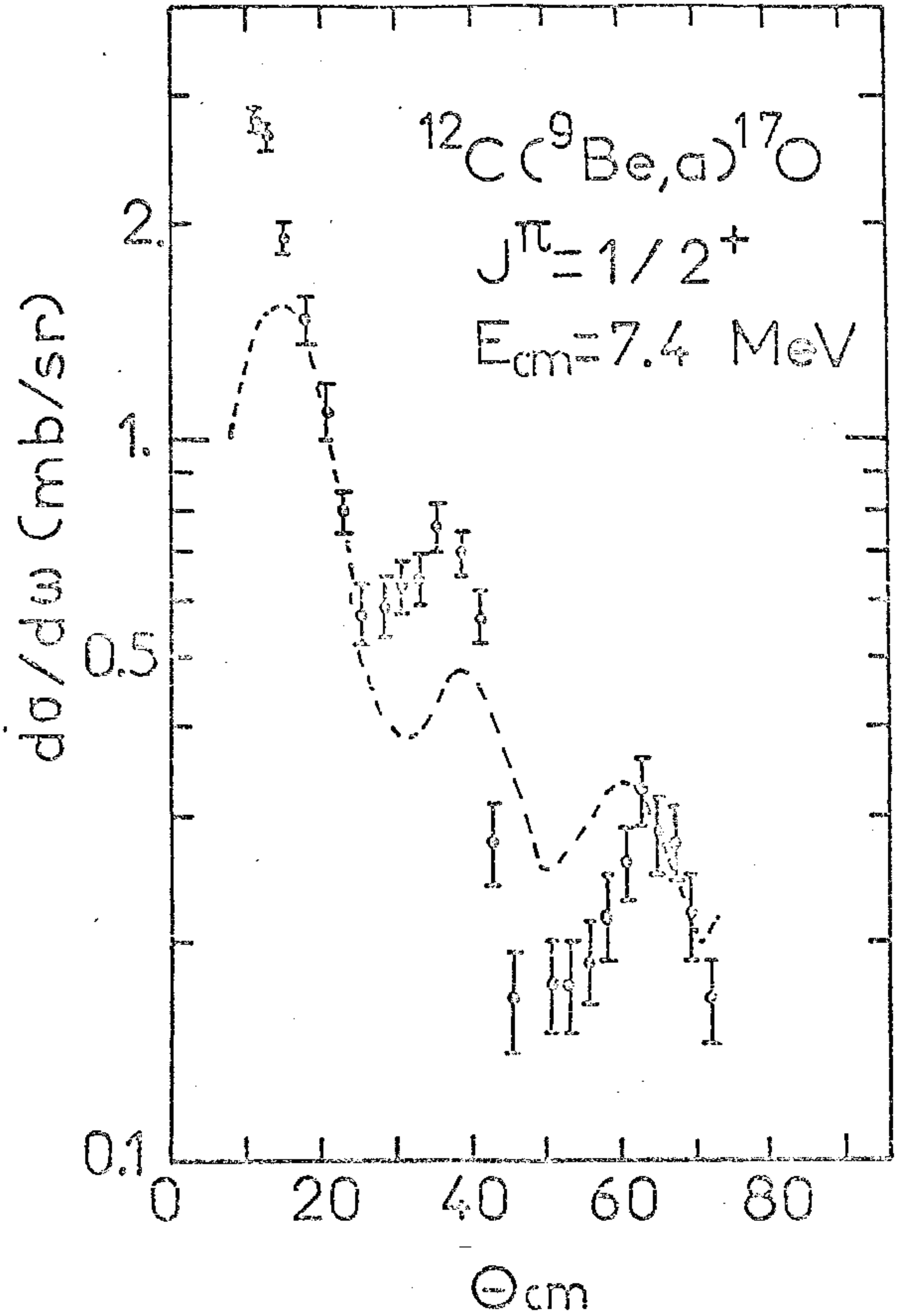


Fig. 1.

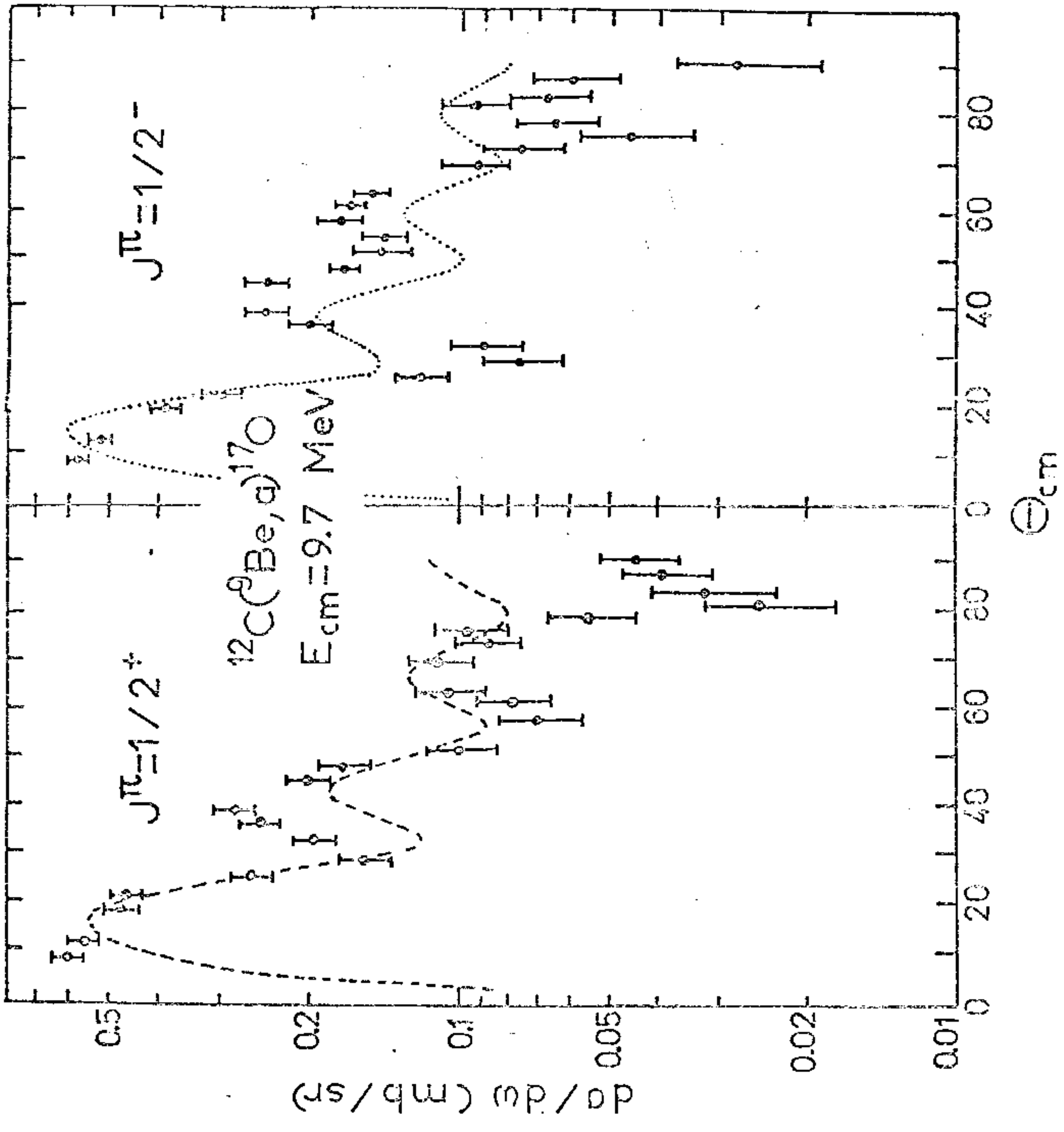

Jπ=1/2⁺
Jπ=1/2⁻
12C(9Be,α)17O
Ecm=9.7 MeV
dσ/dω (mb/sr)
Θcm
0.5
0.2
0.1
0.05
0.02
0.01
0
20
40
60
80

Fig. 2

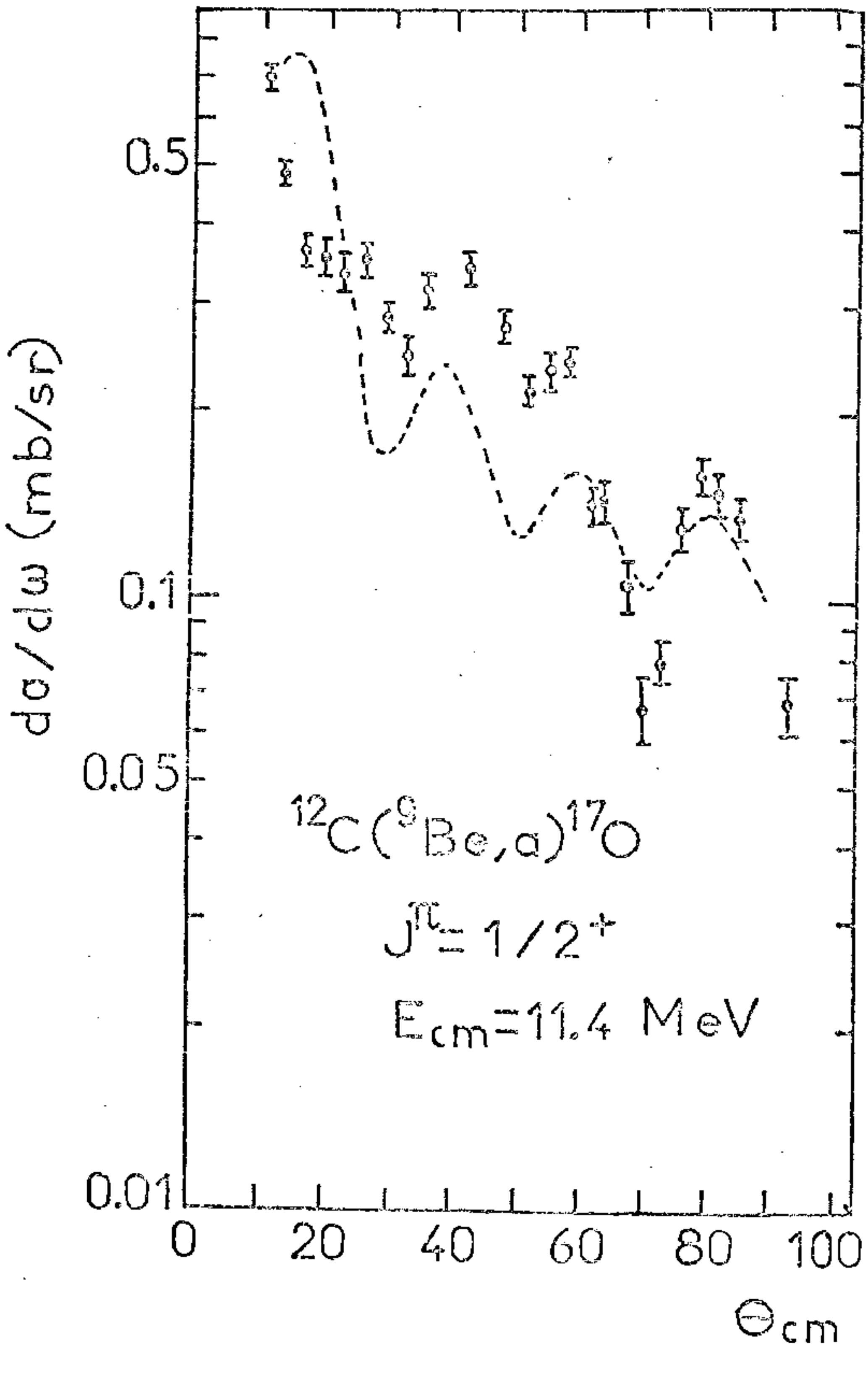

dσ/dω (mb/sr)
0.5
0.1
0.05
0.01
0
20
40
60
80
100
Θcm
12C(9Be,α)17O
Jπ= 1/2+
Ecm=11.4 MeV

Fig. 3

Resonant Behavior of the $^{12}C+^{24}Mg$ System

G. Vourvopoulos, X. Aslanoglou, R. Čaplar[+] and D. Počanić[+]

The resonant behavior of the $^{12}C+^{24}Mg$ system leading to ^{36}Ar as composite system was studied at the energy region of E_{CM}=12-16.7 MeV, via the reaction $^{24}Mg(^{12}C,\alpha)^{32}S$. Existing data at higher energies by Cindro et al[(1)] established a number of resonances at that energy region through the same reaction while back angle elastic and inelastic scattering data by M. Mermaz et al[(2)] at the energy region of E_{CM}=13-29 MeV show a resonant behavior of those channels. Our aim was to compare reaction channel data to the elastic and inelastic ones at the same C.M. energies.

The target used was a highly enriched ^{24}Mg 100μg/cm^2 foil which was bombarded with $^{12}C^{4+,5+}$ beams. The detecting system consisted of four single solid state surface barrier detectors placed at the angles Θ_L = 10°, 30°, 50° and 70°. The detectors were covered by Al foils thick enough to stop the elasticly scattered ^{12}C particles.

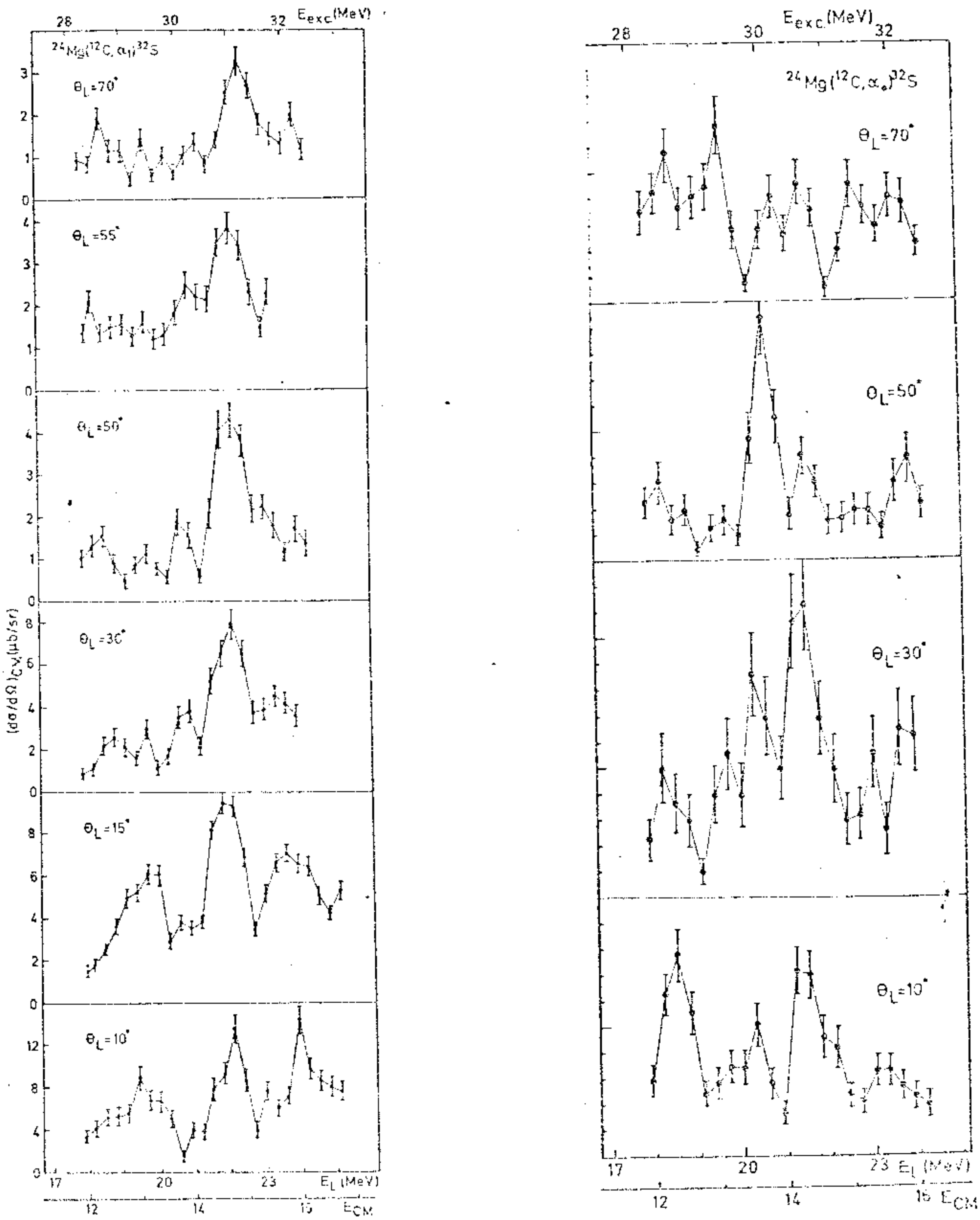
Excitation functions obtained for α_1 and α_o particles at the mentioned angles are shown in Fig.1 . Correlated anomalies are observed at the energies of E_{CM}=12.3, 14.3 and 14.8 indicating the existence of resonances.

Angular distribution measurements obtained at resonant energies did not show a single $P^2_\ell(\cos\theta)$ behavior. This could be caused by the large interference introduced by the non resonating background.

+ R. Boskovic Institute, Zagreb, Yugoslavia

(1) N. Cindro, et al. Phys. Lett. 84B (1979) 55

(2) M. Mermaz, private communication



E_{exc}(MeV)
28
30
32
$^{24}Mg(^{12}C,\alpha_1)^{32}S$
$\theta_L=70°$
$\theta_L=55°$
$\theta_L=50°$
$\theta_L=30°$
$\theta_L=15°$
$\theta_L=10°$
$(d\sigma/d\Omega)_{CM}$(μb/sr)
E_L (MeV)
17
20
23
12
14
16
E_{CM}
$^{24}Mg(^{12}C,\alpha_0)^{32}S$

Fig.1

Resonances in the $^{16}O + ^{14}C$ Systems

G. Vourvopoulos, D. Drake+, J. D. Moses+, J. C. Peng+, N. Stein+ and J. Sunier+.

If resonances that are observed in heavy ion systems in the s-d shell are indeed resonances in the compound nucleus formed, then one should be able to excite these resonances utilizing different entrance channels. ^{30}Si is one of the few nuclei that is amenable to such a study, utilizing the ^{18}O - ^{12}C and ^{16}O - ^{14}C entrance systems. For both entrance systems there is no complete complementary data. The availability of a ^{14}C beam at Los Alamos made possible the study of the reaction $^{16}O(^{14}C,\alpha)^{26}Mg$. An excitation function was taken (Fig.1) in the energy region E_{CM}= 12-21 MeV and a number of anomalies were observed in the excitation function of the ground state and first excited state of ^{26}Mg. For several of these anomalies angular distributions were taken which are indicative of ℓ= 11 resonances.

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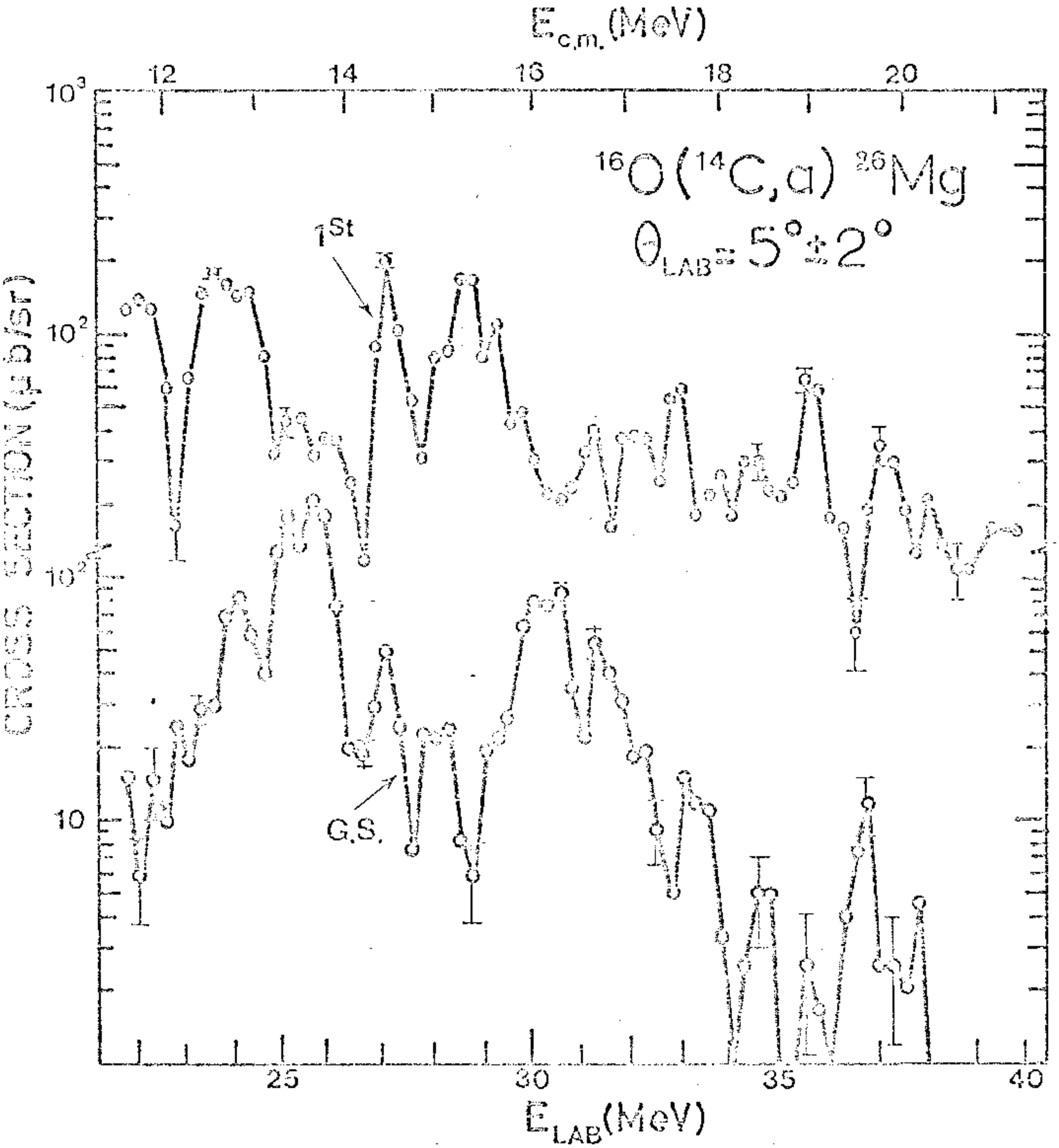
E c.m. (MeV)
12
14
16
18
20
10^3
$^{16}O(^{14}C,\alpha)\,^{26}Mg$
$\Theta_{LAB} = 5° \pm 2°$
1st
10^2
10^2
G.S.
10
CROSS SECTION (μ b/sr)
25
30
35
40
E LAB (MeV)

Fig. 1

Search for Resonances in the $^{9}Be+^{13}C$ System

X. Aslanoglou, G. Vourvopoulos, D. Počanić[+], E. Holub[+]

Excitation function data obtained for the reaction $^{9}Be+^{13}C\rightarrow\alpha+^{18}O$ in the energy range of E_{CM}= 4.4-12 MeV at four angles showed many oscillations of the differential cross section which could indicate the existence of resonances in this system. This year we completed the analysis of the data looking for correlations of the anomalies appearing in the individual excitation curves.

The absolute deviation function was used as criterion for correlations of the anomalies between individual excitation function measurements, defined as

$$D(E) = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{\sigma_i(E)}{<\sigma_i(E)>} - 1 \right|$$

An absolute correlation function of the type

$$C(E) = \frac{2}{N(N-1)} \sum_{\substack{i,j=1 \\ i>j}}^{N} \left[\frac{<C_i(E)\;\; C_j(E)> - <C_i(E)> <C_j(E)>}{\{(<C_i^2(E)>-<C_i(E)>^2)(<C_j^2(E)>-<C_j(E)>^2)\}^{1/2}} \right]$$

was also used where the indices i and j run over the N=8 excitation functions measurements and $<C_i(E)>$ represents the average of $\sigma_i(E)$ in an energy interval of ΔE=3.5MeV for D(E) and ΔE=0.5 MeV for C(E).

Both deviation and correlation functions show maxima at the energies E_{lab}=10.0, 12.25, 16.0 and 21.5 (Fig.1) which correspond to the maximum correlation of the anomalies between individual measurements.

Thus, there are strong indications for the existence of resonances in the $^{9}Be+^{13}C$ system, at the energies of E_L = 10.0, 12.25, 16.0 and 21.5 MeV.

+ " Rudjer Bošković Institute", Zagreb, Yugoslavia

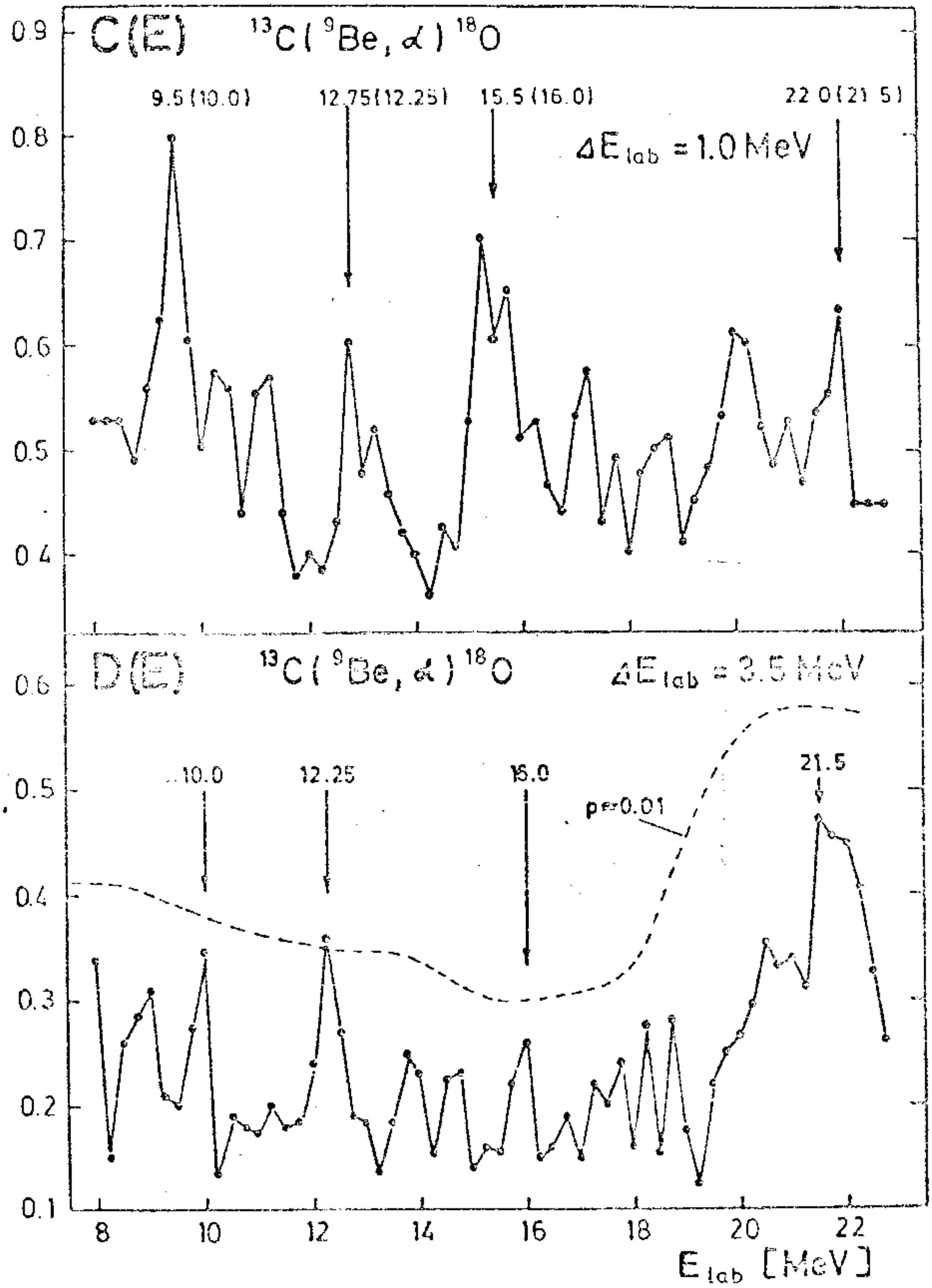
C(E) $^{13}C(^{9}Be,\alpha)^{18}O$
9.5 (10.0)
12.75 (12.25)
15.5 (16.0)
22.0 (21.5)
ΔE lab = 1.0 MeV
0.9
0.8
0.7
0.6
0.5
0.4
D(E) $^{13}C(^{9}Be,\alpha)^{18}O$
ΔE lab = 3.5 MeV
10.0
12.25
16.0
21.5
p=0.01
0.6
0.5
0.4
0.3
0.2
0.1
8
10
12
14
16
18
20
22
E lab [MeV]

Fig. 1

Competition between Isoproduct Channels in ^{16}O and ^{18}O Induced Nuclear Reactions

E. N. Gazis , A. C. Xenoulis, P. Kakanis, A. D. Panagiotou[+] and D. Bucurescu[++].

Competition between isoproduct exit channels, such as pn and d; p2n dn and t; and αpn and αd, producing the same residual nucleus has been identified and measured in several ^{16}O and ^{18}O induced nuclear reactions by detecting discrete γ rays in coincidence with light charged particles.

The ratio σ_{pn}/σ_d in the reactions $^{12}C+^{16}O$ and $^{13}C+^{16}O$ was measured as a function of bombarding energy between 24.5 and 37.5 MeV. Corresponding Hauser-Feshbach calculations gave results in very good agreement with experiment. Isoproduct channel competition was also measured in the reactions $^{16}O+^{16}O$, $^{27}Al+^{16}O$, $^{28}Si+^{16}O$, $^{16}O+^{18}O$, $^{18}O+^{18}O$, $^{19}F+^{18}O$ and $^{28}Si+^{18}O$ at several bombardment energies in the range between 27.5 and 34 MeV.

The results obtained point out that the isoproduct channel competition depends on the kind of the nuclei participating in the reaction, on the bombarding energy and the nature of the final state produced. These data demonstrated that isoproduct competition constitutes a characteristic nuclear property the magnitude of which is amenable to measurement. It is also concluded that for a proper comparison between experimental and theoretical cross sections of heavy-ion reactions the emission of d and t should be explicitly taken into account.

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++ Institute for Physics and Nuclear Engineering, Bucharest, Romania.

Study of Isoproduct Channels in ^{7}Li Induced Reactions

A. E. Aravantinos and A. C. Xenoulis

In a recent publication a method for the study of competition between exit channels, such as pn and d or p2n, dn and t, populating the same residual nucleus in heavy-ion reactions has been proposed[1]. Competition between such channels was measured in several ^{16}O and ^{18}O induced reactions[1].

In the present study the investigation has been focused on ^{7}Li induced reactions which have some interesting particularities with respect to their reaction mechanism. In order to make a systematic investigation in ^{7}Li induced reactions the reactions $^{7}Li+^{12}C$, $^{7}Li+^{16}O$, $^{7}Li+^{30}Si$ and $^{7}Li+^{64}Zn$ were studied with beam energies around 17.0 MeV.

The technique used was that of particle-gamma coincidence. Gamma-rays emitted from the decay of residual nuclei by the pn or d and p2n, dn or t exit channels were measured in coincidence with protons, deuterons and tritons from the mass identified spectrum. A 18% efficient GeLi detector was placed at 90^{o} angle with respect to the beam (solid angle $d\Omega\gamma \simeq 1.8$ ster.) , while the particle detection system consisting of a ΔE-E telescope (150 and 3000 μm thickness) was placed at $\Theta_{lab}=15^{o}$ (solid angle $d\Omega p$ particle $\simeq 25$ mster).

The ratio of gamma-ray yields in coincidence with charged particles represents a measure of the ratio between differential cross sections of the corresponding isoproduct channels. Some results of the measured ratios are given in the following table.

In order to obtain the ratio of angle integrated cross sections, angular distribution measurements were taken for the reactions $^{7}Li+^{12}C$ and $^{7}Li+^{16}O$. The angle of the telescope covered a range between $\Theta_{lab}=10^{o}$ to 80^{o}.

In these measurements an anisotropy of the ratio $d\sigma_{pn}/d\sigma_{d}$ as a function of the charged particle angle was observed. The angular distribution measured for the 351 keV gamma-ray of the ^{21}Ne residual nucleus in the reaction $^{7}Li+^{16}O \rightarrow pn_{/d}+^{21}Ne$ is shown in Fig. 1. In such a case in which the relative differential yields of pn and d exit channels are not isotropic the angular correlation of each channel should be considered separately in order to obtain the ratio of angle integrated cross sections .

In Fig. 2 we show the angular correlation of the p-351 keV and d-351 keV coincidence rate for the reaction $^{16}O(^{7}Li,pn_{/d})\ ^{21}Ne$. A second order polynomial was fitted to the experimental points. The ratio of angle integrated cross sections is given by the formula:

$$d\sigma_{pn}/d\sigma_{d} = \frac{\int_{0}^{90} f_{pn}(\vartheta_{c})\ d\vartheta_{c}}{\int_{0}^{90} f_{d}(\vartheta_{c})\ d\vartheta_{c}}$$

where f_{pn} and f_{d} are the second degree polynomials.

By this procedure it was found that $d\sigma_{pn}/d\sigma_{d}=5.6\pm0.1$. It should be mentioned that in this calculation it is assumed that the reaction $^{16}O(^{7}Li,pn_{/d})\ ^{21}Ne$ has mainly compound nucleus character.

The effect of ^{4}He transfer reaction component in (^{7}Li,t) reaction on the competition between isoproduct channels and the possibility of ^{7}Li Coulomb break up on the ^{197}Au backing are under further investigation.

References

{1} A. C. Xenoulis, E. N. Gazis, P. Kakanis, D. Bucurescu and A. D. Panagiotou, Phys. Lett. 90B (1980) 224

T A B L E

System	Beam Energy	Resid. nucl.	Measured γ-ray	Ratio of the differential cross $d\sigma_{pn}/d\sigma_d$ sections	% contribution of each exit channel (uncer. ±4%) p2n	dn	t
$^{7}Li+^{12}C$	17.2 MeV	^{17}O	871keV($1/2^+ \to 5/2^+$) 2183keV($1/2^-$ $1/2^+$)	2.3±0.4 1.1±0.9			
$^{7}Li+^{16}O$	17.2 MeV	^{21}Ne	351keV($3/2^+ \to 3/2^+$) 1397keV($7/2^+ \to 5/2^+$)	5.2±0.7 3.7±2.0			
		^{20}Ne	1634keV($2^+ \to 0^+$)		0	12	88
$^{7}Li+^{30}Si$	18.0 MeV	^{35}S	1572keV($1/2^+ \to 3/2^+$)	7.0±2.2			
		^{34}S	2127keV($2^+ \to 0^+$)		26	20	54
$^{7}Li+^{64}Zn$	18.0	^{69}Ge	952keV($\frac{11}{2} \to 9/2$)	38.0±16.0			

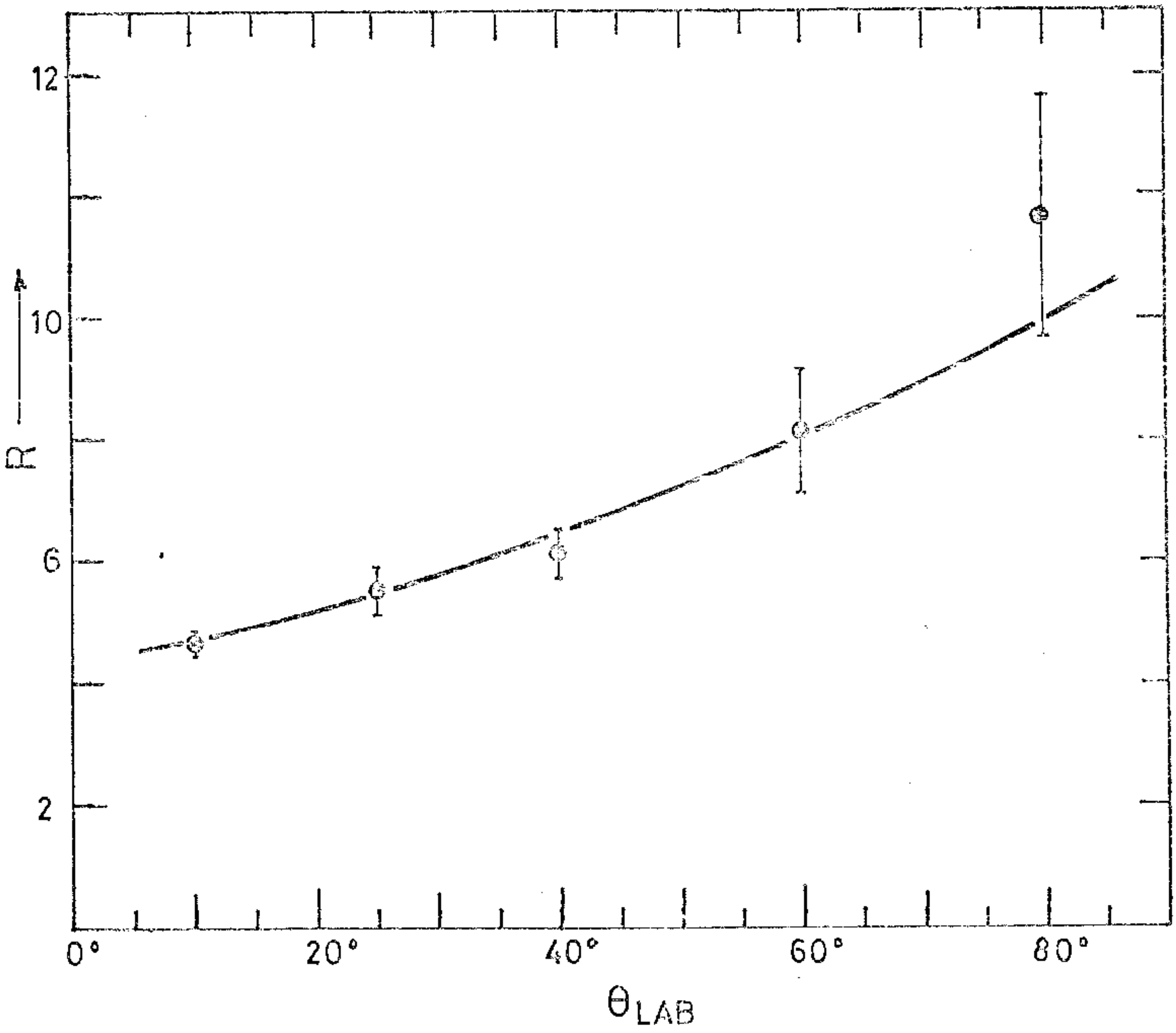
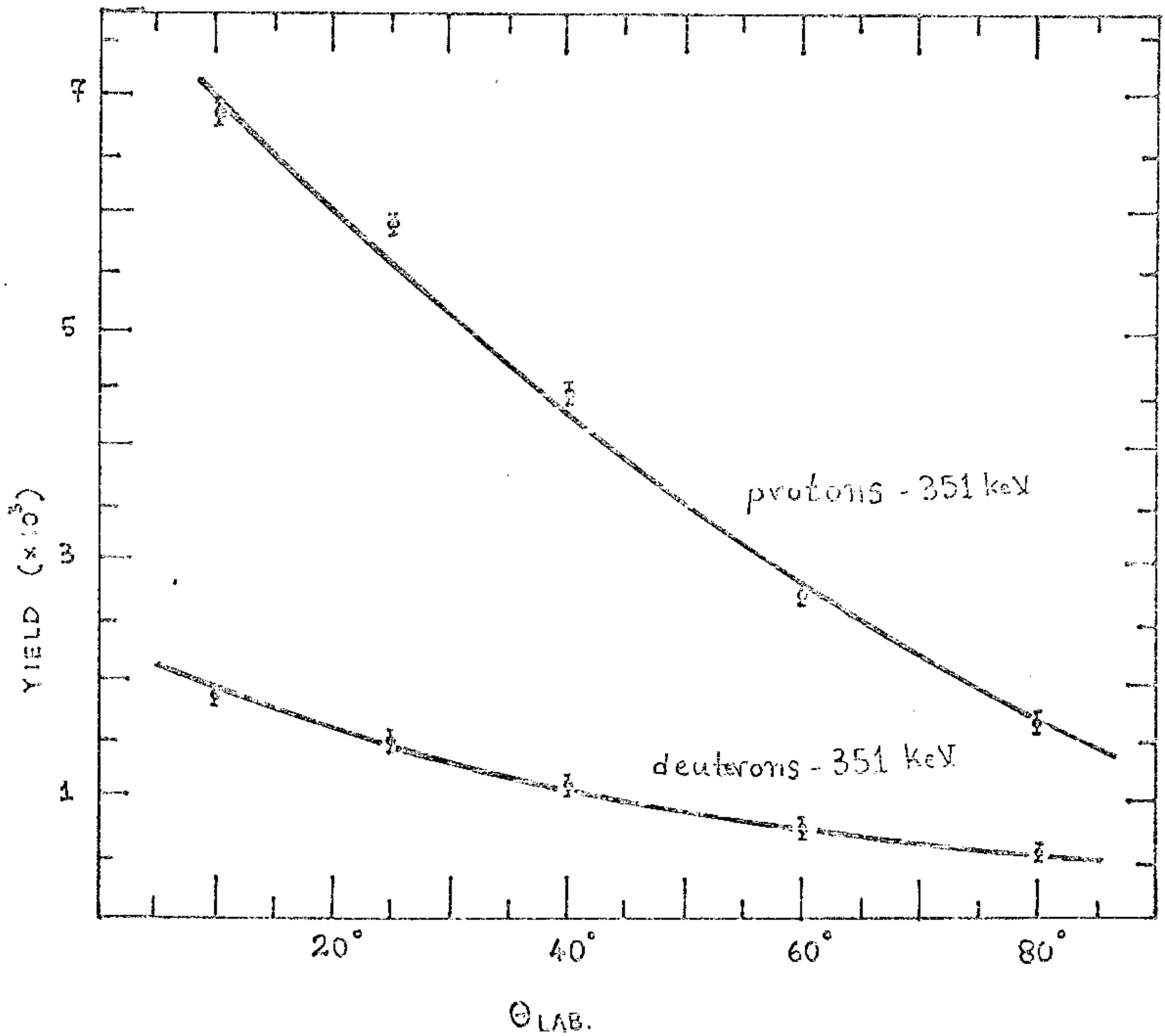


Fig. 1



7
5
3
1
YIELD (x10³)
protons - 351 keV
deuterons - 351 KeV
20°
40°
60°
80°
Θ LAB.

Fig. 2

II. GAMMA RAY SPECTROSCOPY

High Spin States in Odd Ga Isotopes

P. Bacoyeorgos[+], T. Paradellis, P. Assimakopoulos[++]

The purpose of this work is to study the high spin states of the odd Ga isotopes using ^{7}Li as a projectile and the even Ni isotopes as targets.

The nuclear reactions are:

$^{58}Ni\ (^{7}Li,\ 2n\gamma)\ ^{63}Ga$

$^{60}Ni\ (^{7}Li,\ 2n\gamma)\ ^{65}Ga$

$^{62}Ni\ (^{7}Li,\ 2n\gamma)\ ^{67}Ga$

Initially, excitation functions were taken for all three reactions at seven energies:

E_{LAB}= 19,18,17,16,15,14,13 MeV

Then a γ-γ coincidence experiment took place for the $^{62}Ni\ (^{7}Li,2n\gamma)\ ^{67}Ga$ reaction.

Angular distributions were taken at 8 angles:

$0^{o}, 30^{o}, 40^{o}, 55^{o}, 70^{o}, 90^{o}, 110^{o}, 130^{o}$

They were used to define the spins of the high spin states of ^{67}Ga and the lifetimes of them by the D.S.A. method.

Similar work concerning the other two reactions is in progress.

+, University of IOANNINA and NRC "Democritos"
++, University of IOANNINA

Structure and Electromagnetic Properties of ^{63}Zn

C. T. Papadopoulos+, A.C. Xenoulis, P. Bakoyeorgos,
G. Andritsopoulos++, P.A. Assimakopoulos++, N.H. Gangas++
and A.G. Hartas

The levels and electromagnetic properties of ^{63}Zn were studied via spectrometry of prompt γ rays emitted in the reaction ^{63}Cu (p,n γ) ^{63}Zn at bombarding energies between 5.0 and 7.8 MeV.

The level and decay schemes of ^{63}Zn were constructed from single γ-ray energy and intensity measurements and γ-γ coincidence experiments. Twenty five excited states up to 2.5 MeV have been observed.

Multipole mixing ratios of sixty electromagnetic transitions and spin and parity values of all the identified excited states were determined from single γ-ray angular distribution measurements with the aid of the Hauser-Feshbach theory for compound nuclear reactions.

Life times for twenty five excited in ^{63}Zn were obtained from Doppler-shift-attenuation measurements. B(σL) values for many transitions were also obtained.

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++ University of Ioannina

The Structure of ^{94}Tc

E. Adamides, L.D. Skouras and A.C. Xenoulis

The structure of the ^{94}Tc nucleus has been studied via the ^{94}Mo (p,nγ) reaction. For the definite assignment of the level and decay schemes of ^{94}Tc, nγ-coincidence experiments at E_p=8.0 MeV, γγ-coincidence experiments at E_p=7.8 and 8.0 MeV and excitation function measurements between 5.0 and 8.0 MeV bombarding energy with an 100 keV step were carried out. The spins of the identified states of ^{94}Tc and the multipole mixing ratios of transitions deexciting these levels were obtained by angular distributions of single γ rays and cross-section measurements at three bombarding energies of E_p=6.0, 6.4 and 6.9 MeV. The lifetimes of the ^{94}Tc states were measured via the DSA method at E_p=7.2 MeV using the centroid shift technique . From the measured branching ratios, multipole mixing ratios and lifetimes, B(M1) and B(E2) values for many transitions in ^{94}Tc were extracted. Figs. 1 and 2 show the level and decay scheme of ^{94}Tc.

The experimental properties of ^{94}Tc were found in satisfactory agreement with relevant shell model predictions.

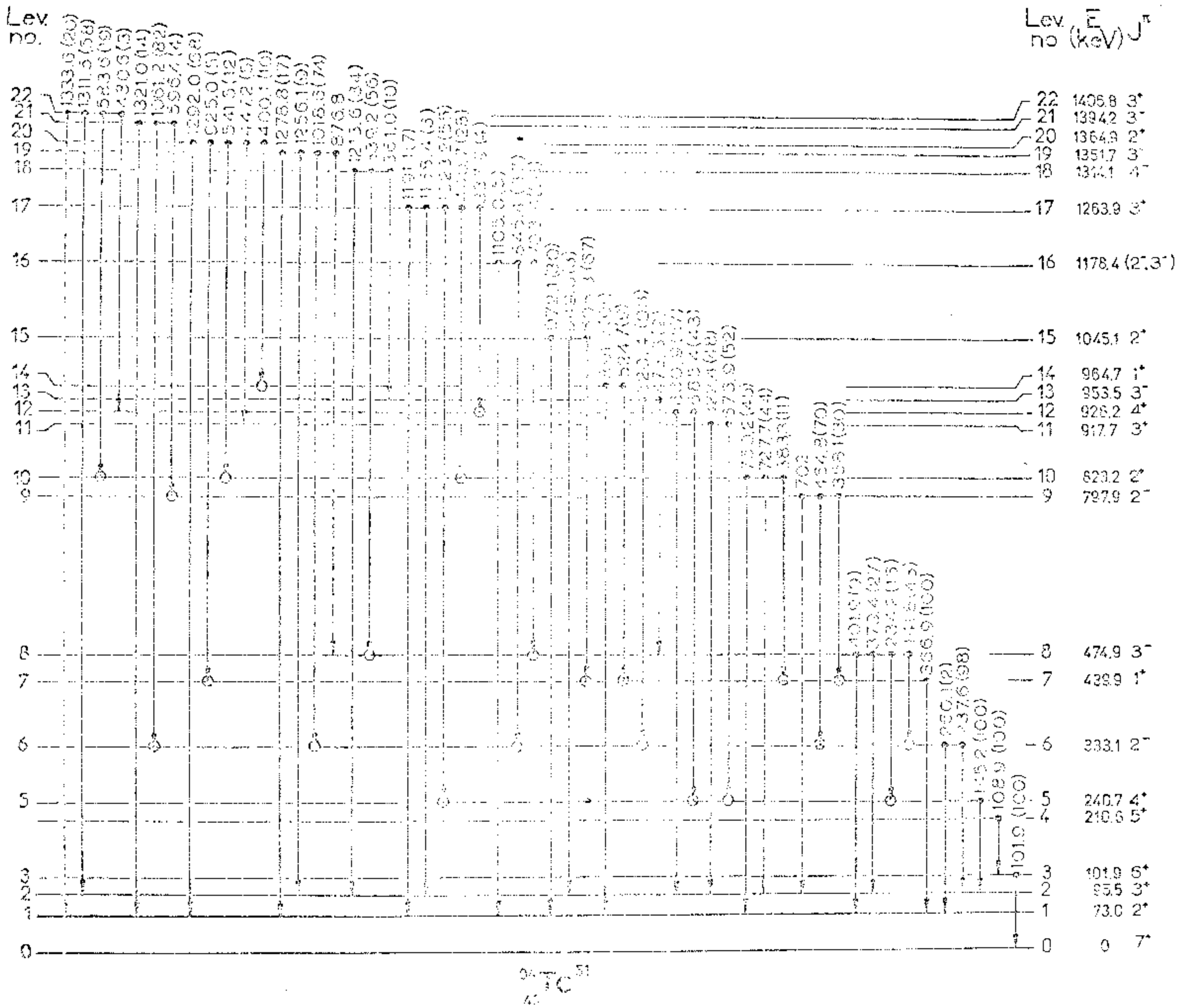

Fig. 1. Proposed scheme for the decay of levels in ^{94}Tc following excitation via the ^{94}Mo(p,nγ) ^{94}Tc reaction. Only the first 22 levels are shown in this figure. The open circles indicate coincidence relationships.

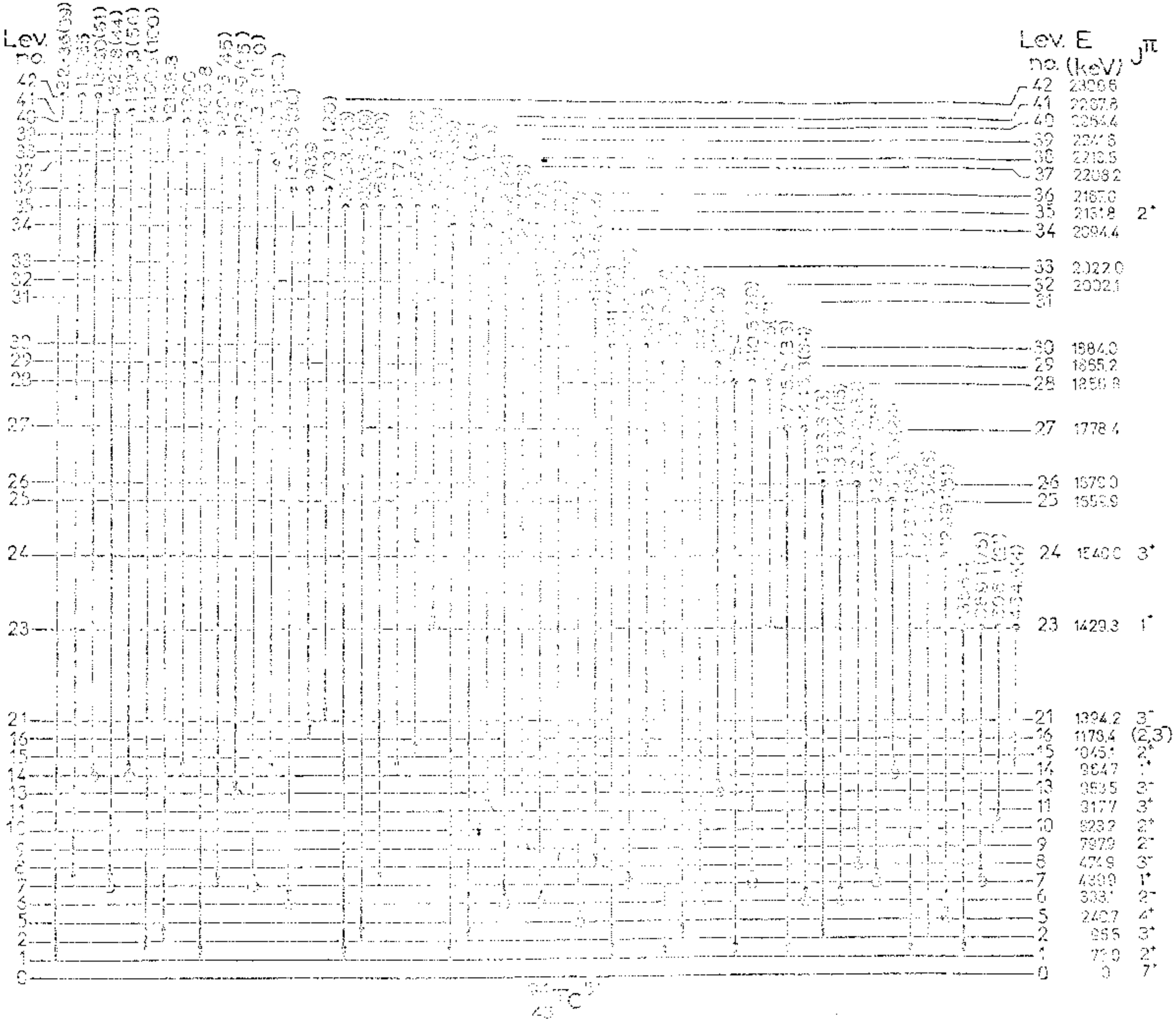

Fig. 2. Proposed scheme for the decay of levels in ^{94}Tc following excitation via the ^{94}Mo(p,n γ) ^{94}Tc reaction. Only levels nos. 23 through 42 are shown together with those below no. 22 which are populated in their decay. The open circles indicate coincidence relationships.

Structure of Low-Lying States, in ^{94}Mo

E. Adamides, L.D. Skouras and A.C. Xenoulis

In the present study the electromagnetic properties of four low-lying , low spin states in ^{94}Mo were determined utilizing spectrometry of prompt γ rays emitted in the reaction ^{94}Mo(p,p´) ^{94}Mo*(γ) at 4.8 and 5.0 MeV bombarding energies. More specifically, mixing ratios of transitions and lifetimes of excited states were determined by angular distributions and DSA measurements of single γ rays.

The experimental properties were compared with the predictions of two shell-model calculations. In the first calculation a ^{90}Zr core is assumed and the two valence protons of ^{94}Mo are considered to be in the $g_{9/2}$ orbital while the two neutrons are distributed among the close spaced $d_{5/2}$, $s_{1/2}$, $d_{3/2}$ and $g_{7/2}$ orbitals. In the second calculation we have assumed a ^{88}Sr core and distributed the four valence protons in the $p_{1/2}$ and $g_{9/2}$ orbitals . The two valence neutrons were restricted to be in the $d_{5/2}$ and $s_{1/2}$ orbital. The spectra obtained from the two calculations are compared with experimental results in Fig.1. From the two models employed the first produces better agreement with experiment on transition rates while the second calculation (see Fig.1) can account for all the observed levels . A merge of the two model spaces appears to be the natural starting point for a more extended calculation of the structure of ^{94}Mo.

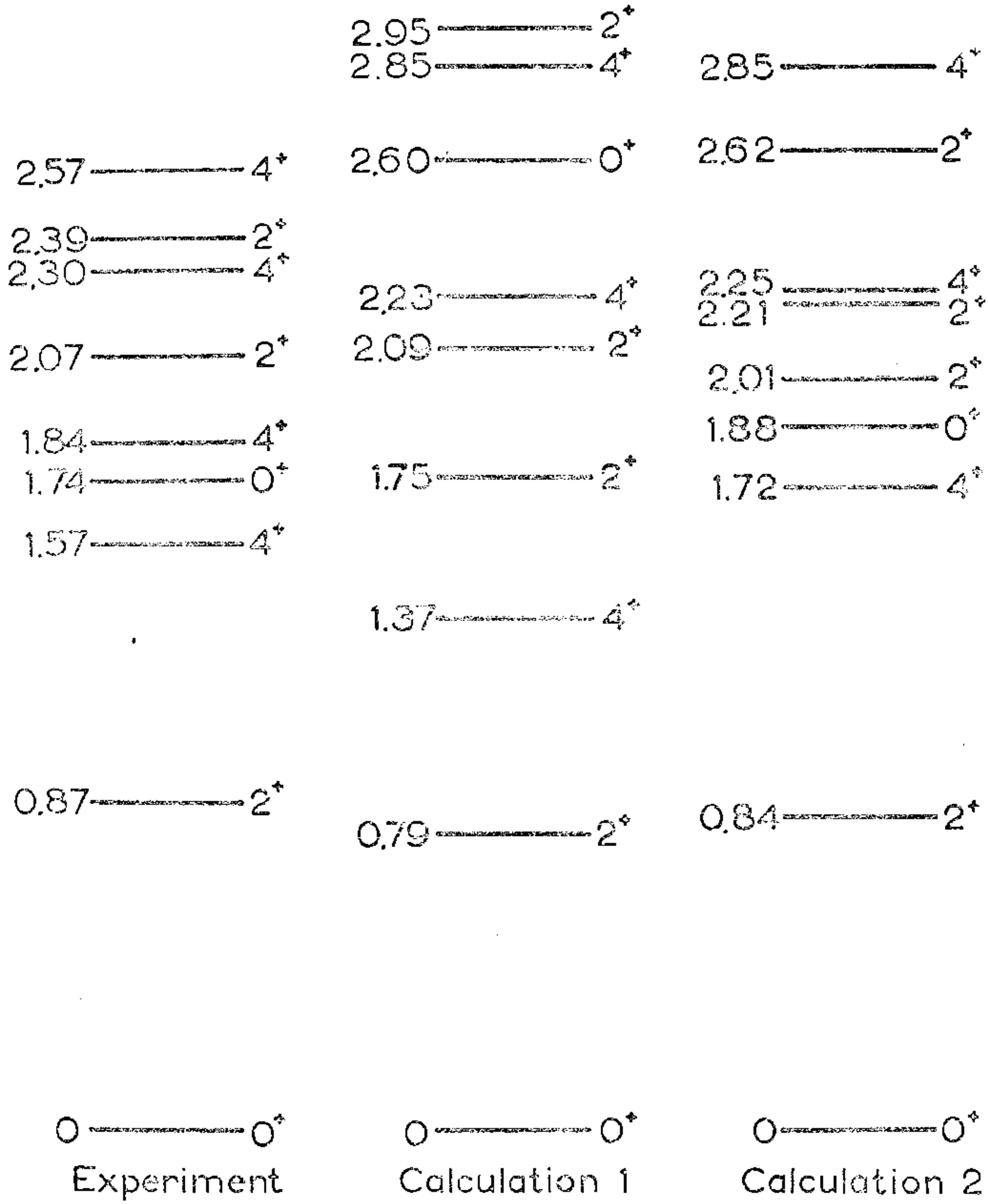
2.95 2+
2.85 4+
2.85 4+
2.57 4+
2.60 0+
2.62 2+
2.39 2+
2.30 4+
2.23 4+
2.25 4+
2.21 2+
2.07 2+
2.09 2+
2.01 2+
1.84 4+
1.88 0+
1.74 0+
1.75 2+
1.72 4+
1.57 4+
1.37 4+
0.87 2+
0.79 2+
0.84 2+
0 0+
0 0+
0 0+
Experiment
Calculation 1
Calculation 2

Fig 1.

Measurements of Multipole Mixing Ratios in ^{124}Te

S. Papaïoannou+ and C.A. Kalfas

The systematic study of the $2_2^+ \to 2_1^+$ transition of the transitional even-even nuclei in the A=150 region shows a consistent sign of the E2/M1 mixing ratio δ over a wide range of nuclei. A sudden change of this sign occurs when going from N=88 to N=90. An attempt is made in this work to correlate the behaviour of the N=72, 74 nuclei with the one of the N=88 , 90 nuclei.

Using the reaction $^{124}Te(p,n)$ ^{124}I the mixing ratios of several $\Delta J=0,1$ transitions in ^{124}Te have been studied.

In the angular correlation experiments a Ge(Li) detector and a Na(I) crystal were used and the data were stored in a TN-1700 M.C.A. based on a NOVA computer. The deduced A_{22} and A_{44} coefficients were used to determine multipole mixing ratios and to assign spin values in several energy levels. Further work is in progress in ^{128}Xe.

+ University of Ioannina

III. APPLIED ATOMIC AND NUCLEAR PHYSICS

P.A.C. Studies in DNA and DNA(Cu^{++})

C. A. Kalfas, E. G. Sideris[†], S. Elkateb[*], P. W. Martin[**] and M. Kuhnlein[***]

The technique of perturbed angular correlations of γ-rays has been used in a variety of studies on biological macromolecules {1-5}. Information on rotational correlation times, conformational transformations and molecular structure has been obtained from these measurements. Recently Vis et al {6} have reported studies of DNA between pH values 6 and 8 using ^{111m}Cd as a label.

In certain situations it has been shown that ^{111}In can be used in place of ^{111m}Cd with identical results {7}. When relative effects are being investigated, such as the detection of conformational transformations, changes in the molecular rotational correlation time should be reflected in the measured perturbation factors. Furthermore, measurements of the rotational correlation time, τ_c, can be important for the development of dynamical models of biological macromolecules. Allison and Schurr {8} have recently developed a model of DNA in which torsional motions can account for the rather small value of τ_c (28ns) obtained from fluorescence depolarization measurements {9}. The present work was initiated in order to evaluate the potential of ^{111}In as a probe for such studies of DNA.

Angular correlation measurements were performed on the 173-247 keV transitions in ^{111}Cd following the decay of ^{111}In. Binding of ^{111}In to DNA could only be achieved below about pH = 3.0, where DNA is single stranded. At this low pH the DNA undergoes a mild acidic degradation during which even the last residual hydrogen bonds between the two chains are broken and thus the DNA molecules are in the form of single polynucleotide chains {10}.

The results presented here were obtained with the computer-controlled angular correlation apparatus at Demokritos. Samples contained 170 μg of calf-thymus DNA per ml in 5mM $NaNO_3$, i.e. 5×10^{-4}M DNA-(P). The ^{111}In was added as $^{111}InC\ell_3$ in dilute HCℓ , the final pH being adjusted to 2.8 by the addition of NaOH. The ^{111}In concentration in the solution was less than 5×10^{-12} M; thus the ratio of molar concentration of the metal over the molar concentration of DNA-(P) was of the order of 10^{-8}. At this ratio of concentrations no effect of metals on the stability of the DNA helix has been reported {11} . In order to determine the effect of a metal ion on DNA, divalent Cu was added as 5×10^{-4}M nitrate.

The results of the theoretical fits to the (a) DNA{Cu^{++}} data and (b) DNA with no Cu^{++} data can be summarized in the following table:

(a) $f = 0.98 \pm 0.02$; $\omega_o = 7.7 \pm 0.2$ MHz; $\tau_c = 86^{+5}_{-4}$ ns;

(b) $f = 0.93 \pm 0.03$; $\omega_o = 6.8 \pm 0.3$ MHz; $\tau_c = 62^{+12}_{-10}$ ns;

where f is the fraction of ^{111}In bound to DNA, ω_o is the smallest quadrupole interaction frequency and τ_c is the correlation time.

From the change of the value of τ_c it appears that the effect of the metal ion is to provide higher rigidity in the DNA molecule, even when this is single stranded. These results are in line with a hypothesis advanced earlier on the formation of intermolecular copper ion bonds formed between single stranded DNA molecules {11,12} . The expected higher rigidity of the interconnected DNA single strand molecules in the presence of Cu^{++} is in agreement with our observations.

The measured rotational correlation times are much too small to correspond to the rotation of the whole DNA molecule, estimated to be at least of the order of a millisecond {13}. Our results can be explained either by assuming that the Indium probe is not bound rigidly to the DNA molecule, or by allowing segmental flexibility in the DNA itself, with relaxation rates comparable to that of the torsional motions suggested by Allison and Schurr. Until more is known about Indium binding sites on DNA, these two mechanisms cannot be distinguished.

In order to use ^{111}In at biological pH, it may first be necessary to form an intermediary complex which can subsequently be bound specifically to DNA. The more interesting double-helix system would then be amenable to PAC studies and the results interpretable in terms of dynamical models of DNA.

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Determination of Relative and Absolute Abundance of Stable Nitrogen Isotopes by Proton Induced Nuclear Reaction

A. C. Xenoulis and C. E. Douka*

The simultaneous determination of ^{14}N and ^{15}N contained in biological samples gives the possibility to study biological processes with the ultimate purpose to improve conditions and yield of cultivation. Such a simultaneous elemental analysis has been achieved utilizing the $^{14}N(p,p'\gamma)$ and $^{15}N(p,\alpha\ \gamma)$ nuclear reactions at 4.3 MeV bombarding energy by measuring the thick-target yield of the emitted γ rays with energy 2312.9 - and 4439.1-keV , respectively. The bombarding energy was chosen at 4.3 MeV on the evidence of excitation function measurements in order to take advantage of a strong resonance in the cross section of the ^{14}N (p,p'γ) reaction observed at 4.0 MeV bombarding energy. The future work involves utilization of the resonance for quantitative absolute determination of ^{14}N and also for depth distribution measurements of either ^{14}N or hydrogen.

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IV. THEORETICAL NUCLEAR PHYSICS

The Geometry of the Quantization of Angular Momenta ($\bar{l},\bar{s},\bar{j}$) in Fields of Central Symmetry

G. S. Anagnostatos

In a recent publication {1} the geometry of the quantization of the orbital angular momentum ($\bar{\ell}$) and its projection (m_ℓ), in relation to the geometry of the regular and quasi-regular polyhedra, was given. In the present article the geometry of the quantization of the intrinsic angular momentum (spin, $\bar{s}$) and of the total angular momentum ($\bar{j}$), in relation to the geometry of the same polyhedra, is presented. As a result, a geometrical presentation of all angular momenta ($\bar{\ell},\bar{s},\bar{j}$) in fields of central symmetry becomes possible through polyhedra which inherently include this symmetry. This fact may be the reason for the many surprising successes of the isomorphic model {2-3}. The model employs these polyhedra to represent dynamic average forms of the nuclear shells, resulting in the correct justification of the magic numbers.

In Fig. 1, vector illustrations for the relationships between the magnitudes of the orbital (a), intrinsic (b), and total (c) angular momenta and their z-components (for the examples shown) are presented. That is, the directions of the orbital, intrinsic, and total angular momentum vectors are unspecified in the polar angles φ, but are specified in the azimuthal angles ϑ, according to the relationships

$$\vartheta^{m_\ell}=\cos^{-1}(m_\ell/\sqrt{\ell(\ell+1)}) \quad , \qquad (1)$$

$$\vartheta_s^{m_s}=\cos^{-1}(m_s/\sqrt{s\ (s+1)}) \quad , \quad \text{and} \qquad (2)$$

$$\vartheta_j^{m_j}=\cos^{-1}(m_j/\sqrt{j\ (j+1)}) \quad , \qquad (3)$$

The quantization of direction of the orbital angular momentum{1}given by Eq. (1) is shown in Fig.2 in relation to the equilibrium Leech {4}polyhedra. Only the cases(ℓ=1,2,3,4 for all m_ℓ and ℓ =5 only for m_ℓ=5) of interest in this work to facilitate the demonstration of the quantization of the intrinsic and total angular momenta are included.

As seen from Fig.2(c), the angle

$$\theta^{m_s=+1/2}_{s=1/2} = 54^{o}\ 44'\ 8.''2 \qquad (4)$$

is identical (in any order of accuracy) to the angle $\widehat{z3A}$ and $\widehat{z3B}$. Also, the angle

$$\theta^{m_s=-1/2}_{s=1/2} = 125^{o}\ 15'\ 51.''8 \qquad (5)$$

is identical to the angles $\widehat{z3C}$ and $\widehat{z3D}$.

In Fig. 2 (a)-(d) total angular momentum vectors $\bar{j}$ are shown resulting from application of the parallelogram rule to spin vectors $\bar{s}$ (considered in the direction 31_{6-8} mentioned earlier, common for all cases shown, except j=3/2 m_j=3/2) and to orbital angular momentum vectors already specified in Ref {1}

It is of great interest that the resulting $\bar{j}$ (for all nine cases shown) have the correct j and m_j quantum numbers as registered on each related part of Fig.2.This is also true for all other cases (totally thirty) not shown in Fig.2, but derived from those shown by central or plane reflections which leave the quantization axis (z-axis) unchanged.

A common spin orientation exists for each group of $\bar{j}$ which results from the $\bar{j}$ shown in Fig. 2.(except for j=3/2) by each of the above reflections. The determination of spin orientation in all other cases requires an individual effort for each $\bar{j}$, e.g., for the case j=3/2, m_j=3/2, shown in Fig.2 (b)

In conclusion , the $\bar{\ell},\bar{s},\bar{j}$ vectors shown in Fig.2 (a)-(d), or those which can be determined as discussed in the text, can be seen as the different orientiations of the orbital, spin, and total angular momenta vectors in three-dimensional space. Thus, the equilibrium polyhedra of fig.2, which are employed to represent dynamic average forms of nuclear shells in the framework of the isomorphic model of nuclear structure, can also form a basis for dynamic average motion patterns of particles in fields of central symmetry. Moreover, the results presented here may help the development of a fundamental theory of the atomic nucleus, just as the study of regular linear arrays of identical atomic groups led to the complete theory of crystal structure.

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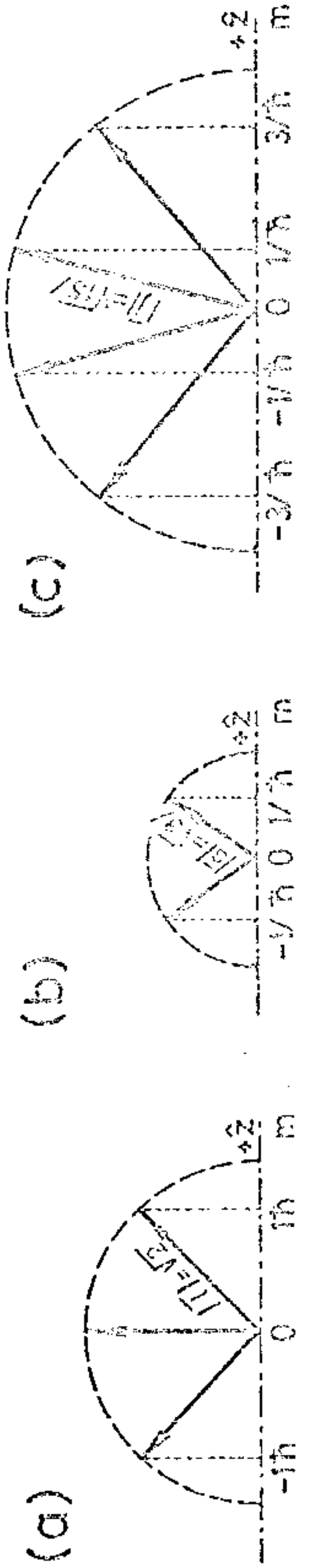

Fig. 1

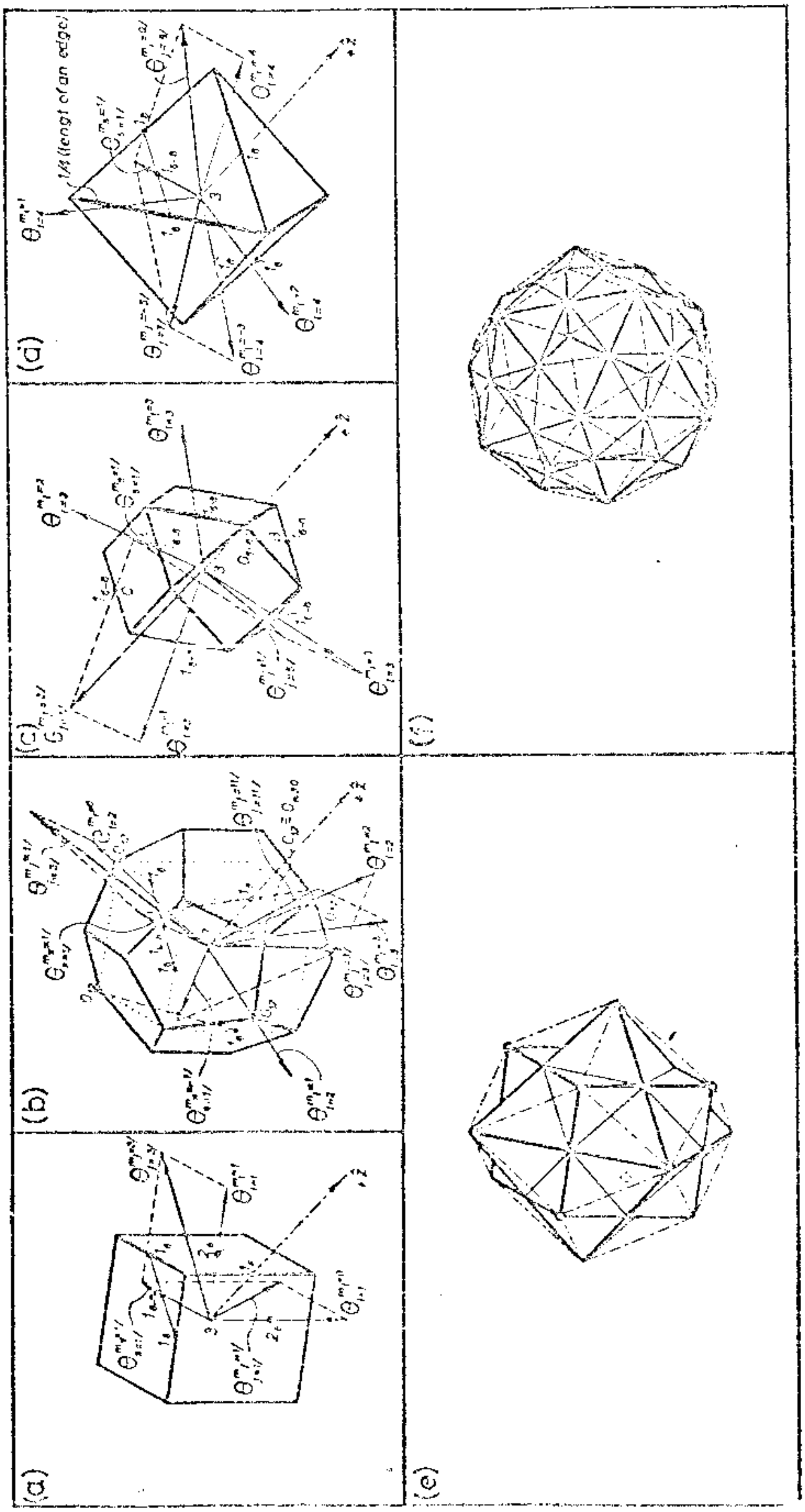

Fig. 2

A Symmetry Description of the Independent Particle Model

G.S .Anagnostatos

In a recent publication {1} and the previous work of this Annual Report, the geometry of the quantization of angular momenta ($\bar{\ell}, \bar{s}, \bar{j}$) is given. As a consequence in the present work, a symmetry description of the independent particle model is presented taking the 1p shell as an example.

In Fig.1 (a) the quantization of direction of the orbital angular momentum for $\ell=1$ (considered as a constant of motion) is given in relation to an octahedron. This polyhedron, in the framework of the isomorphic model {2-3}of nuclear structure, represents the average dynamical form of the 1p shell. As seen, the directions of the orbital angular momentum in three space are axes of symmetry passing from the vertices of this polyhedron. In Fig. 1 (b), the quantization of direction of the spin (considered as a constant of motion, e.g. in s-states) is presented.

In Fig. 1(c) and (d) the $j= 1/2$, $m_j=1/2$ and $j=3/2$, $m_j=3/2$ are derived applying the parallelogram rule to the orbital angular momenta of Fig.1(a) and to the spin of Fig.1(b) . In Fig. 1(c) the case $j=3/2$, $m_j=1/2$ is presented, where the vectors $\bar{\ell}$ and $\bar{s}$ do not come from Fig. 1 (a) and (b). This j,m_j case is derived in relation to the previously found $\bar{j}$, as will become apparent shortly. Fig.1 (f) and (g) demonstrates the expected total J ($0 \leq J \leq 1$) for two particles with individual angular momenta $j_1= j_2=1/2$. In a similar way, Fig. 1 (h) - (ℓ) demonstrates all expected total J ($0 \leq J \leq 3$) for two individual particles with $j_1=j_2=3/2$, while Fig. 1 (m) and (n) demonstrates the two expected total J ($1 \leq J \leq 2$) for two particles with $j_1=1/2$ and $j_2=3/2$.

The fact that even number of neutrons or of protons at the ground state couple their $\bar{j}$ to total $\bar{J}=0$, makes us to assume that Fig. 1 (f), (h), and (i) refer to either two neutrons or to two protons. The same fact, however, makes us to assume that the remaining cases of j coupling in Fig. 1 refer to one neutron and to one proton (odd-odd nuclei). Besides the cases shown in Fig. 1, there are other equivalent cases resulting by symmetric operations of the octahedron, which leave the quantization axis (z-axis) unchanged.

Part (o) of Fig. 1 shows $\bar{j}_1$ and $\bar{j}_2$ vectors, already used in the previous parts of the figure, in such a way that we distinguish between neutron and proton $\bar{j}$'s . Each $\bar{j}$ shown corresponds to a particular τ value (either $\tau=1/2$ or $\tau=-1/2$), to particular n and ℓ values (n=1 and ℓ=1), and to particular j and m_j values (1/2 or 3/2). Thus, for the example taken (1p shell), Fig. 1 (o) presents a symmetry description of the Independent Particle Model .

{1} , {2-3} : See references with same numbers in the previous work of this Annual Report.

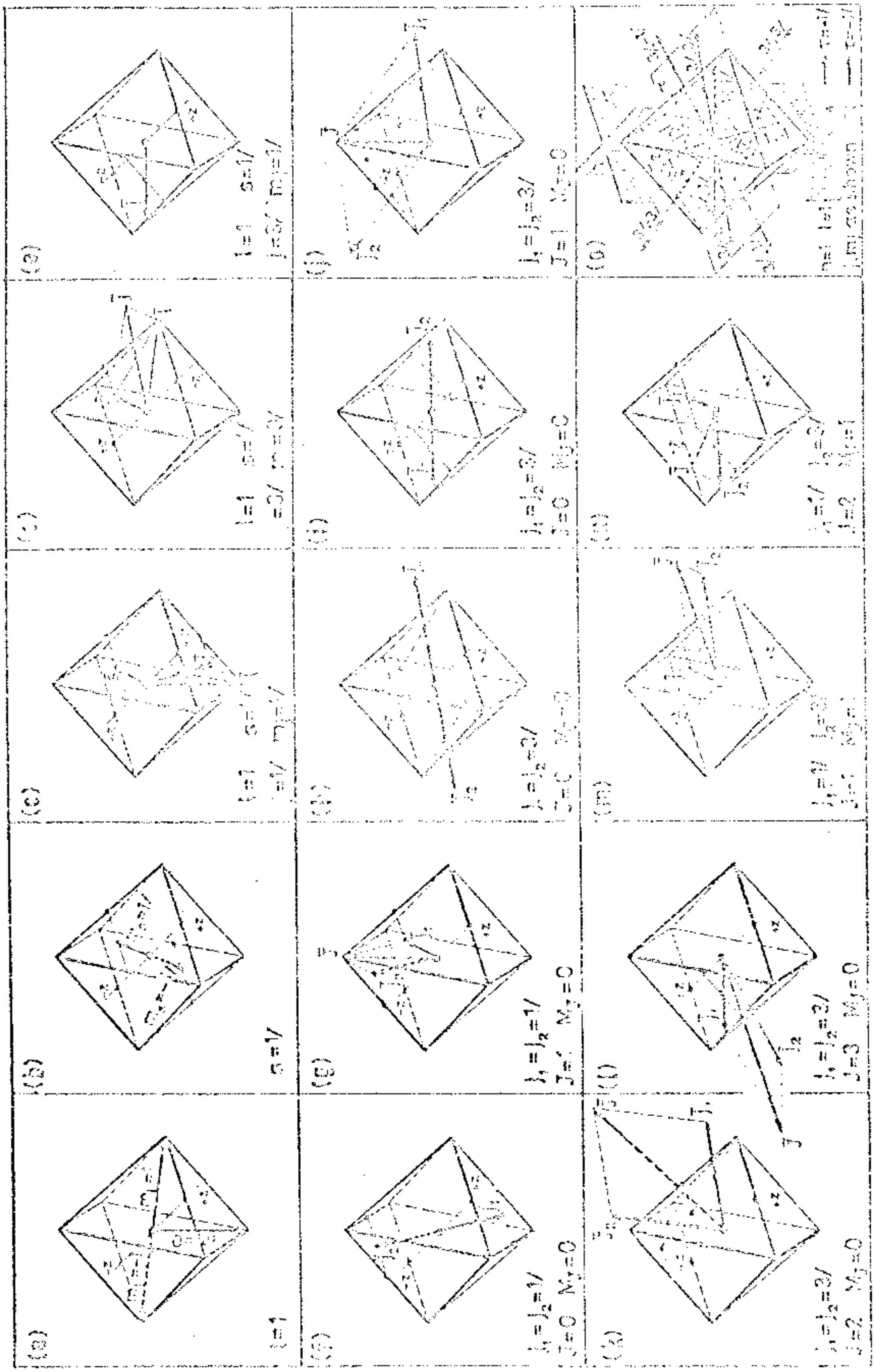

Fig. 1

V. DATA COLLECTION AND PROCESSING

Hardware Development and Maintenance

V. Katsolis, S. Kossionides , A. Sokos and A. Chionakis

The data collection system suffered several break downs during the past year. The main source of problems was the memory of the PDP -11 controller and the expand memory of the PDP-15, both of which have been repaired several times in the past.

Other repairs and adjustments were performed on:

- the power supply of the PDP-15
- the magnetic tape TU 10
- the DEC-tape
- the Teletype KSR-35
- the controller of the H.P. 1300 A X-Y display system
- the Multi-channel Analyzer NS 630
- Several analog and digital modules.

An alarm system for detecting loops between clean and machine grounding has been tested and set in continuous operation, so as to avoid interference of peripheral noise with the measuring systems.

An interface was constructed in order to connect a Tektronix 4010 terminal to the data collection system.

A new printing terminal, LA 36 DEC DIGITAL writer, was added to the data collection system. In order to achieve speed of 30 characters per sec, a corresponding interface was constructed.

Finally , a device was designed and constructed by which, in conjunction with the existing 8070 device and the computer, a Faraday cup of the accelerator can be controlled.

VI. ACCELERATOR OPERATION

Th. Asthenopoulos, N. Andreopoulos , N. Divis, N. Iliadis and G. Prokos

During 1979 the Tandem was utilized for a total of 3064 hours. Heavy ions were employed 62% of the time and light ions (protons and deuterons) 38%.

The operation was nearly trouble free with eight tank openings during the year for minor problems and foil changes. The positioning of the upcharge screen was improved and the belt has accumulated over 7000 hours of operation.

Fig. 1. shows the beam time percentage versus terminal voltage for the years 1978 and 1979. Although the accelerator was used 66% of the time at potentials larger than 4.MV (3/4 of the maximum voltage), there is an apprecia-ble use of the Tandem at potentials less than 2MV.

A desalinization plant was placed in operation , supplying cooling water of larger resistivity (4MΩ/cm) to magnets, power supplies, pumps etc.

A new beam line was installed for particle-gamma coincidence. The following items were also designed and constructed:

1. High-vacuum and low vacuum gauge controls
2. System of collimating slits, for experimental apparatus.
3. Constant current power supply for sputter source.

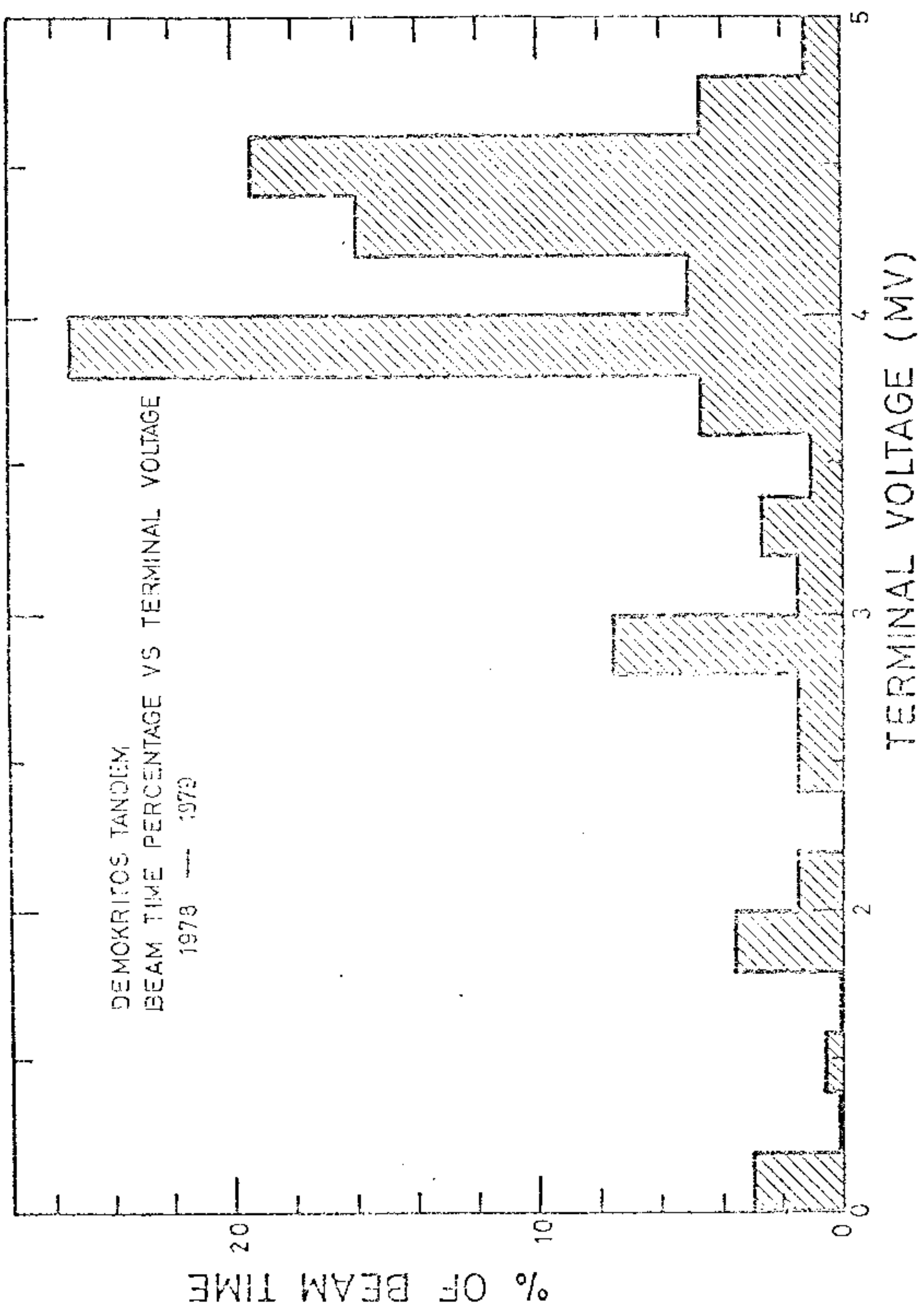
DEMOKRITOS TANDEM
BEAM TIME PERCENTAGE VS TERMINAL VOLTAGE
1978 — 1979
TERMINAL VOLTAGE (MV)
% OF BEAM TIME
0
10
20
0
2
3
4
5

Fig. 1

VII. PERSONNEL

Research Staff

Dr. G. Vourvopoulos, Director
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Dr. E. Kossionides
Dr. Th.Paradellis
Dr. L. Skouras
Dr. A. Xenoulis

Graduate Students

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S. Papaïoannou

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Prof.	P. Assimakopoulos	(Univ. of Ioannina)
Dr.	A. Hadjiantoniou	(Demokritos)
Prof.	A. Panagiotou	(Univ. of Athens)
Dr.	K. Papadopoulos	(National Technical Univ. of Athens)
Dr.	J. Paschopoulos	(National Science Foundation)

Operational Staff

Accelerator Support Group

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A. Asthenopoulos

N. Divis

N. Iliadis

G. Prokos

Electronics Group

A. Chionakis

A. Sokos

Computer Programmer

Mrs. K . Dimakou, B.S.Mathematics

Maschine Shop

O. Topikoglou

Graphics

F. Trouposkiadis

Visiting Scientists

Prof. D. Skiotis, Royal Melbourne Inst. of Technology	Jan - Dec / 79
Dr. F. Riess, University of Munich	March 1-30/79
Dr. E. Warburton, Brookhaven National Lab	May 6-10/79
Dr. R. Caplar, R. Boskovic Inst.	May 14 June 5/79
Dr. D. Pocanic, R. Boskovic Inst.	May 14 June 5/79
Prof. B. Rosner, Technion Israel Inst. of Technology	June11-14/79
Dr. A. Roy, Bhaba Research Center	Sept.4-11/79
Dr. J. Szikiai, Hungarian Academy of Sciences	Oct 7-30/79
Dr. E. Nolte, Technical University of Munich	Nov 2-9/79
Dr. R. Caplar, R. Boskovic Inst.	Dec 7-21/79

VIII. P U B L I C A T I O N S

A. Papers published in 1979

1. H.A. Mavromatis and L.D.Skouras
   "A study of ^{17}O"
   Nucl. Phys. A326(1979) 83

2. C.A. Kalfas, A.C. Xenoulis, E. Adamides, S. Papaïoannou and L.D. Skouras
   "Properties of electromagnetic transitions from high-spin states in ^{94}Mo"
   Z. Phys. A292(1979) 153

3. T. Paradellis and O. Skouras
   "Quantitative determination of Bromine labelled organic compounds"
   J. Radian. Chem.50(1979) 303

4. T. Paradellis, G.J. Costa, R. Seltz, C. Lebrun , D. Ardouin, F. Guilbault, M. Vergnes and G. Berrier
   "High-spin states in ^{69}Ge from the $^{55}Mn(^{16}O,pn)$ reaction"
   Nucl.Phys.A330(1979) 216

5. G. Vourvopoulos, T. Paradellis, G. Bergdolt, G.J.Costa and F. Diez
   "Fragmentation of a previously reported $g_{9/2}$ analog state in ^{63}Cu"
   Phys. Rev. C19(1979) 38

6. A.C. Xenoulis and C.A. Kalfas
   "Structure and directional-correlation measurements in ^{97}Tc from $^{97}Mo(p,n\gamma)$ $^{97}Tc^{*}(\gamma)$ spectrometry"
   Phys. Rev.C20 (1979) 145

8. A. C. Xenoulis and C. E. Douka

"Determination of relative and absolute abundance of stable nitrogen isotopes by proton induced nuclear reactions"

J. Radian. Chem <u>54</u>(1979) 205

9. N. Cindro, G. Vourvopoulos, X. Aslanoglou , G. Andritsopoulos , P. Assimakopoulos and P. Bakoyeorgos

" The spin and parity of 10.9 MeV resonance in $^{16}O+^{12}C$"

J. Phys.G: Nuclear Phys.<u>V5</u> (1979) 309

10. A. H. Khan, M. Khaliquzzaman, M. Husain, M. Abdullah and A.A. Katsanos

"Elemental Analysis of liquids by external beam PIXE down to PPB level"

Nucl. Instr. and Meth.<u>165</u> (1979) 253

2. Papers accepted for publication to appear in 1980

1. P.W. Martin, C.A. Kalfas and K. Skov

   "Study of conformation changes in bovine serum Albumin by perturbed angular correlation".

   Nucl. Instr. Meth.

2. C. A. Kalfas, E.G. Sideris, S. Elkateb, P.W. Martin and M. Kuhnlein

   "Determination of rotational correlation times from perturbed angular correlations of γ-rays; ^{III}Indium bound to single stranded DNA and DNA (Cu^{++})".

   Chemical Physics Lett.

3. G. Andritsopoulos, X. Aslanoglou, P. Sakoyeorgos and G. Vourvopoulos

   "$^{12}C+^{12}C$ resonances studied through gamma rays"

   Phys. Rev. C

4. G.S. Anagnostatos, S.Touliatos, A.Kyritsis and J. Yapitzakis

   "Quadrupole moments and rms charge radii of nuclei with $\leq Z \leq 60$"

   Atomkernenergie 35 (1980) 60

5. G. S. Anagnostatos

   "Comments on extension of the variable-moment-of-inertia model to high spins".

   Phys. Rev. C

6. A.C. Xenoulis, E.N. Gazis, P. Kakanis, D. Bucurescu and A.D. Panagiotou.

   "Competition between exit channels leading to the same residual nucleus in heavy-ion reactions".

   Phys. Lett. 90B(1980) 224

7. Elemental Analysis of Biological Materials, Current Problems and Techniques with special reference to trace elements, A.A. Katsanos

   IAEA Technical Report No.197 (1980) pp.231-251

C. Conferences - Reports

1. L.D. Skouras

   "Shell-model calculations in the A=90 region"
   Inst. of Phys. Conference series 49 (1979) 85
   (Invited Paper)

2. T. Paradellis

   "Recent experimental results in odd Ga and Ge nuclei"
   Inst. of Phys. Conference series 49 (1979) 43
   (Invited paper)

3. G. S. Anagnostatos

   "Vibratio-rotation structure in ^{96}Mo"
   Inst. of Phys. Conference series 49 (1979) 246

4. T. Paradellis, G. Costa and G. Vourvopoulos

   "Alignment of nuclear states in (p,γ) reactions on semi -thick target"
   Inst. of Phys. Conference series 49 (1979) 216

5. T. Paradellis and C.A. Kalfas

   "Mean-life measurements in ^{68}Ge"
   Inst. of Phys. Conference series 49 (1979) 223

6. T. Paradellis

   "Electromagnetic properties of excited states in ^{69}Ge"
   Inst. of Phys. Conference series 49 (1979) 224

7. S. Papaïoannou and C.A. Kalfas
   "Measurements of multipole mixing ratios of some transitional even-even nuclei"
   Inst. of Phys. Conference series 49 (1979) 281

8. A. Perris, E. Sideris and A.A. Katsanos
"Study of the biological action of protons at different energies"
4th Hellenic Actinological Conference, Athens, Oct. 1979

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1. A.A Katsanos
"Trace elements Analysis in external beam PIXE"
IAEA WP/5/1488 (1979)

2. G.S. Anagnostatos, S. Touliatos, A. Kyritsis, and Y. Yapitzakis
"Quadrupole moments , rms charge radii and isospin symmetry in the isomorphic model"
Greek AEC, DEMO REPORT 79/9 (1979)