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[INDC(POL)-1]

PROGRESS REPORT
ON NUCLEAR DATA RESEARCH IN POLAND

/May 1967 - April 1968/

to the International Nuclear Data Committee

Edited by

Tomasz Niewodniczański

The Government Commissioner for the Use of Nuclear Energy

Warsaw, Poland

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Editor's Note

This Progress Report on nuclear data research in Poland /May 1967 - April 1968/ contains only information on research, which is closely related to the activities of the International Nuclear Data Committee of the International Atomic Energy Agency in the field of neutron physics. It does not include any information about other nuclear research as for example in the field of charged particles nuclear physics or the use of neutrons for solid state physics studies.

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1. ENERGY SPECTRA OF LONG RANGE PARTICLES FROM THE THERMAL NEUTRON FISSION OF ^{235}U

M. Dakowski, J. Chwaszczewska, T. Krogulski, E. Piasecki, and M. Sowiński - Institute of Nuclear Research, Świerk.

The emission of light particles as ^{1}H, ^{2}H, ^{3}H, ^{4}He, ^{6}He, ^{8}He, Li, Be, C and O from the thermal-neutron fission of ^{235}U have been investigated using counter telescope and two parameter analysis.

Energy spectra of ^{1}H, ^{2}H, ^{3}H, ^{4}He and ^{6}He have been investigated using a semiconductor counter telescope. The ΔE and E detectors were 50 μm and 1.500 μm thick respectively. These data were published in Phys. Lett. 25B, 213 /1967/.

The obtained results are presented in Figs. 1 and 2. In Table 1 the relative intensities of the ^{1}H, ^{2}H, ^{3}H , and ^{6}He with respect to emission of 100 alpha particles, energy of these particles in a peak and F.W.H.M. of the energetic spectrum are given.

Not for publication

TABLE 1

Particle	Relative intensity	E /peak/ MeV	F.W.H.M. MeV
p	1.15 ± 0.15	8.6 ± 0.3	6.9 ± 0.5
d	0.5 ± 0.1	7.9 ± 0.3	7 ± 1
t	6.2 ± 0.5	8.6 ± 0.3	6.7 ± 0.6
α	100	15.7 ± 0.3	9.8 ± 0.4
^6He	1.1 ± 0.2	12.9 ± 0.5	8.7 ± 0.7

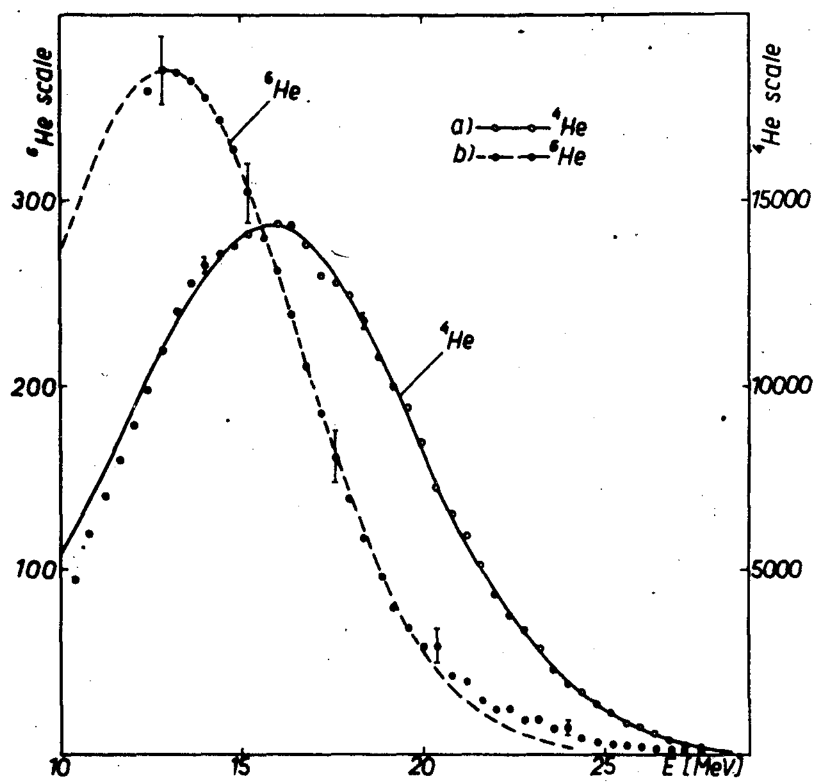
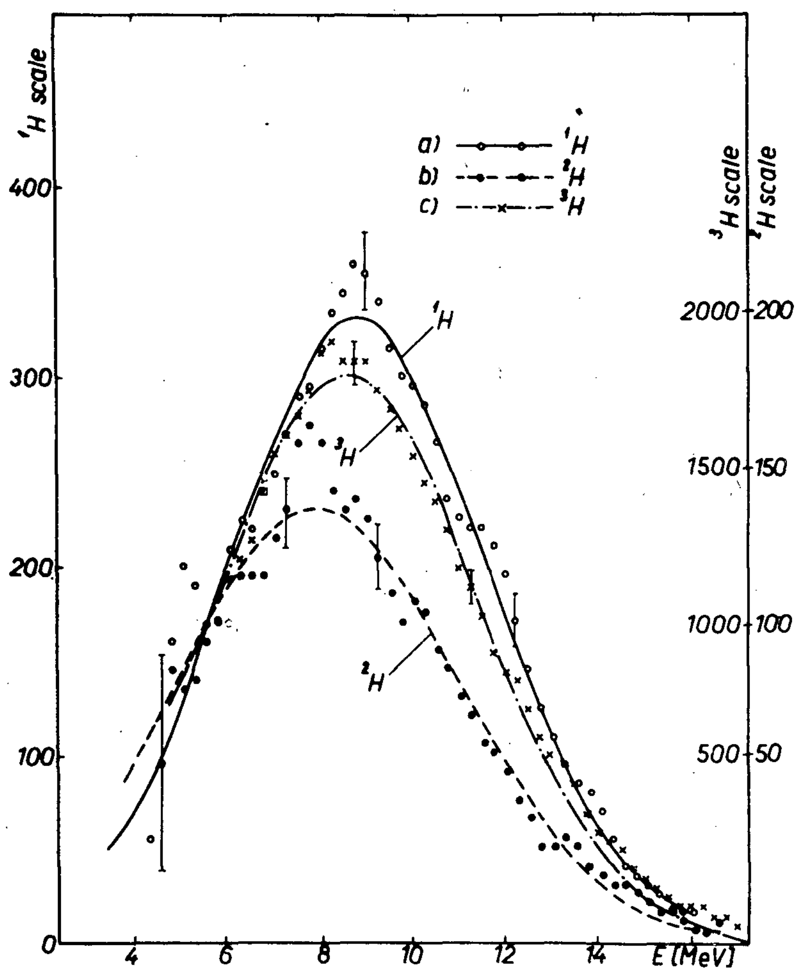


Fig. 1.



¹H scale
³H scale
²H scale
a) ¹H
b) ²H
c) ³H
0
100
200
300
400
500 50
1000 100
1500 150
2000 200
4
6
8
10
12
14
E [MeV]

Fig. 2.

Not for publication

2. THE ENERGY SPECTRA OF THE Li AND Be NUCLEI EMITED FROM THE THERMAL NEUTRON FISSION OF ^{235}U

M. Dakowski, J. Chwaszczewska, T. Krogulski, E. Piasecki, M. Sowiński, A. Stegner, and J. Tys - Institute of Nuclear Research, Świerk.

The energy spectra of the Li and Be nuclei were measured. The results of these measurements are prepared for publication.

The ^{8}He, C and O nuclei were observed and would be investigated exactly in near future. Some from observed oxygen nuclei are knocked-out by fragments from U_3O_8 target.

Emission of correlated two alpha particles /^{8}Be/ from thermal-neutron fission of ^{235}U was observed too /about 30 events/.

Not for publication

3. LOW-ENERGY PART OF THE SPECTRUM OF ALPHA PARTICLES FROM THERMAL NEUTRON FISSION OF ^{235}U

J. Chwaszczewska, M. Dakowski, T. Krogulski, E. Piasecki, M. Sowiński, A. Stegner, and J. Tys - Institute of Nuclear Research, Świerk.

Measurement of the low-energy part of the spectrum of alpha particles emited in the thermal-neutron fission of ^{235}U was performed. The upper limit of the ^{235}U /n, α /^{232}Th reaction cross-section was estimated to be 3 mb for the transitions to the single excited state up to 5 MeV.

The results of these measurements are prepared for publication.

Not for publication

4. EXCITATION CURVE OF THE REACTION $^{181}Ta(n,p)^{181}Hf$

J.S. Brzosko, E. Gierlik, A. Sołtan jr., and Z. Wilhelmi
Institute of Experimental Physics, University of Warsaw.

The cross section of the $^{181}Ta(n,p)^{181}Hf$ reaction was determined using the activation method. The neutrons were obtainedfrom the $^{3}H(d,n)^{4}He$ reaction.

The deuterons were accelerated in the Van de Graaff accelerator. The neutron flux was monitored with the $^{27}Al(n, alpha)^{24}Na$ reaction [1,2] . ^{181}Hf was identified by means of 482 keV γ - rays accompanying its decay. The radiation was measured using a scintillation spectrometer with Na I(Tl) (2" x 2") crystal.

Our results (■) with other data (△) [3] are presented in Fig. 1. The theoretical predictions were based on the statistical model with the level density parameters taken from [4] .

The marked discrepancy between the theoretical curves and our experimental results, as seen in Fig. 2, cannot be improved by fitting the model parameters. It suggests rather small if any, contribution of the compound reaction mechanism in the investigated reaction.

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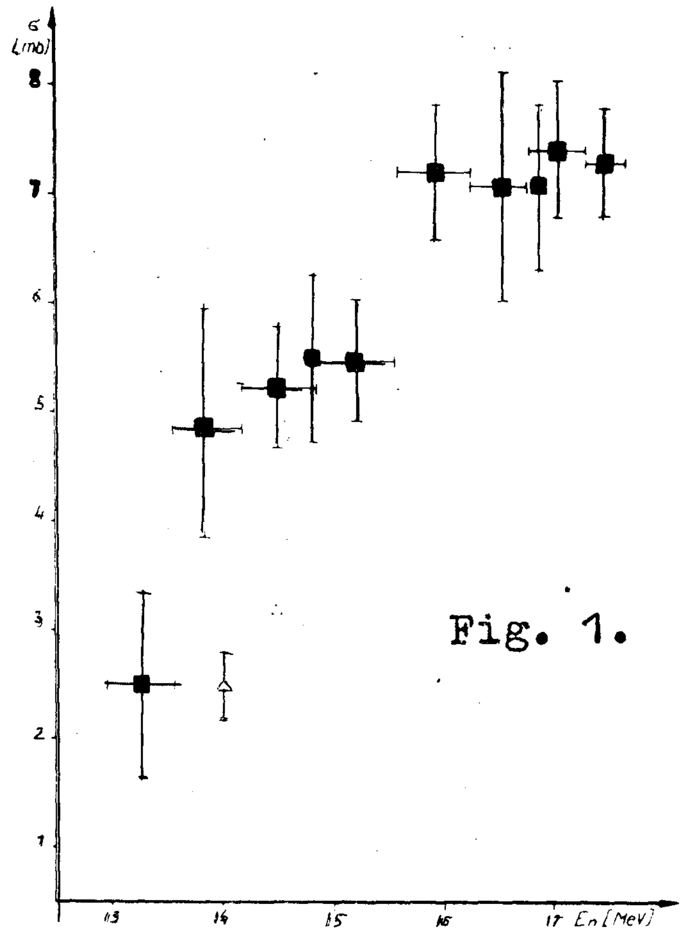


Fig. 1.

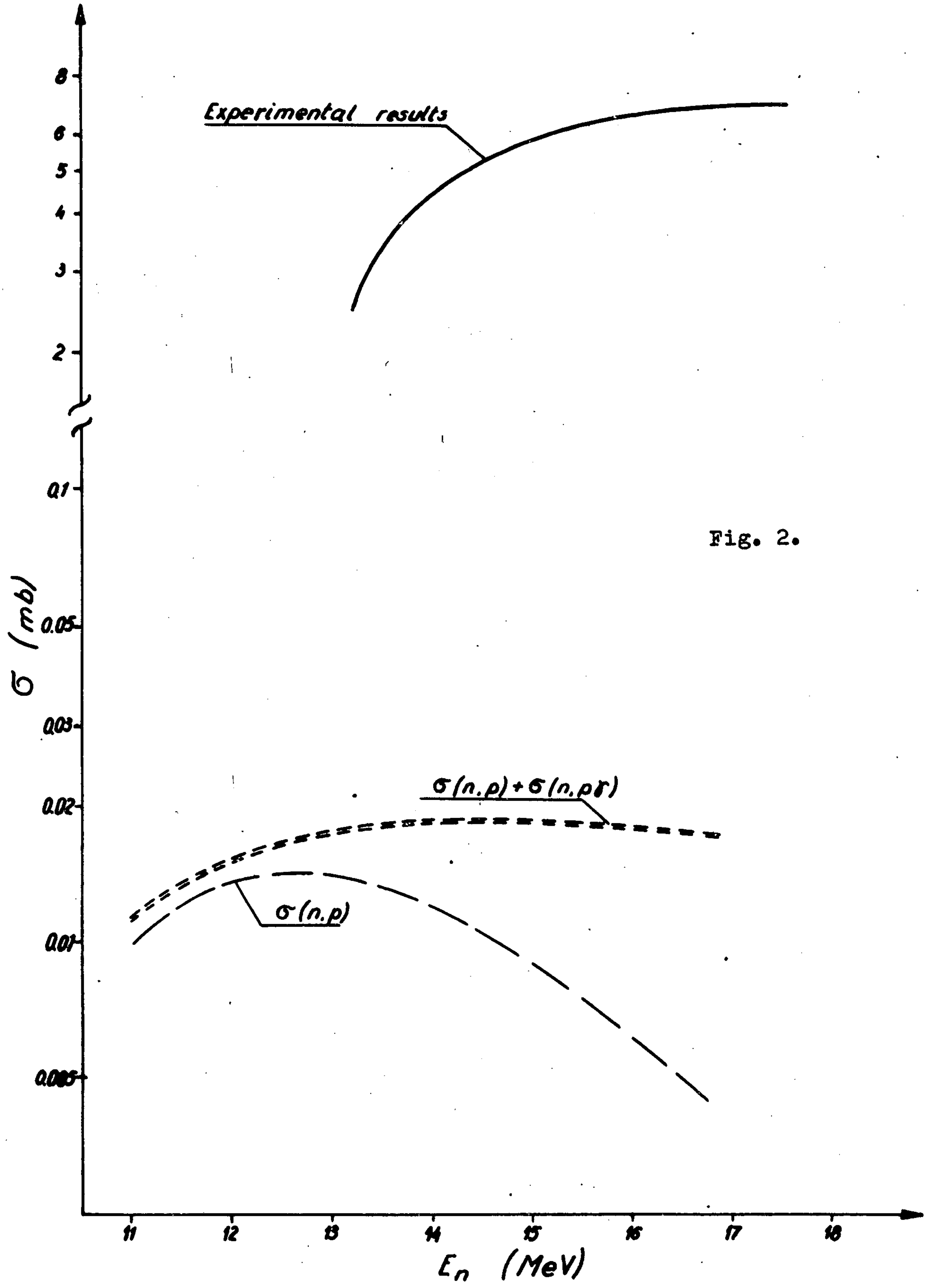

Experimental results
σ(n,p)+σ(n,pγ)
σ(n,p)
σ (mb)
E_n (MeV)
8
6
5
4
3
2
0.1
0.05
0.03
0.02
0.01
0.005
11
12
13
14
15
16
17
18

Fig. 2.

Not for publication

5. (n,d) REACTIONS WITH 14.1 MeV NEUTRONS

M. Dąbrowska, B. Sikora, J. Toke, E. Wesołowski

Institute of Experimental Physics, University of Warsaw.

Our group is investigating the (n,d) pick-up reactions with 14.1 MeV neutrons and medium weight nuclei of the d 3/2 and d 5/2 shell.

Partial results containing the $^{35}Cl(n,d_0)^{34}S$ angular distribution and its comparison with the DWBA theory were reported in the contribution to XX Meeting of Polish Physical Society in Lublin /September 1967/. Further results, on the $^{23}Na(d,n_1)^{22}Ne^*$ reaction were contained in a student's diploma work /K. Dzięciołowski, Faculty of Physics, Warsaw University 1967/. The above mentioned results are in agreement with the measurement performed by the italian group of Milano /M. Fazio et al. Nuovo Cimento 51 B, 459, 1967 and M. Fazio et al. preprint INFN, 1968/.

In the course of measurement are angular distributions of deuterons of the following reactions:

$^{23}Na(n,d_0)^{22}Ne$, $K^{39}(n,d_{0,1})^{38}A$ gnd, 1 st. exc.

$^{41}K(n,d_{0,1})^{40}A$ gnd, 1 st. exc.

The experimental method used is based on a scintillation counter telescope with CsJ Tl crystals and particle identification by two parameter pulse analysis.

Not for publication

6. INVESTIGATIONS OF THE (n,α) REACTIONS WITH 14.2 MeV NEUTRONS

M. Jaskóła, W. Osakiewicz, J. Turkiewicz, Z. Wilhelmi
Institute of Nuclear Research and Institute of Experimental Physics, University of Warsaw.

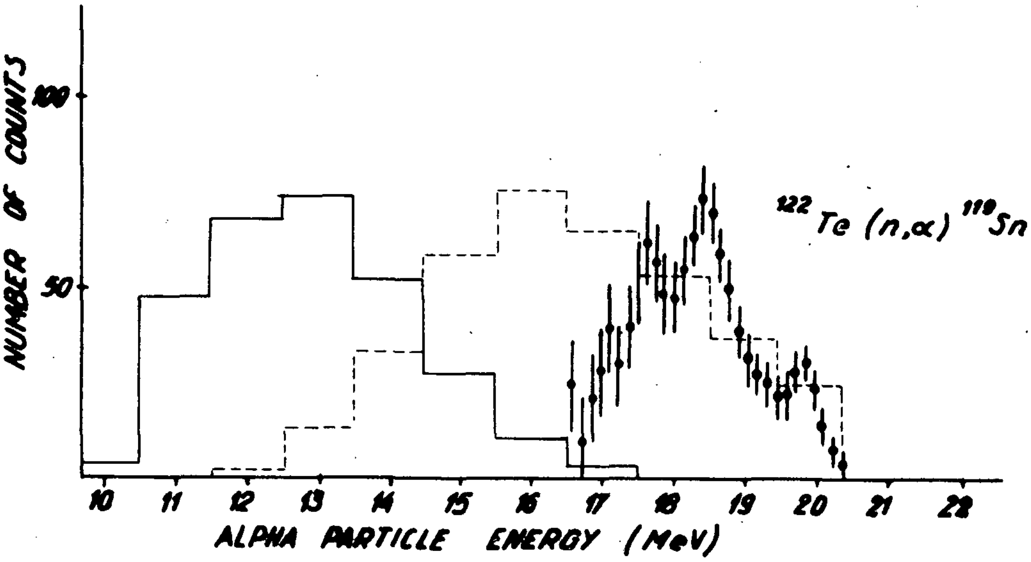
The energy spectra of alpha particles from the $^{122}Te(n,\alpha)\ ^{119}Sn$, $^{159}Tb(n,\alpha)\ ^{156}Eu$ and $^{169}Tm(n,\alpha)\ ^{166}Ho$ reactions at 14.2 MeV have been studied using the semiconductor detector technique. The results of the measurements are shown in Fig. 1. All the spectra were measured for the forward angles $0^{\circ} \pm 60^{\circ}$. The error bars in the figure refer to statistical errors only. The same Fig. 1 shows also theoretical predictions obtained by applying the Weisskopf-Ewing formula. As it can be seen, the evaporation theory is completely inadequate to the description of the investigated reactions. The experimental spectra are shifted forward the higher energies in comparison with the predictions of the compound nucleus theory. The existence of high energy alpha particles in all experimental spectra suggests the presence of strong direct effects in investigated reactions. If direct interaction mechanism with alpha particles emitted mainly in knock-out process dominantes in reaction, it seems reasonable to expect the single neutron levels to be preferentially excited. The comparison of the experimental spectra for $^{159}Tb(n,\alpha)\ ^{156}Eu$ and $^{169}Tm(n,\alpha)\ ^{166}Ho$

reactions with the results of the single neutron level density calculations is shown in Fig. 2. The calculations were based on Nilsson scheme with $\delta = 0.3$ in both cases. As it can be seen, the observed spectra are in good agreement with calculated level density.

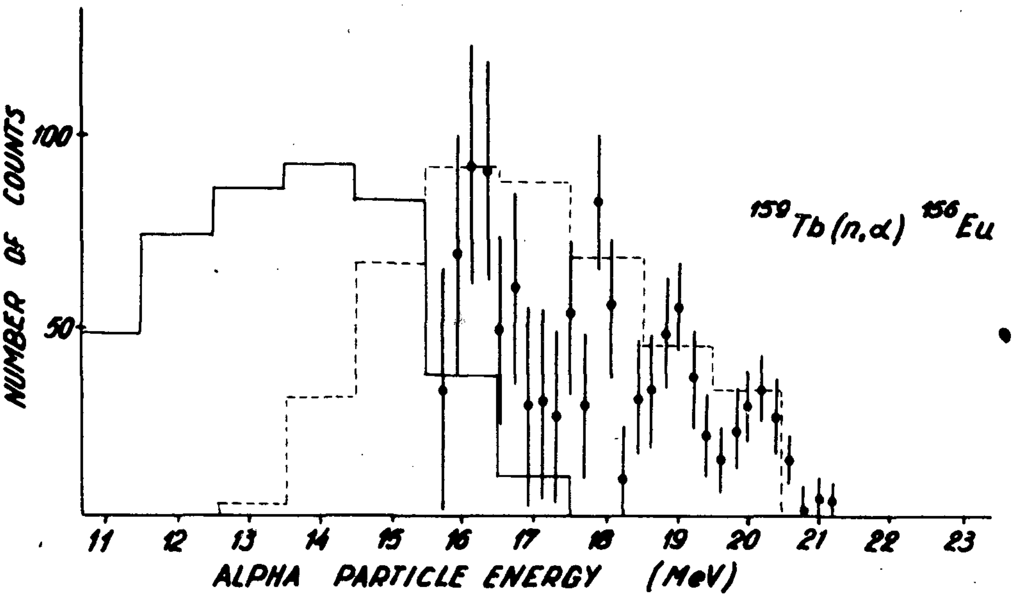
The strong excitation of single neutron levels suggests that in investigated reactions the knock-out process of alpha substructures from nuclear surface plays an important role.

Part of these results were published in the Report INR No 814/I/PL /1967/.

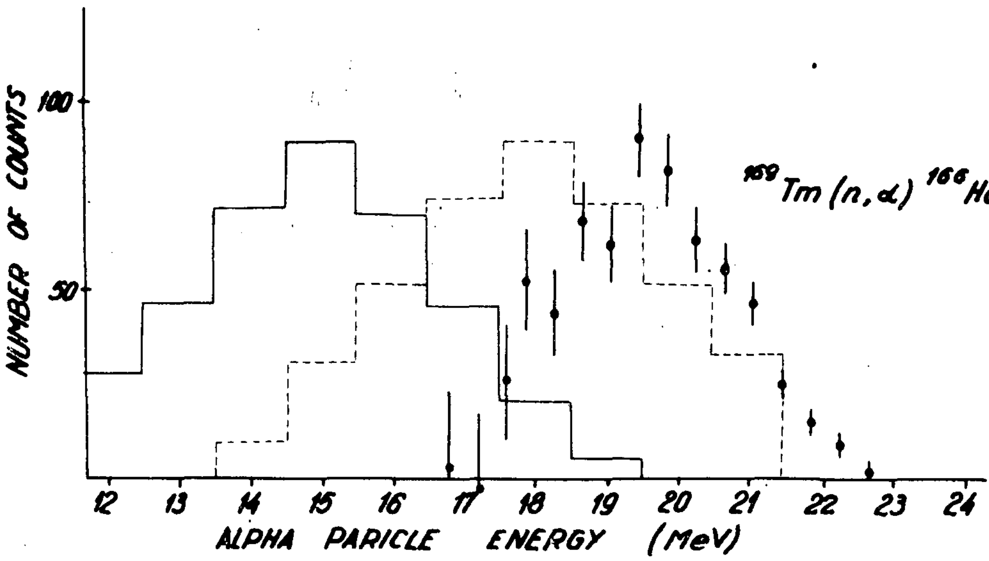
Complete work will be published in Nuclear Physics.



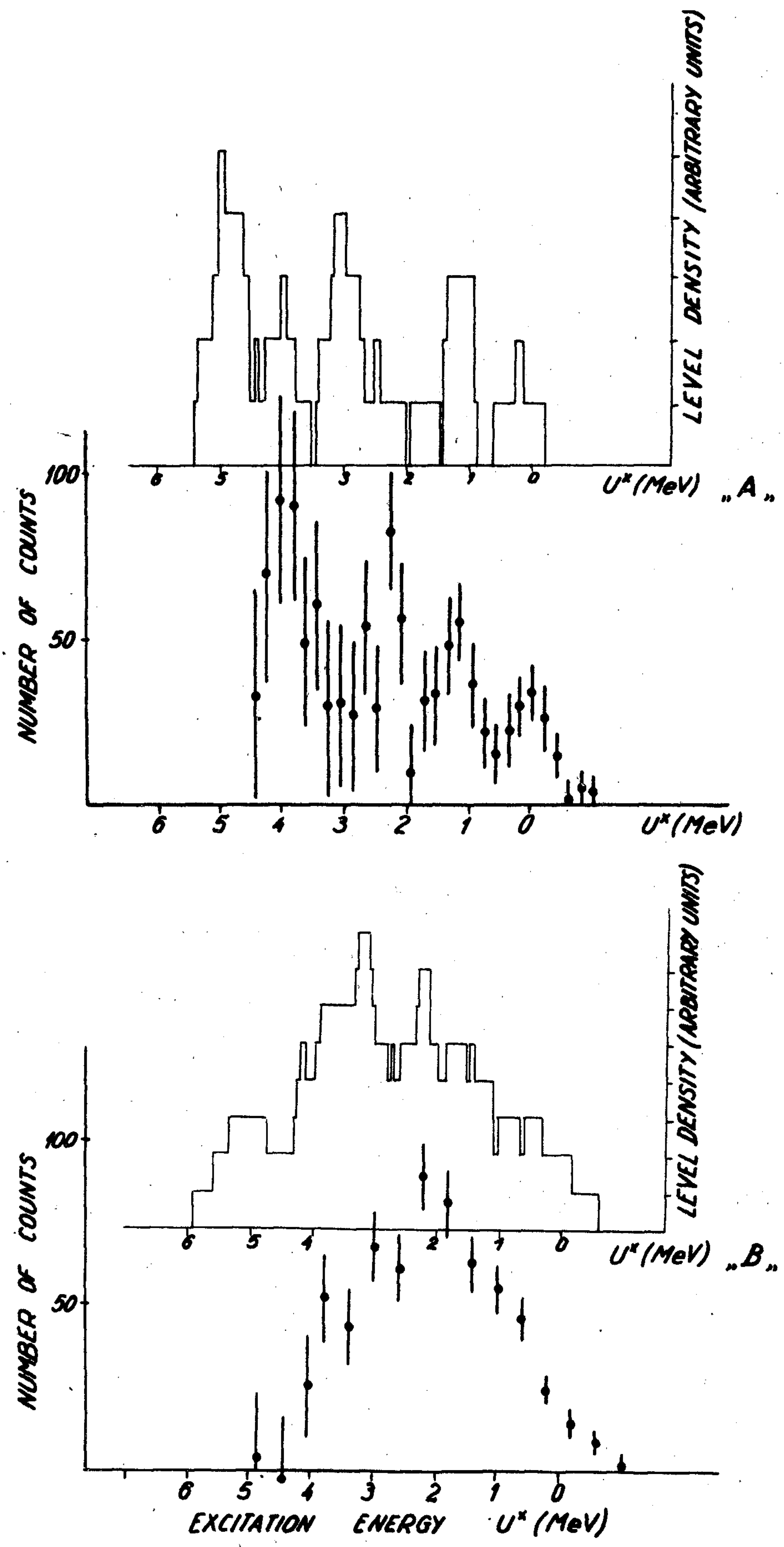
$^{122}Te\ (n,\alpha)\ ^{119}Sn$
NUMBER OF COUNTS
100
50
10 11 12 13 14 15 16 17 18 19 20 21 22
ALPHA PARTICLE ENERGY (MeV)



$^{159}Tb\,(n,\alpha)\ ^{156}Eu$
NUMBER OF COUNTS
100
50
11 12 13 14 15 16 17 18 19 20 21 22 23
ALPHA PARTICLE ENERGY (MeV)



$^{169}Tm\,(n,\alpha)\ ^{166}Ho$
NUMBER OF COUNTS
100
50
12 13 14 15 16 17 18 19 20 21 22 23 24
ALPHA PARICLE ENERGY (MeV)


LEVEL DENSITY (ARBITRARY UNITS)
NUMBER OF COUNTS
100
50
6 5 4 3 2 1 0
U^x (MeV)
„A"
LEVEL DENSITY (ARBITRARY UNITS)
NUMBER OF COUNTS
100
50
6 5 4 3 2 1 0
U^x (MeV)
„B"
EXCITATION ENERGY U^x (MeV)

Not for publication

7. EXCITATION CURVE OF THE REACTION $^{181}Ta(n,2n)^{180m}Ta$.

J. Brzosko, B. Fryszczyn, E. Gierlik, Saganek,
A. Sołtan jr., Z. Wilhelmi, Institute of Experimental Physics, University of Warsaw.

The cross-section of the reaction $^{181}Ta(n,2n)^{180m}Ta$ was determined using the activation method. The neutrons were obtained from the reaction $^{3}H(d,n)^{4}He$. Tritium was absorbed in zirconium of 0.37 mg/cm^2 thickness.

The deuterons were accelerated to 1740 keV energy in the Van de Graaff accelerator. The relative excitation curve was obtained as a result of simultaneous activation of 22 samples placed on a ring with the neutron target in its centre. The angular distribution of the neutron flux was monitored by the $^{27}Al(n,\alpha)$ ^{24}Na reaction, the excitation curve of which is well known [1,2] . The absolute value of the cross-section was measured for the neutron energy 14.2 ± 0.2 MeV relative to the reaction $^{27}Al(n,\alpha)$ ^{24}Na, of which the cross-section was assumed 121 mb.

^{180m}Ta was identified by means of X-radiation accompanying its decay (E_{KX} = 53 keV for ^{180}Hf , and E_{KX} = 57 keV for ^{180}W), and of γ - radiation with two components, $E_{\beta^- max}$ = 605 keV, and $E_{\beta^- max}$ = 705 keV [3] . The X-radiation was measured using a scintillation spectrometer with NaI/Tl /1" x 1 $\frac{3}{4}$"/ crystal. The half-period

$T_{1/2} = (8.13 \pm 0.05)$ h was observed [4, 5] .

In calculating the cross-section, it was assumed 0.56 ± 0.06 KX-ray quanta from ^{180}Hf and ^{180}W for one decay of ^{180m}Ta.

The experimental data and the theoretical predictions are presented in the Figure. The indicated errors do not comprise uncertainties due to assuming the number of X-ray photons for one decay of ^{180m}Ta.

The experimental results were compared with the statistical theory predictions. The Fermi gas level density was taken according to Lang and Le Couter. Calculations of the cross-section for producing only one isomeric state of the final nucleus ^{180m}Ta were performed basing on the Vandenbosch and Huizenga theory and on its modifications. Numerical calculations were carried out on the GIER computer by the method described in [6,7] . The level density parameter "a" was taken after [10] as 22.5 MeV^{-1}.

In the calculations the competitive (n,p) ,(n,np) and (n,3n) reactions were taken into account.

The calculations were performed for several values (0.1 - 1.0) of the ratio $f/f_{r.b.}$; here f is the moment of inertia of the nucleus, and $f_{r.b.}$ the moment of inertia of the nucleus considered as a rigid body. Some of the calculation result for $f/f_{r.b.} = 0.1$ and 0.25 are shown in the Figure.

The marked discrepancy, as seen in Figure between the theoretical curves and our experimental results can not be improved by fitting the "a" and $f/f_{r.b.}$

The much better agreement is obtained when the competitive $(n,n'\gamma)$ reaction is taken into account /solid line/.

These results were published in the Report INR No 795/I/PL /1967/.

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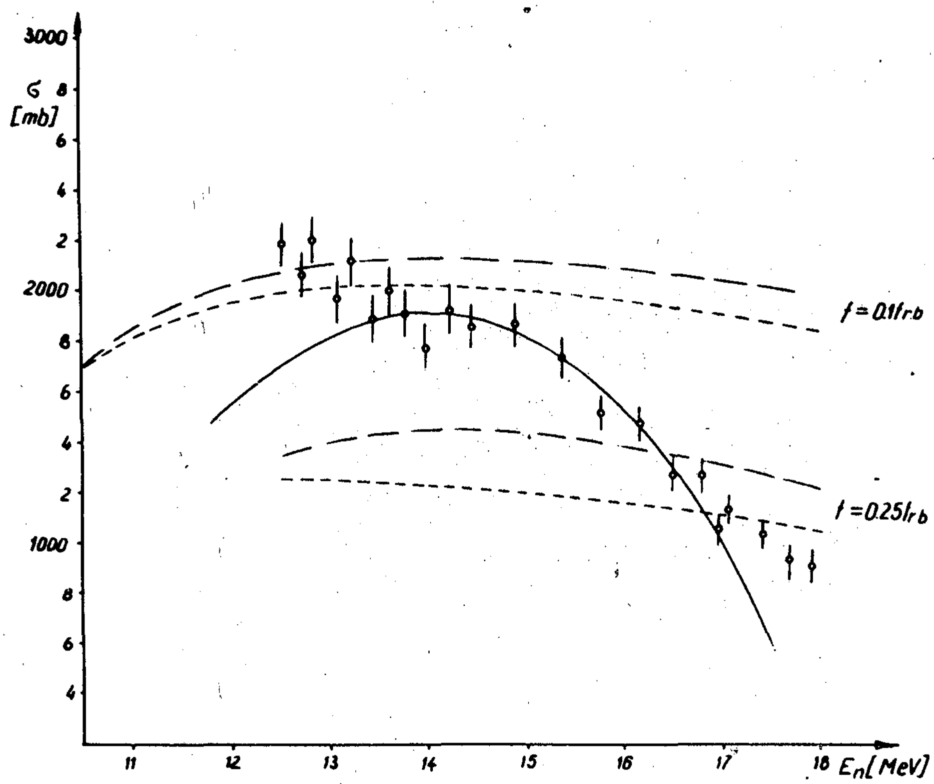

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8. EXCITATION CURVES AND ISOMERIC RATIOS FOR THE (n,2n) REACTIONS IN THE VICINITY OF THE CLOSED SHELLS.

P. Decowski, A. Marcinkowski, K. Siwek, Z. Wilhelmi, A. Abboud [x], Institute of Experimental Physics, University of Warsaw and Institute of Nuclear Research.

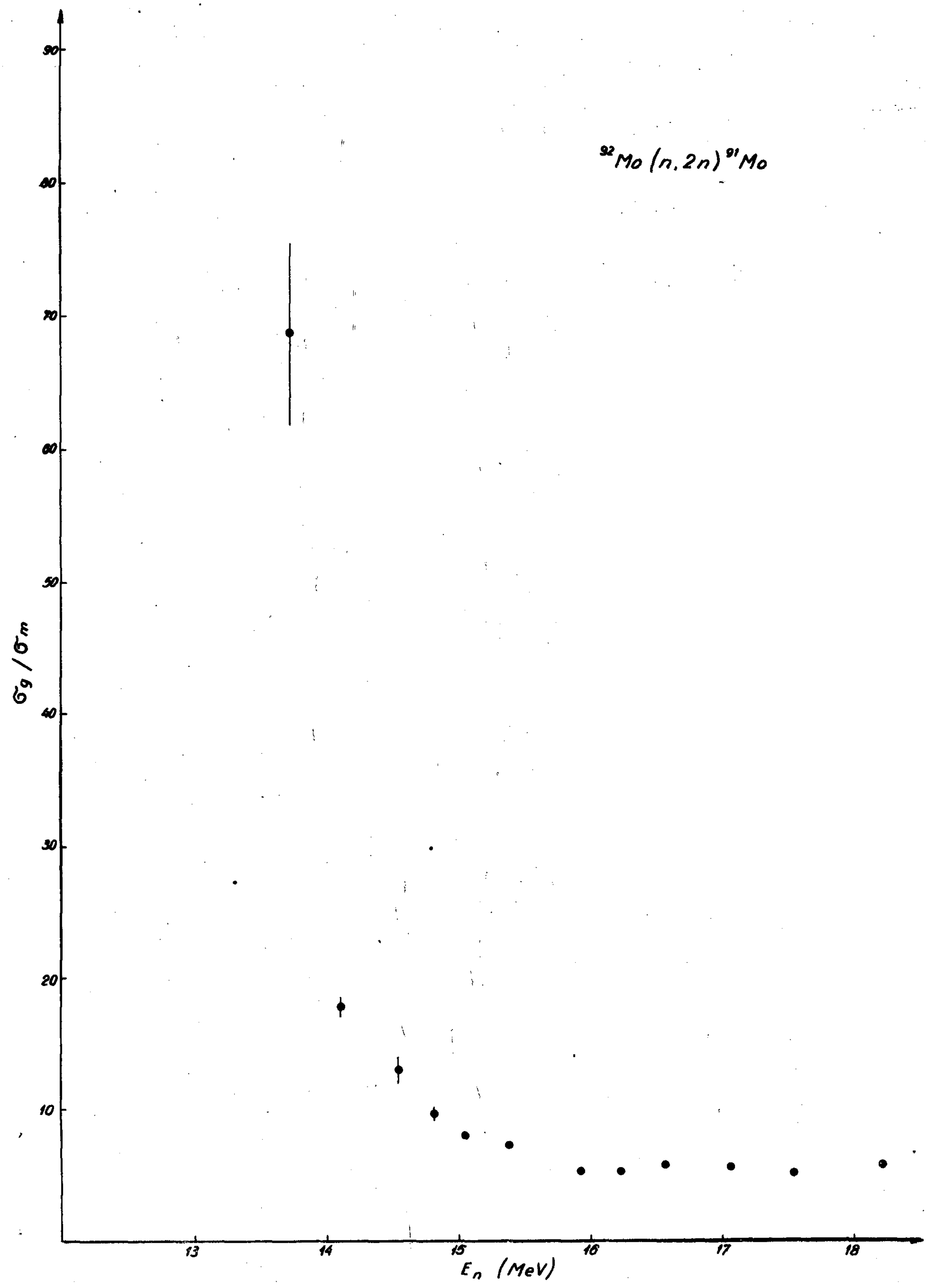
The excitation curves and the isomeric ratios for the ^{92}Mo(n, 2n)^{91g,m}Mo, ^{74}Se(n,2n)^{73g,m}Se and ^{90}Zr(n,2n)^{89g,m}Zr reactions have been measured in the neutron energy range 13.6 - 18.2 MeV. The experimental results for the isomeric ratios are presented in Figs. 1 - 3 and for the total cross sections in Figs. 4 - 6 /in the case of the ^{90}Zr(n, 2n)^{89}Zr reaction we present preliminary results/.

The theoretical calculations based on the developed superconductor level density [1] are in progress. The calculations account for the rapid change in Fermi-gas level density as well as the damping of the superconductivity effects in the vicinity of the closed shells.

References

1. P. Decowski et al. Nucl. Phys. 110 /1968/.

[x] On leave from Atomic Energy Establishment, U.A.R.



$^{92}Mo(n,2n)^{91}Mo$
σ_g/σ_m
90
80
70
60
50
40
30
20
10
13
14
15
16
17
18
E_n (MeV)

Fig. 1.

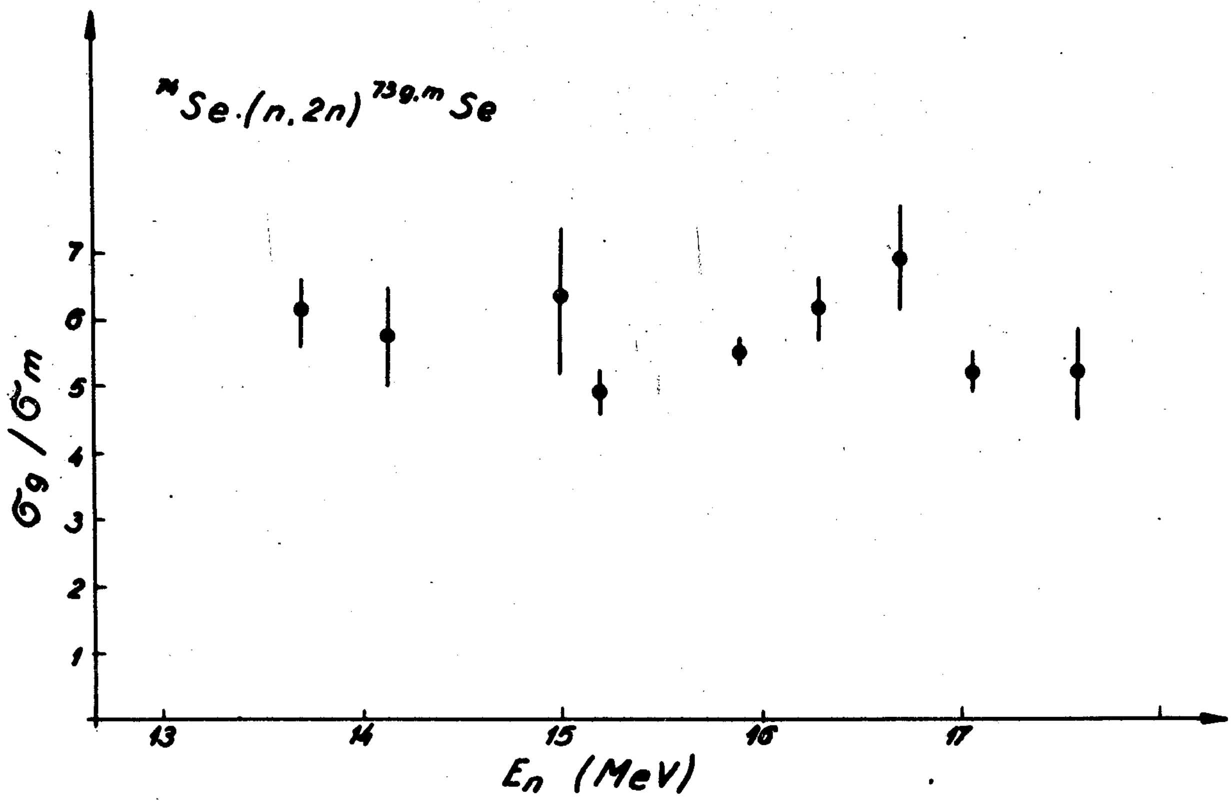


Fig.2.

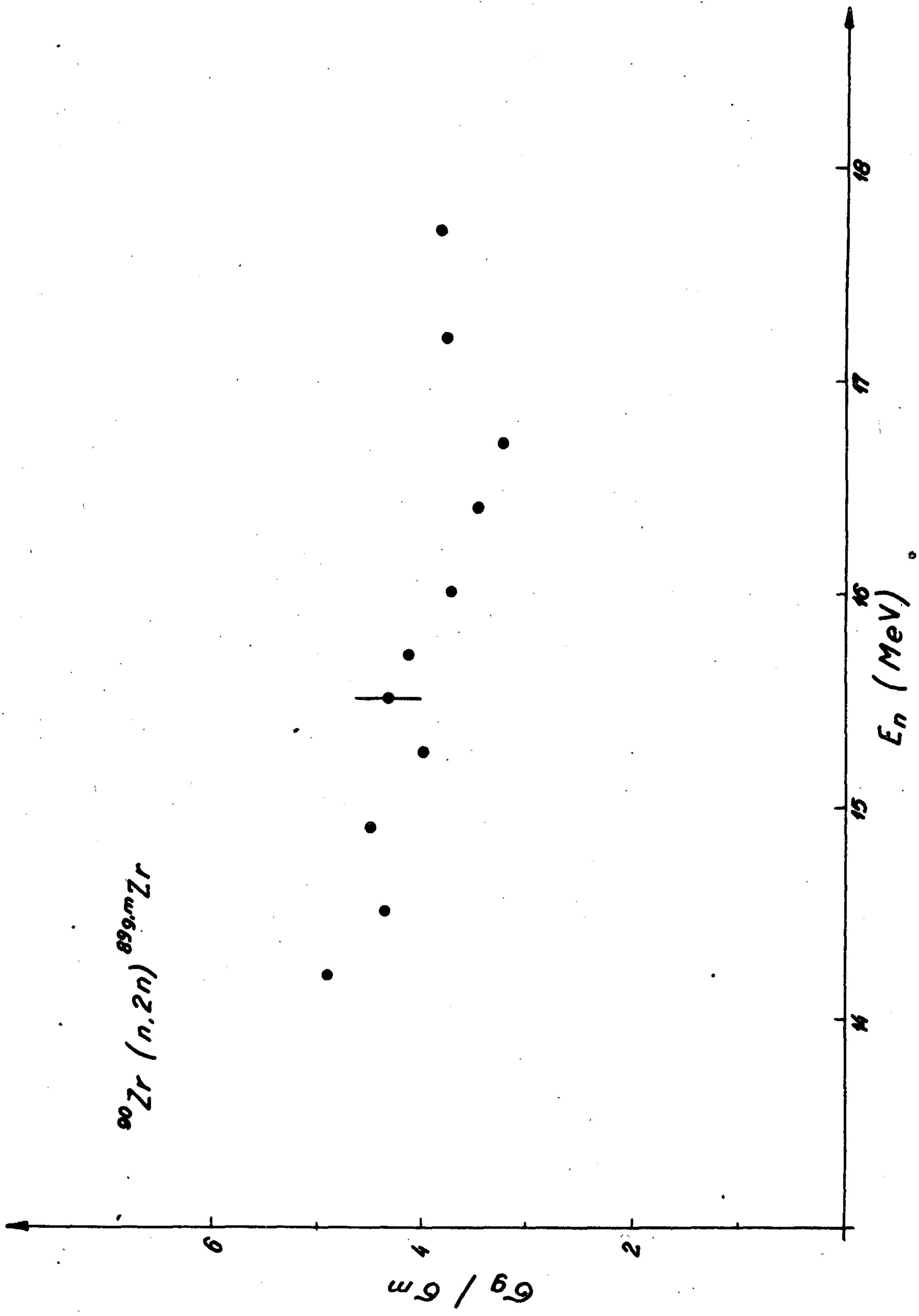


Fig.3.

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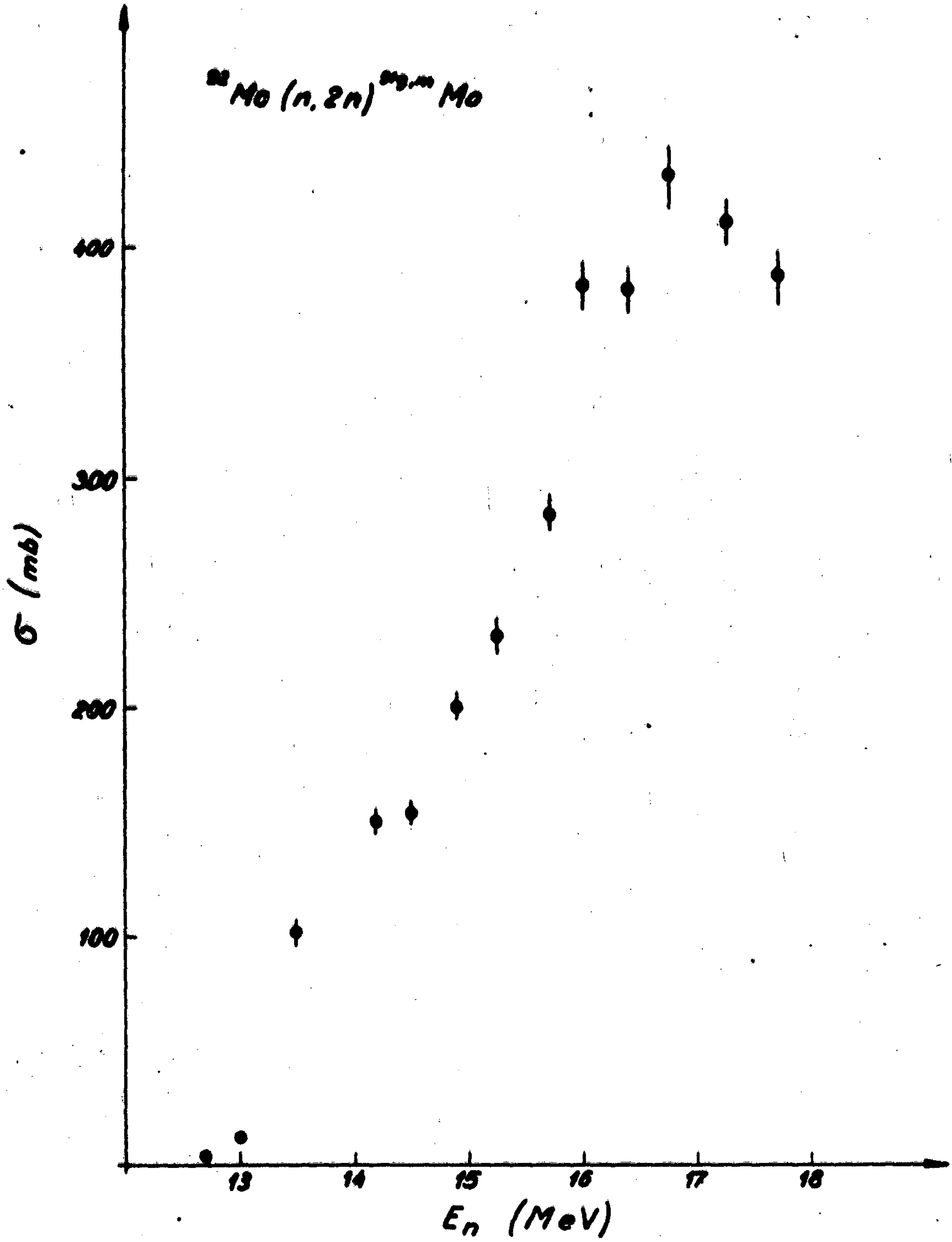

Fig.4.

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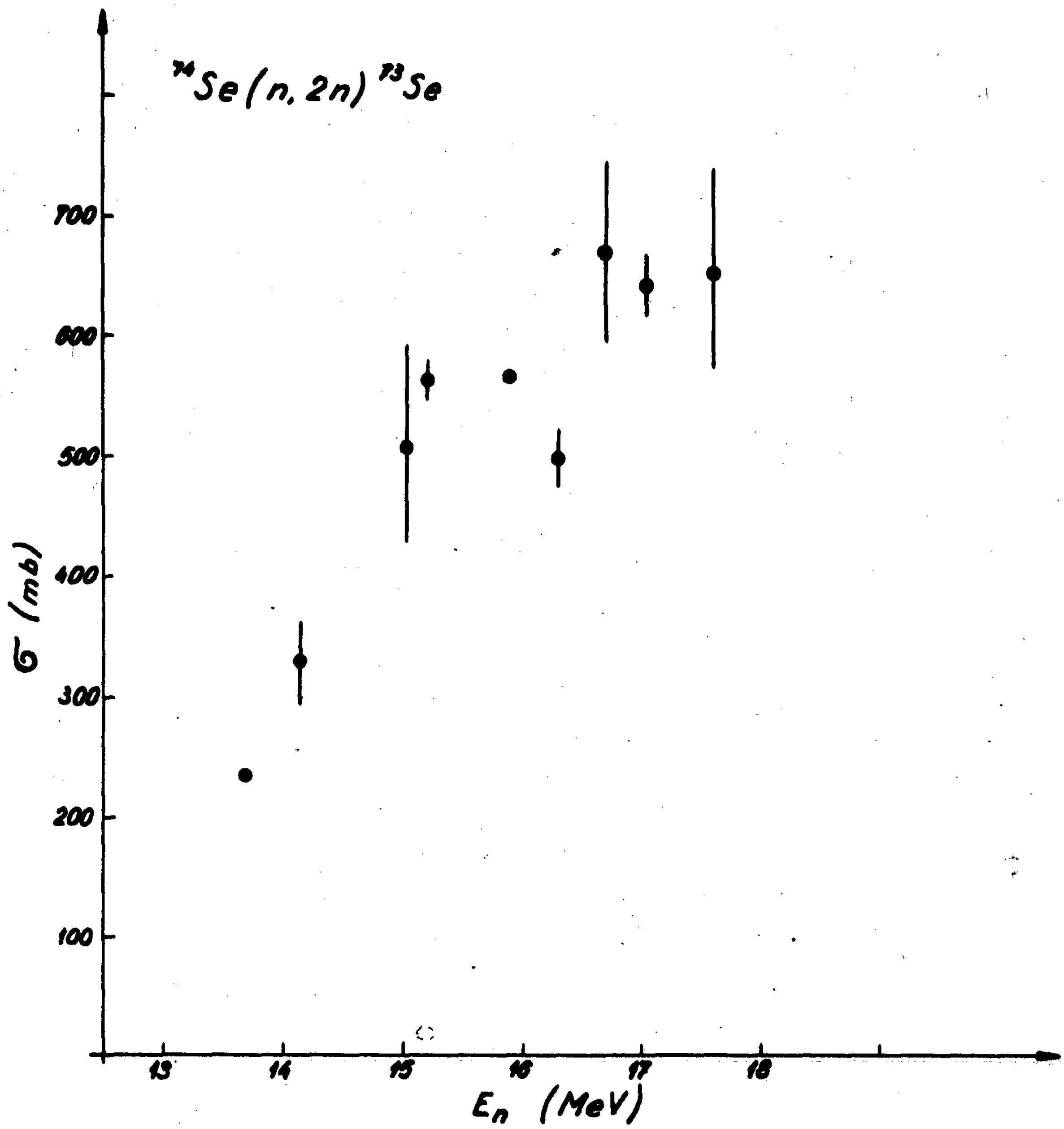

Fig.5.

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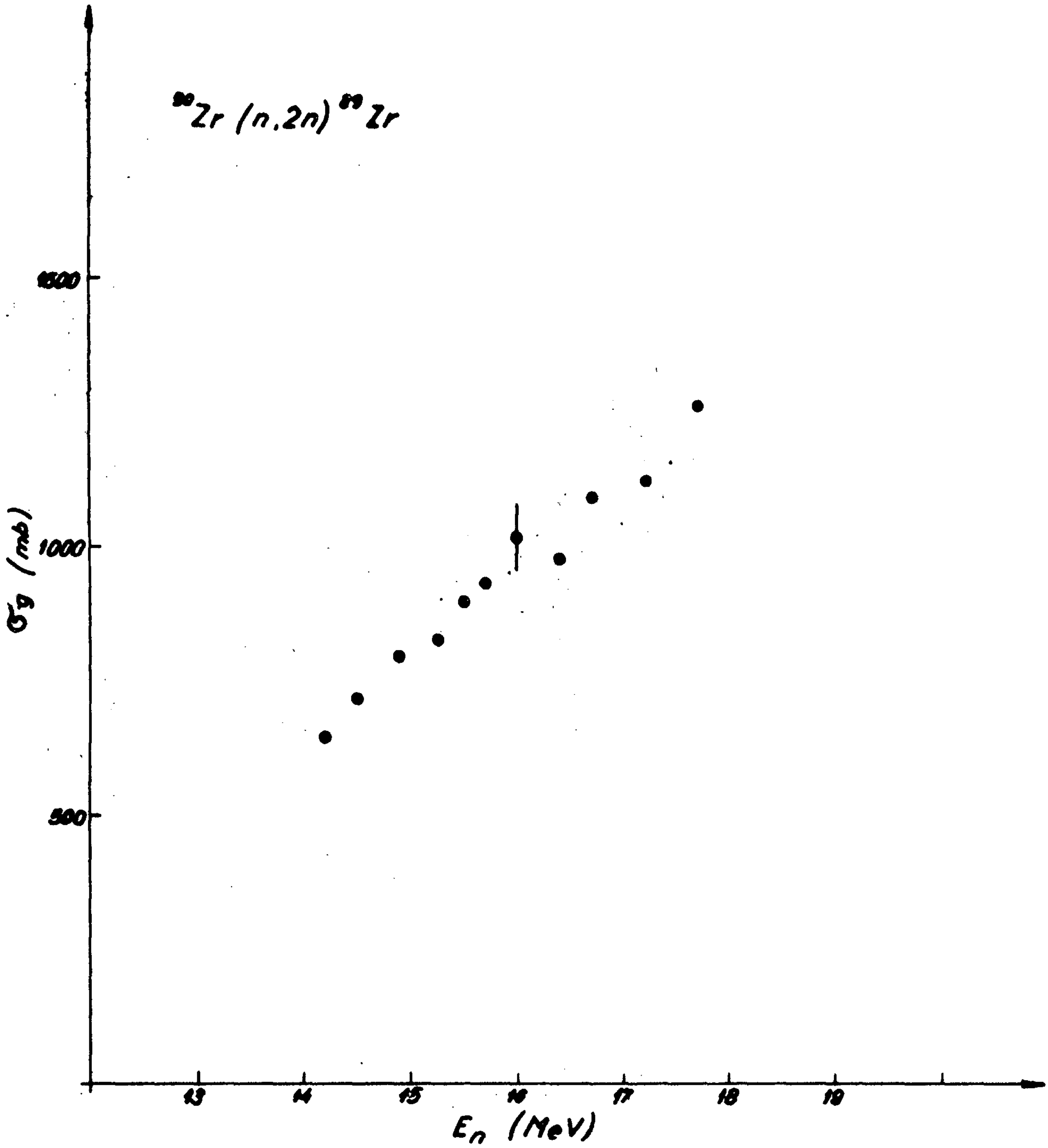

Fig.6.

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9. ISOMERIC RATIOS AND TOTAL CROSS SECTIONS FOR THE $^{59}Co(n,2n)^{58g,m}Co$ $^{58}Ni(n,p)^{58g,m}Co$ and $^{59}Co(\gamma,n)^{58g,m}Co$ REACTIONS

P. Decowski, W. Grochulski, A. Marcinkowski, K. Siwek, I. Śledzińska, Z. Wilhelmi, Institute of Experimental Physics University of Warsaw and Institute of Nuclear Research, Warsaw, Poland.

The following reactions have been studied: $^{59}Co(n,2n)^{58g,m}Co$, $^{58}Ni(n,p)^{58g,m}Co$ and $^{59}Co(\gamma,n)^{58g,m}Co$. The isomeric ratios and total cross sections were measured and compared with the predictions of the statistical model based on the developed superconductor level density [1] .

The activation method with the use of fast-slow coincidence spectrometer was applied. Comparison of the experimental results with the theoretical ones points distinctly to the superiority of the superconductor level density. Fig. 1 shows the isomeric ratios for the reaction $^{59}Co(n,2n)^{58g,m}Co$ / ɸ - our results, ɸ ɸ - results of [2,3] /. The solid lines show the predictions of the superconductivity model for various intervals of gamma cascade interruption [5] described by pairs of numbers /in MeV/. The dashed lines show the predictions of the Fermi gas model with $a = 7.78$ MeV^{-1}. Fig. 2 presents the measured isomeric ratios for the reaction $^{58}Ni(n,p)^{58g,m}Co$ / ɸ - our results, ·

- results of [3,4] /. The lines a/ and b/ refer to calculations in which the individual levels of the final nucleus ^{58}Co have been taken into account. Three and four lowest energy levels were considered respectively. The measured σ/σ value for the $^{59}Co(\gamma,n)^{58g,m}Co$ reaction is 1.21 ± 0.05 while the theoretical one is 1.09 for the 0.5 - 1,5 gamma cascade cutoff interval.

The divergency between the experimental and theoretical cross sections for the reactions $^{59}Co(n,2n)^{58}Co$ and $^{58}Ni(n,p)^{58}Co$ may be ascribed to that the gamma emission competitive to the neutron emission in the excitation energy range, directly above the (n,2n) and (n,pn) reaction thresholds, has been neglected. A rough method of providing for this process, consisting in effectively increasing the neutron binding energy by ΔS_n, has been applied. Fig. 3 and 4 present the excitation curves for $^{58}Ni(n,p)^{58}Co$ and $^{59}Co(n,2n)^{58}Co$, as well as the results of calculations based on the superconductor /solid lines/, and on the Fermi gas /dashed lines/ level densities. The curves S + 1, S + 2, S + 3 are the results of calculations for $S_n = 1,2,3$ MeV respectively, a/ and b/ meaning as above. These measurements were contributed to the International Conference on Nuclear Structure, Tokyo September 1967 and will be published in Nuclear Physics.

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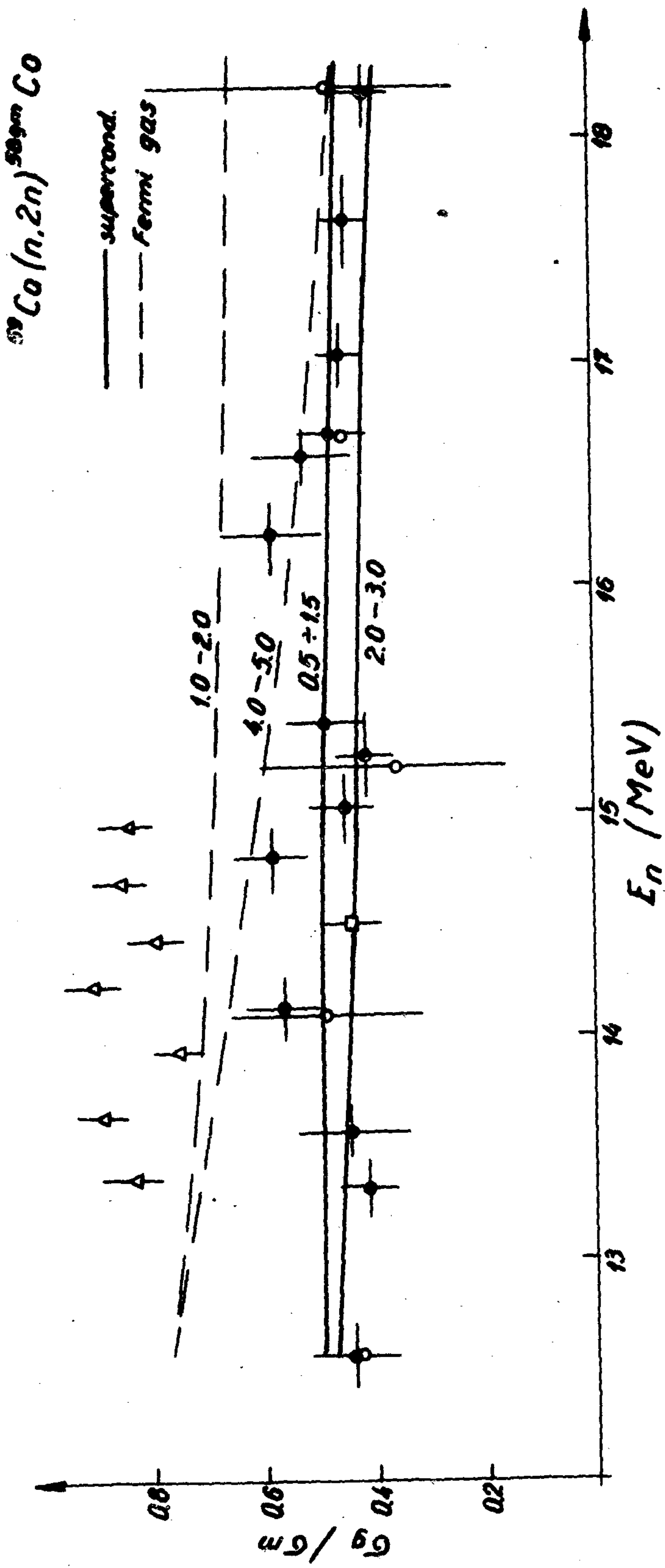

Fig. 1.

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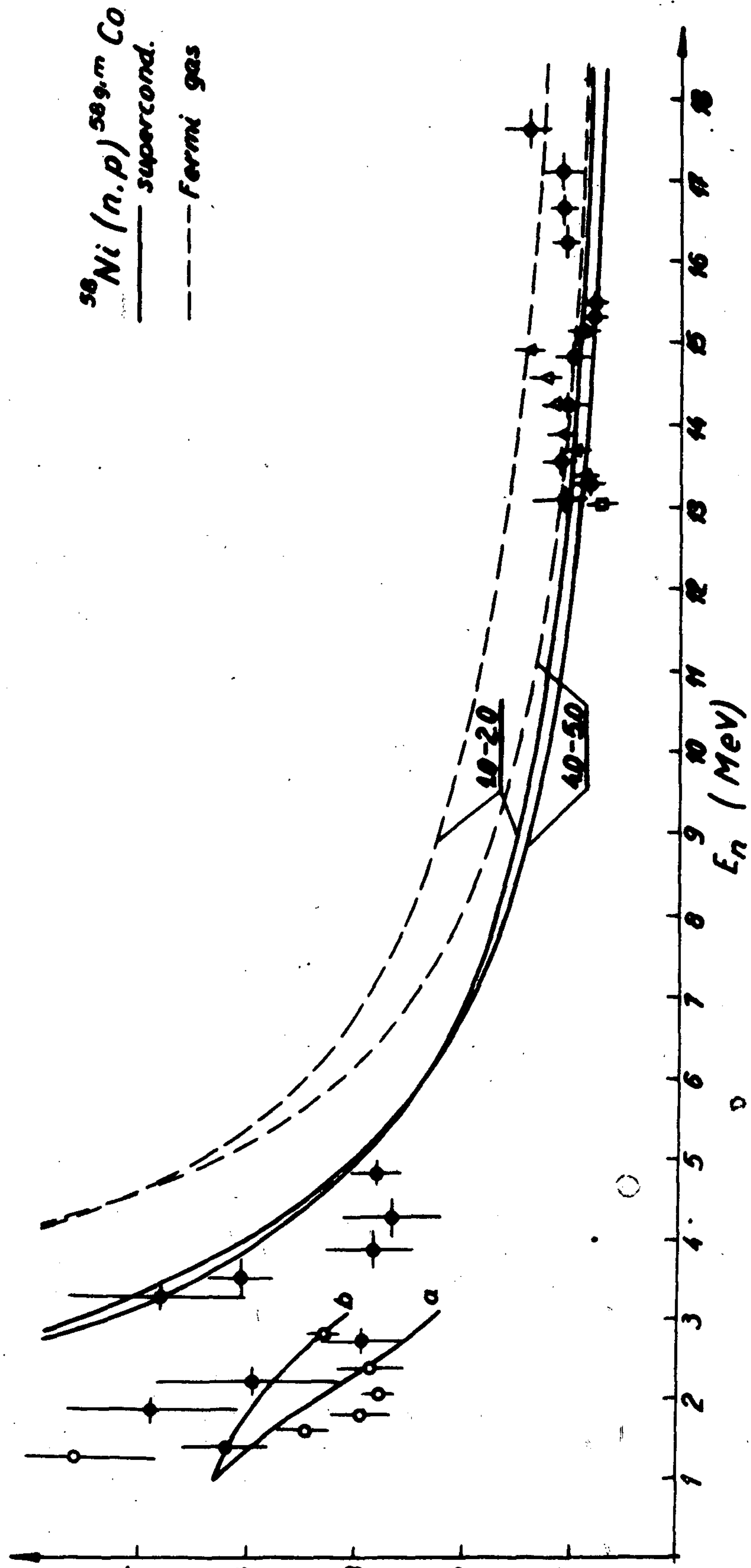

Fig. 2.

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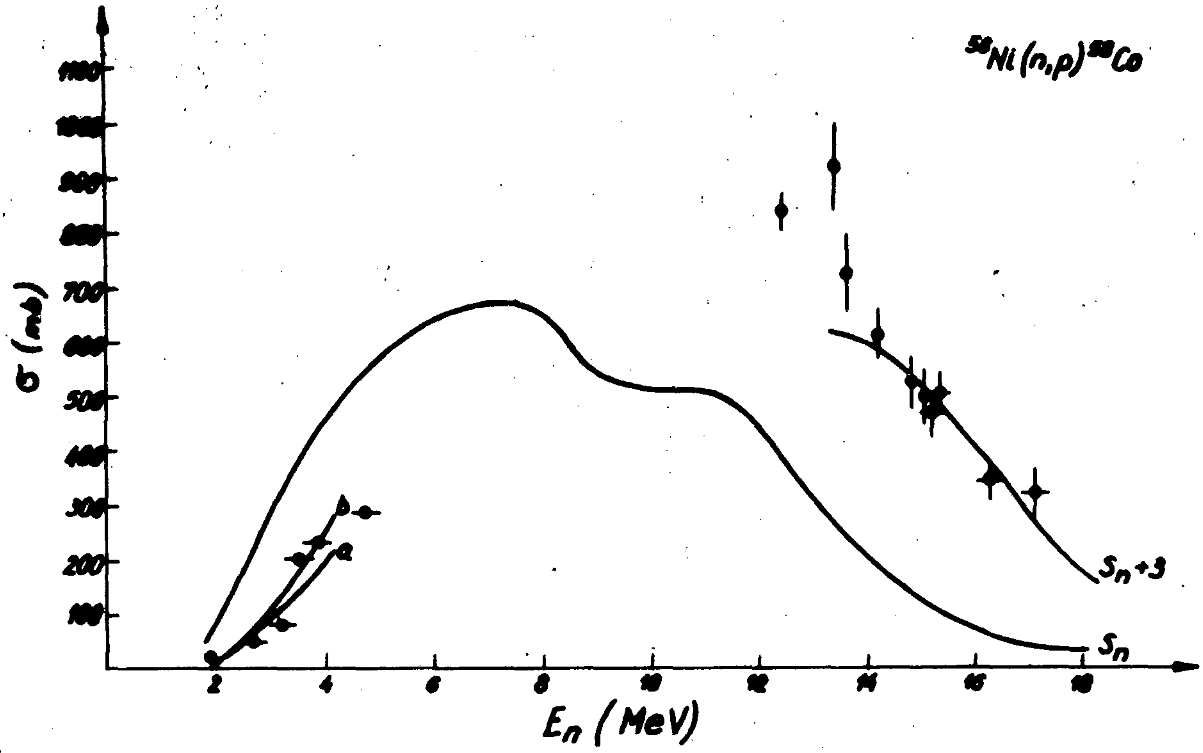

Fig. 3.

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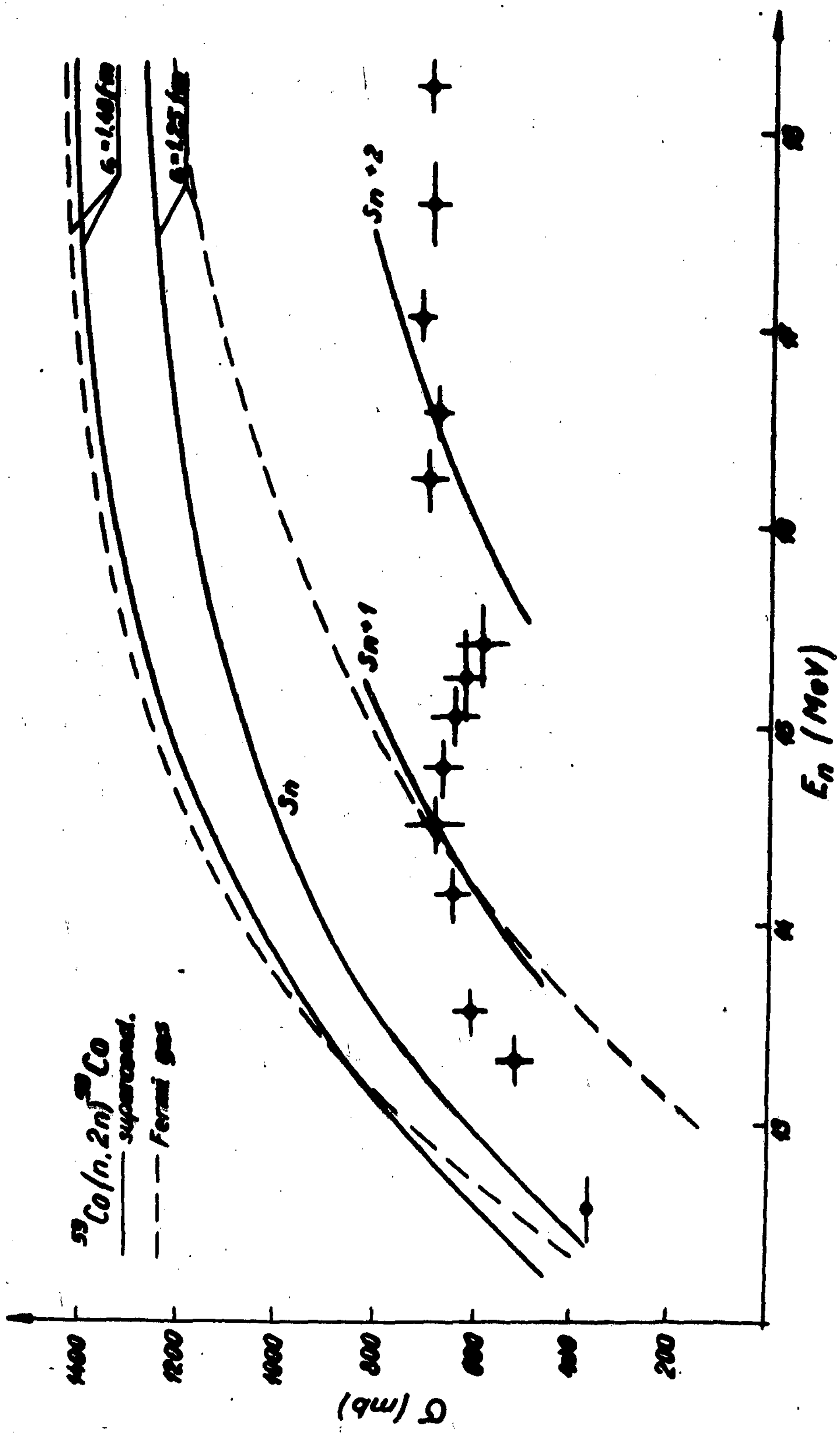

Fig. 4.

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10. ON THE EFFECTS OF SUPERCONDUCTIVITY IN NUCLEAR LEVEL DENSITY

P. Decowski, W. Grochulski, A. Marcinkowski, K. Siwek, Z. Wilhelmi, Institute of Experimental Physics, University of Warsaw and Institute of Nuclear Research, Warsaw, Poland.

Formulae, based on the superconductivity model, which do not include free parameters have been derived and the nuclear level densities calculated. The saddle point method, which gives the known expression for the level density [1], has been applied

$$\varrho = \frac{\exp S}{(2\pi)^{3/2}\sqrt{\det\left|\left(\frac{\partial^2 S}{\partial\mu_i\partial\mu_j}\right)\mu_o\right.}}$$

The entropy S, the energy E of the nucleon system, the numbers of neutrons N_n and protons N_p as well as the grand partition functions Z_n and Z_p for both kinds of nucleons are related by the equation: $S = \ln Z_n + \ln Z_p - \mu_1 E - \mu_2 N_n - \mu_3 N_p - \mu_1 E - \mu_2 N_n - \mu_3 N_p$. The lagrangian multipliers μ_1^o, μ_2^o and μ_3^o determining the saddle point are found from the system of $\left.\frac{\partial S}{\partial \mu_i}\right|_{\mu_i} = 0$ where $i = 1, 2, 3$. According to Sano and Yamasaki [2]: $\ln Z \approx -\frac{1}{t}\sum_k(\varepsilon_k - \lambda - E_k) + 2\sum_k \ln[1-\exp(-E_k/t)] - \frac{\Delta^2}{G}$

where ε_k's are the energies of two-particle levels of nucleons of the given kind, λ is the Fermi level,

$E_k=\sqrt{(\varepsilon_k-\lambda)^2+\Delta^2}$, Δ the energy gap, G the pairing interaction constant, and t the thermodynamic temperature $(t=1/\mu_1^0)$. The function Z in the form given served as a basis for the calculation, by means of a computer, of all the functions necessary for determining ρ . The spin cutoff parameter in spin dependent level density formula [1] : $\rho(E,J)=\frac{(2J+1)\rho(E)}{2(2\pi)^{1/2}\sigma^3}\exp\left(\frac{-J(J+1)}{2\sigma^2}\right)$ was found from the equation: $\sigma^2=\frac{1}{2}\sum_k\frac{m_k^2}{\cosh^2\frac{1}{2}(E_k/t)}$ where m_k is the magnetic spin number of two-particle levels. The differences in level densities between even, odd-A and odd nuclei have been provided for by assuming that the level density of a nucleus with an odd number of nucleons of the given kind is the same as that of a nucleus with an even number of nucleons but with the excitation energy shifted by $E_k=\sqrt{(\varepsilon_{k'}-\lambda)^2+\Delta_0^2}$ where k' is the first unoccupied level. Two-particle levels ε_k taken from Nilsson diagrams were used in the calculations. The G constant for protons and neutrons was determined by comparing the differences of calculated condensation energies of nuclei with even and odd numbers of nucleons with the differences of their masses taken from the tables.

In Fig. 1 the variation of the excitation energy U , spin cutoff parameter σ^2 , Δ_n , Δ_p , and

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$M=\sqrt{\det\left|\left(\frac{\partial^2 S}{\partial\mu_i\partial\mu_j}\right)\right|}$ with the temperature t for the ^{58}Fe nucleus is given. The function M shows discontinuities at temperatures $t_c^{p,n}$ at which the superconductivity effects for nucleons of the given kind disappear. Figs. 2, 3 present a comparison of the values of ϱ and of the nuclear temperature $T = \left(\frac{d \ln \varrho}{dU}\right)^{-1}$ calculated with those found experimentally by Tsukada et al. [3] . The dashed line in Fig. 3 gives the temperatures calculated from the shifted Fermi gas model for $a = 7.78$ MeV^{-1}/Co/ and $a = 14.7$ MeV^{-1}/In/. The agreement with experiment is better in the case of superconductivity density. The model of calculation of level densities presented was used when comparing experimental data referring to isomeric ratios for reaction of /n,2n/, /n,p/ and / γ ,n/ type with the theoretical predictions [4] . Here the agreement was also better than when use was made of the Fermi gas model.

These calculations were contributed to the International Conference on Nuclear Structure, Tokyo September 1967 and will be published in Nuclear Physics.

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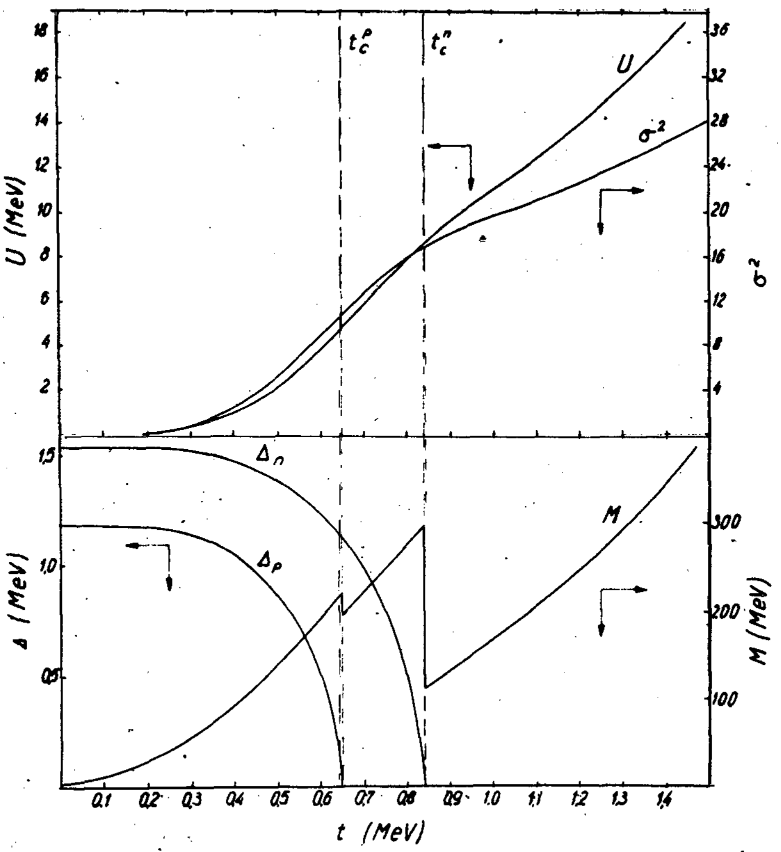
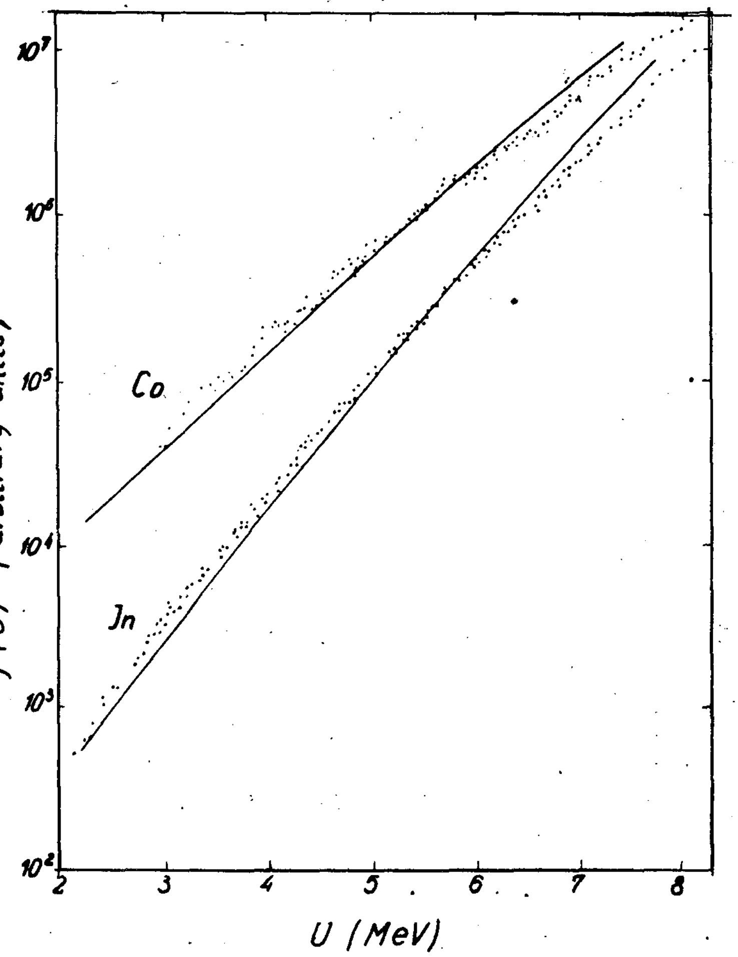


U (MeV)
σ²
U
t_c^p
t_c^n
Δ (MeV)
M (MeV)
$Δ_n$
$Δ_p$
M
t (MeV)

Fig. 1.



ρ(U) (arbitrary units)
Co
Jn
U (MeV)

Fig. 2.

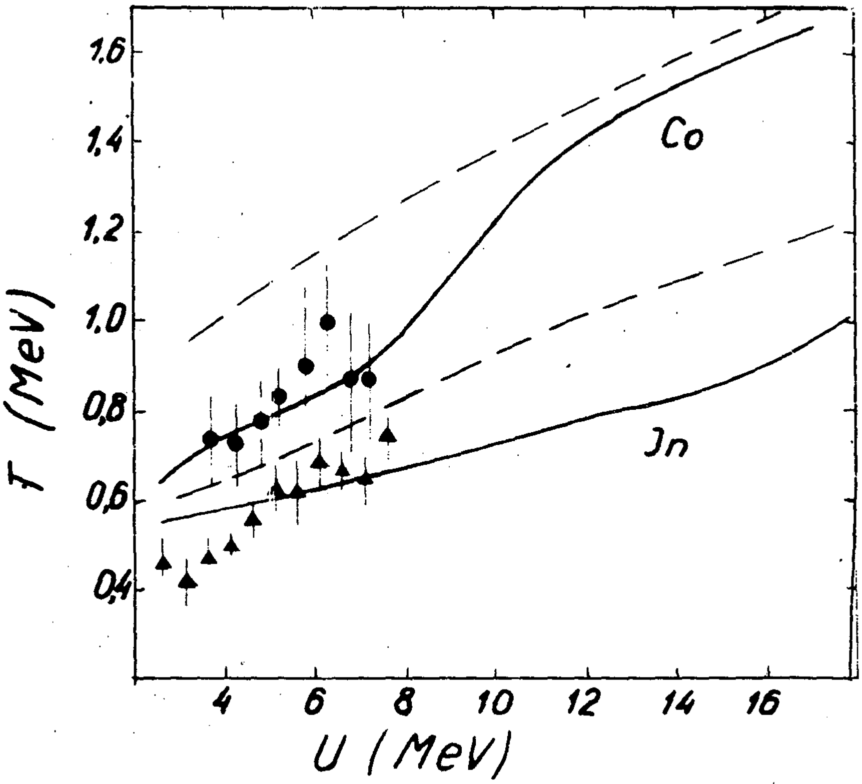


Fig. 3.

Not for publication

11. FAST NEUTRON EXCITATION OF ISOMERIC ACTIVITIES IN ^{112}In AND ^{114}In ISOTOPES

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Institute of Nuclear Research, Świerk

All measurements have been performed using fast neutrons from d + T reaction with the average neutron energy equal to 14.7 MeV.

In general, the activation method has been used in the measurements of the cross-section, applying the NaI/Tl/ crystals for γ -ray detection and GM counters for the beta counting. Because we are dealing with millisecond lifetimes as well as much longer decays of some isomeric states, different methods have been used in both cases.

MEASUREMENTS OF 40 msec ACTIVITY IN INDIUM

The millisecond activities were produced by activation of stable indium isotopes with the pulsed neutron generator and were investigated during the time between pulses. The beam pulser was designed[1] for pulsing the deuteron beam of the neutron generator.

In Fig. 1 a general scheme of the experimental set-up for the measurements of decay curves and γ -ray spectra is presented.

The samples of natural indium and 88 % enriched ^{113}In were used in the experiment. In Fig. 2 typical energy spectrum of γ -rays for natural indium sample is presented.

Fig. 3 shows the decay curve for 311 keV γ peak obtained after substraction of the background.

Nonexistence of 43 msec activity when enriched ^{113}In sample has been used, enables to ascribe this activity to ^{114}In isotope.

MEASUREMENTS OF LONGER ACTIVITIES

The ordinary activation methods have been used when measurements of the other activites of In isotopes were performed. In the case of a ground state decay of ^{114}In, the G.M. counter has been used for β counting. The decay curve is shown in Fig. 4.

The cross section for ^{115}In(n,2n)^{114g}In reaction was calculated after proper correction of counting rate for finite thickness of the sample [2] .

The 158 keV line of the ^{112m}In activity /see Fig. 5/ was investigated using a scintillation counter for γ detection. Typical γ -ray spectrum is shown in Fig. 6. As a result, the half life and isomeric cross section value has been obtained.

The decay of the ^{112}In ground state was measured using the annihilation line and 621 keV line of ^{112}Cd as well as β electrons. Because of the decay of ^{112m}In isomeric level, the decay curve shows a superposition of two lifetimes. The value of half life of the ground state was taken from [3] as equal to 14.4 min. The decay curve was fitted using least-square method and then the cross-section ratio σ_n/σ_g

was calculated, after correction for the changes of neutron flux during the irradiation process.

As a result of the experiment, the following values were obtained for the measured quantities:

Isotope	T 1/2	cross-section
^{114g}In	71.9 ± 0.1 sec.	164 ± 20 mb.
^{114m}In	43.5 ± 1 msec	440 ± 46 mb.
^{112g}In	14.4 ± 0.2 min.	703 ±102 mb.
^{112m}In	20.9 ± 0.2 min.	837 ± 98 mb.

The 390 keV γ line with 1.8 half life has been observed and it can be ascribed to $^{113}In(n,n)\,^{113m}In$ reaction. The estimated value for the cross-section equal to (35 ± 8) mb has been obtained. There is a quite strong difference in the σ_{n_1}/σ_g ratios for ^{112}In and ^{114}In which are 1.2 and 6.9 respectively. At the same time agreement between both total cross-sections for (n,2n) reaction is much better and both cross-sections agree very well with theoretical values [4] .

It may suggest the existence of an unknown isomeric level in ^{112}In decaying directly to the ground state and in such a way, changing the population probabilities of both known long living levels.

DISCUSSION

Two experimental facts, namely, the absence of 43 ms decay, when ^{113}In sample has been irradiated and relatively large value of the cross-section for natural indium, assures that this activity comes from $^{115}In(n,2n)^{114}In$ reaction and that short-lived activity comes from decay of isomeric level.

This isotope has already very well known isomeric level with energy 191 keV and $T_{1/2}$ = 50 days. The cross-section for the production of this activity was equal to 1550 mb for 14.7 MeV neutrons taken from the excitation function [5] .

Then, the question arises about the energy of the second isomeric level, because the emission of 311 keV γ quanta can populate ground state as well as 191 keV isomeric state.

It is not possible to establish the decay scheme by standard methods, because of long lifetime of both levels regarded as final states of nucleus. However, because $\sigma_{n_2} = 3\,\sigma_g$ the transition directly to the ground state is out of question. Therefore, the following level scheme of ^{114}In is suggested: see Fig. 7. There is no direct evidence for the spin value of the second isomeric level. Therefore, the isomeric cross-section ratios for ^{114}In were analyzed in terms of statistical theory in hope to get some approach to the problem.

In Fig. 8 values of isomeric cross-section ratios for ^{114}In are plotted versus spin value of $^{114m_2}In$ level.

The result obtained is somewhat surprising, because rather low spin value /2 or 3/ are preferable. On the other hand, for ^{116}In, which has very similar decay scheme, spin of second isomeric state is believed to be 8^- or $5,6^-$. Keeping in mind the risk, connected with application of the statistical approach to the explanation of the individual properties of nuclei, let us discuss the result obtained.

For indium isotope, following shell-model configurations are usually prescribed: ground states of $^{112,114,116}In$ having spin 1^+ are due to $/g_{9/2}^{-1}, g_{7/2}^{-1}/$configuration. The spin values 4^+ and 5^+ of the first isomeric states in ^{112}In and $^{114,116}In$, respectively, can be explained by $/g_{9/2}^{-1}, s_{1/2}/$ or $/g_{9/2}^{-1}, s_{1/2} + d_{3/2}/$ configurations.

The only reasonable way to get the negative parity isomeric state with large spin value, as it is observed in the case of ^{116m}In, is to assume $/g_{9/2}^{-1}, h_{11/2}/$ configuration. Conversely, all low-lying isomeric states of odd-proton indium isotopes are $p_{1/2}^{-1}$ type.

Assuming that $^{114m_2}In$ is $/p_{1/2}^{-1}, d_{3/2}/$ type, then, we get a doublet with spin values 1^- and 2^-, with one proton and one neutron excited. Such configuration can explain the lack of the direct transition from the second isomeric state to the ground state at least in the pure shell model. Now, the problem is, how far the direct transition from such configuration to the ground state is forbidden, but it seems that at present no definite answer can be given without detailed calculations indluding both, shell model and pairing affects. Also, there are no experimental data concerning this problem. The conclusion of this rather speculative part of paper is that the experimental data do not allow to reject any of $/p_{1/2}^{-1}, d_{3/2}/$ or $/g_{7/2}^{-1}, h_{11/2}^{1}/$ configurations for 502 keV isomeric level.

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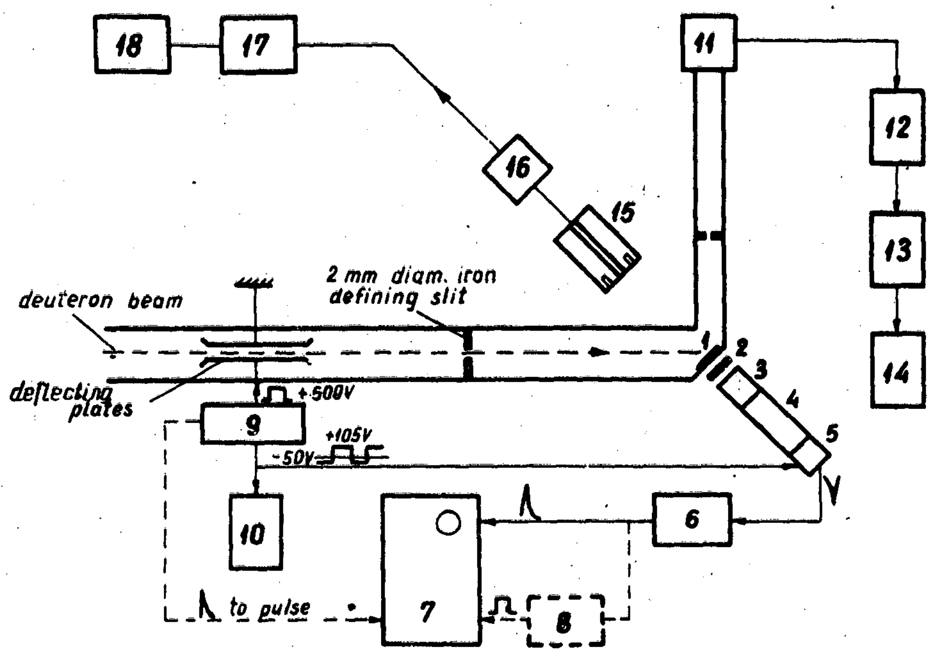

Fig.1

Block diagram of the equipment for measuring gated gamma ray spectra and half lives of activities:
1. tritium target, 2. probe, 3. NaI/TI/crystal, 4. Dumont 6292 photomultiplier, 5. cathode follower, 6. double line linear pulse amplifier, 7. 400-channel kicksorter, 8. single-channel analyzer, 9. beam pulser, 10. scaler, 11. solid state detector + charge sensitive preamplifier, 12. amplifier, 13. single-channel analyzer, 14. scaler, 15. long counter, 16. preamplifier, 17. amplifier, 18. scaler.

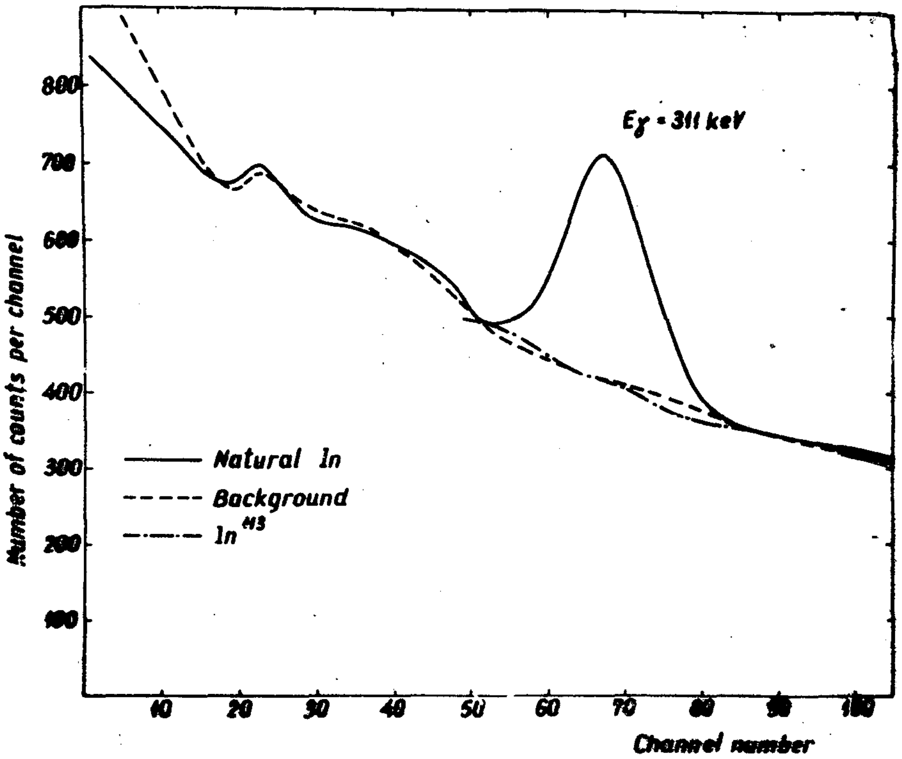

Fig.2

Gated scintillation spectra of gamma rays obtained by irradiation of natural enriched (^{113}In) indium with 14. 7 MeV neutrons.

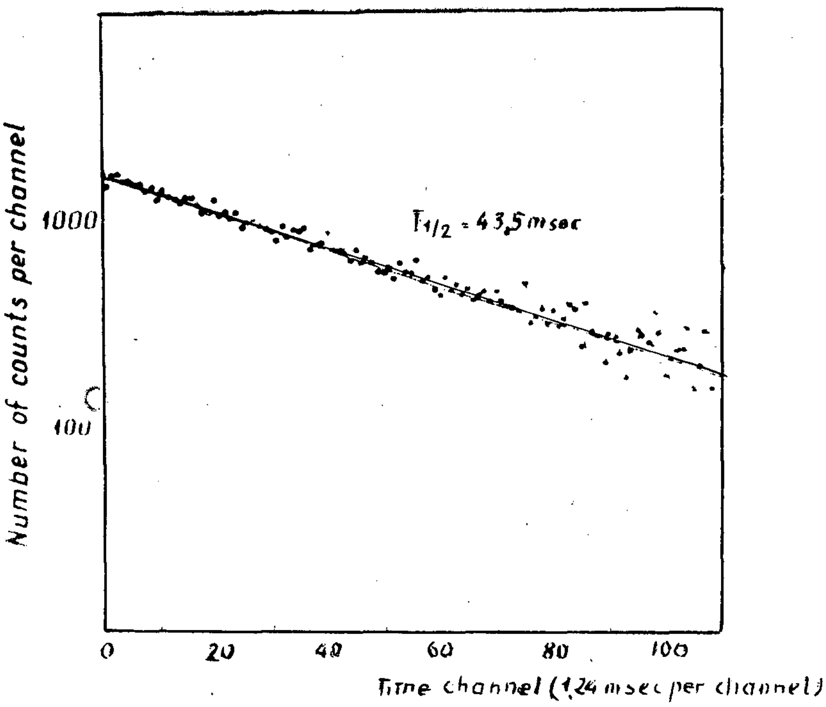

Fig.3

Decay of the 311 keV line of ^{114m_2} In

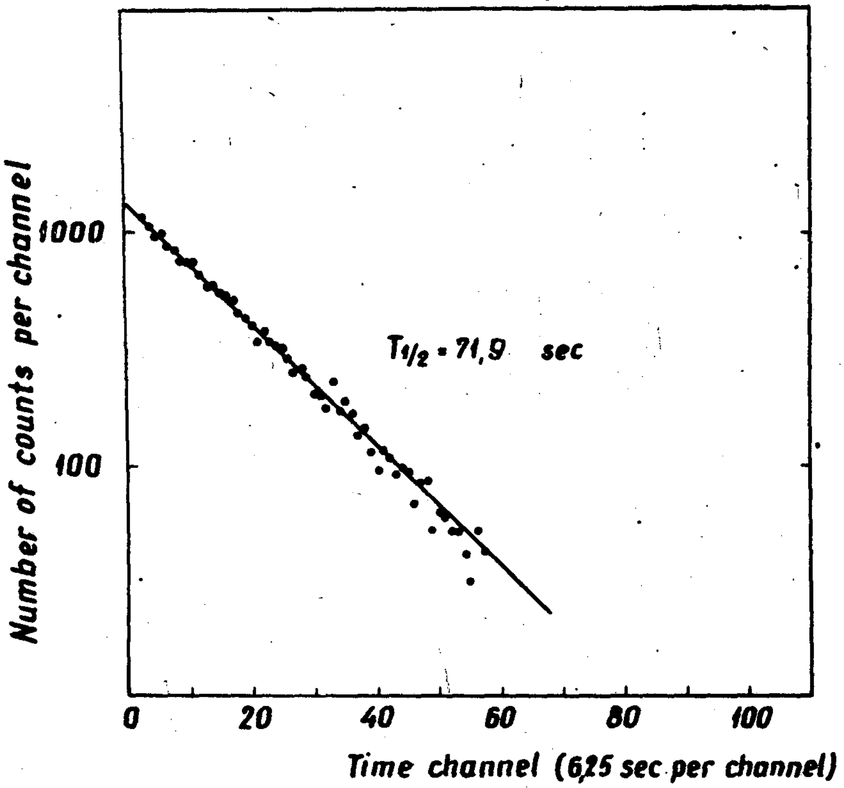

Fig. 4.

Decay of the ground state of ^{114}In

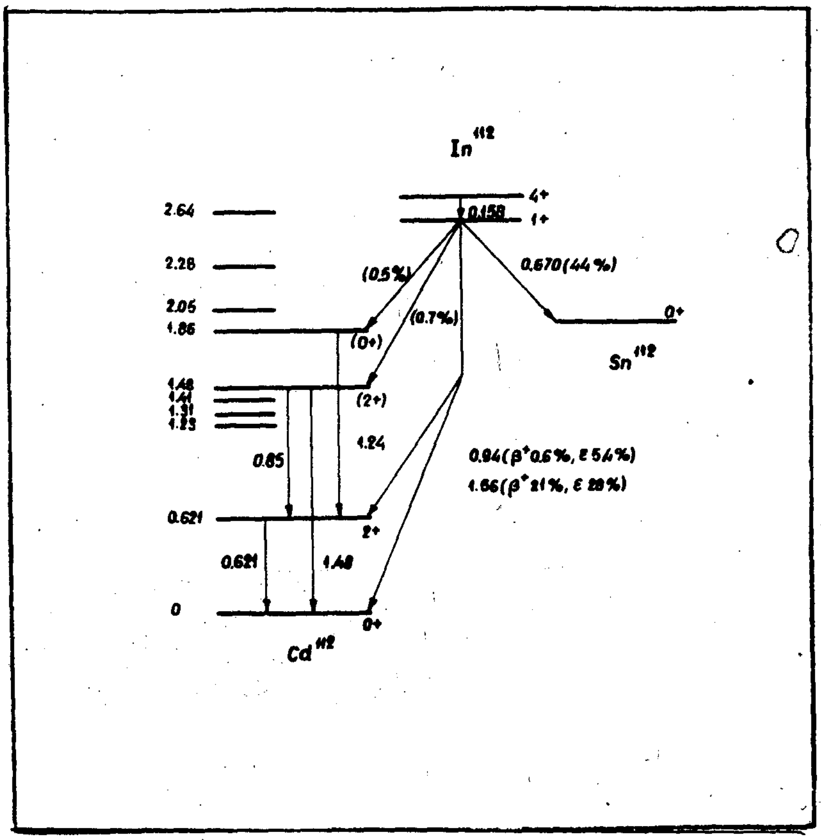

Fig. 5.

Decay scheme of ^{112}In

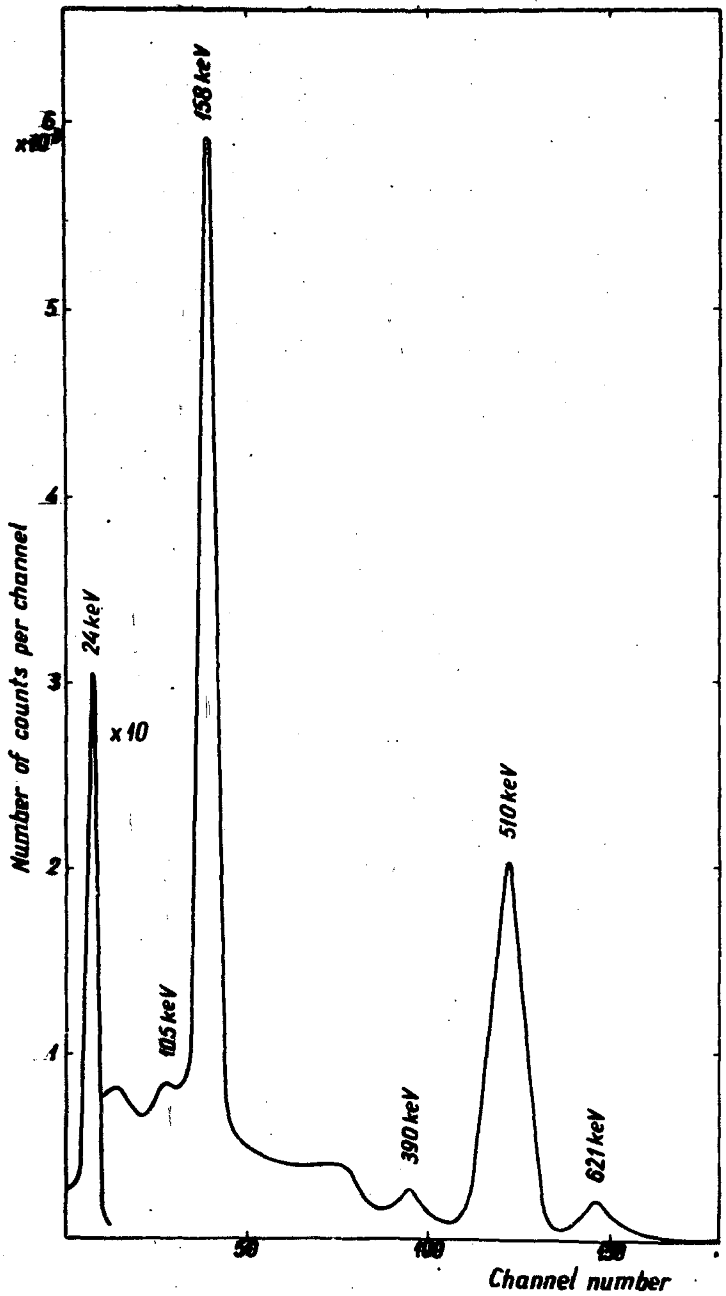

Fig. 6.

γ ray spectrum from $^{113}In\ (n,2n)^{112g,m}In$ and $^{113}In\ (n,n')^{113m}In$.

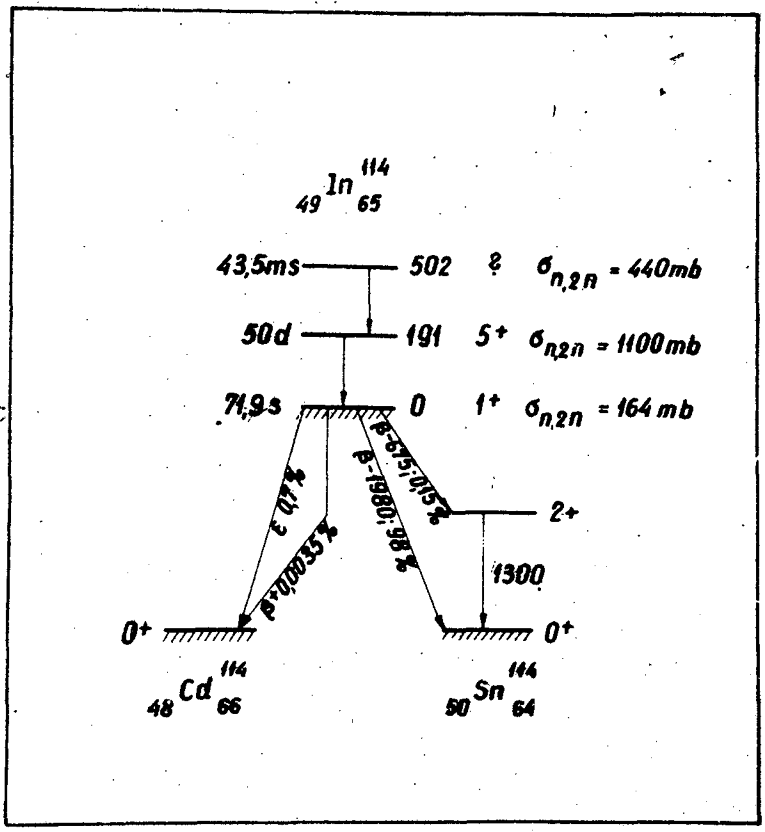

Fig. 7.

Decay scheme of ^{114}In

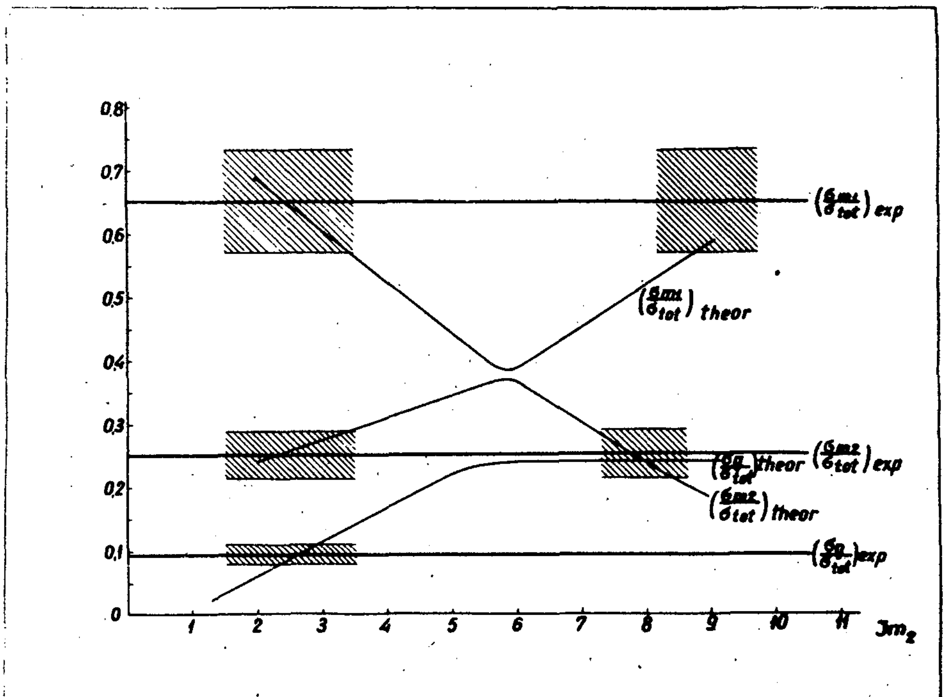

Fig. 8.

The isomeric cross section ratios for ^{114}In versus spin value of $^{114m_2}In$. The solid lines are result of calculations using GILBERT and CAMERON [6] formulas. The use of LE COUTEUR [7] formulas gives similar results.

Not for publication

12. EXCITATION CURVE OF THE $^{181}Ta(n,\gamma)$ ^{182}Ta REACTION IN THE ENERGY RANGE 0.03 - 5.1 MeV.

J.S. Brzosko, E. Gierlik, A. Saganek, A. Sołtan jr. and Z. Wilhelmi, Institute of Experimental Physics, University of Warsaw.

The activation method was used to determine the cross section of the $^{181}Ta(n,\gamma)$ ^{182}Ta, reaction. The neutrons were obtained from the reactions $^{3}H(p,n)^{3}He$ and $^{2}He(d,n)^{3}He$. The neutrons flux was monitored by the $^{197}Au(n,\gamma)$ ^{198}Au, $^{63}Cu(n,\gamma)$ ^{64}Cu and $^{64}Zn(n,p)^{64}Cu$ reactions.

The group of γ - rays of the energy (800-1300) keV accompanying β^{-} -decay of the ^{182}Ta isotope was measured to obtain the activity of the final product of the $^{181}Ta(n,\gamma)$ ^{182}Ta reaction. The results of the theoretical calculations along with the experimental one are given in Figure. Unpublished experimental California University data are also included.

The calculations were carried out according to the statistical theory of the compound nucleus.

The probability of the compound nucleus γ -rays emission was calculated in two different manners: assumming the proportionality to third power of the emited γ -ray energy /doted line/ or to the product of second power of the emited γ -ray energy and the cross section for the (γ,n) inverse reaction /solid line/.

Second method is analogous to Starfelt calculations [1] .

The nuclear level density was calculated according to Gilbert and Cameron [2] with their parameters. The comparison of the theoretical and experimental results points out the superiority of the second approach.

It seems that this reaction is described well by proposed model in the whole measured energy range.

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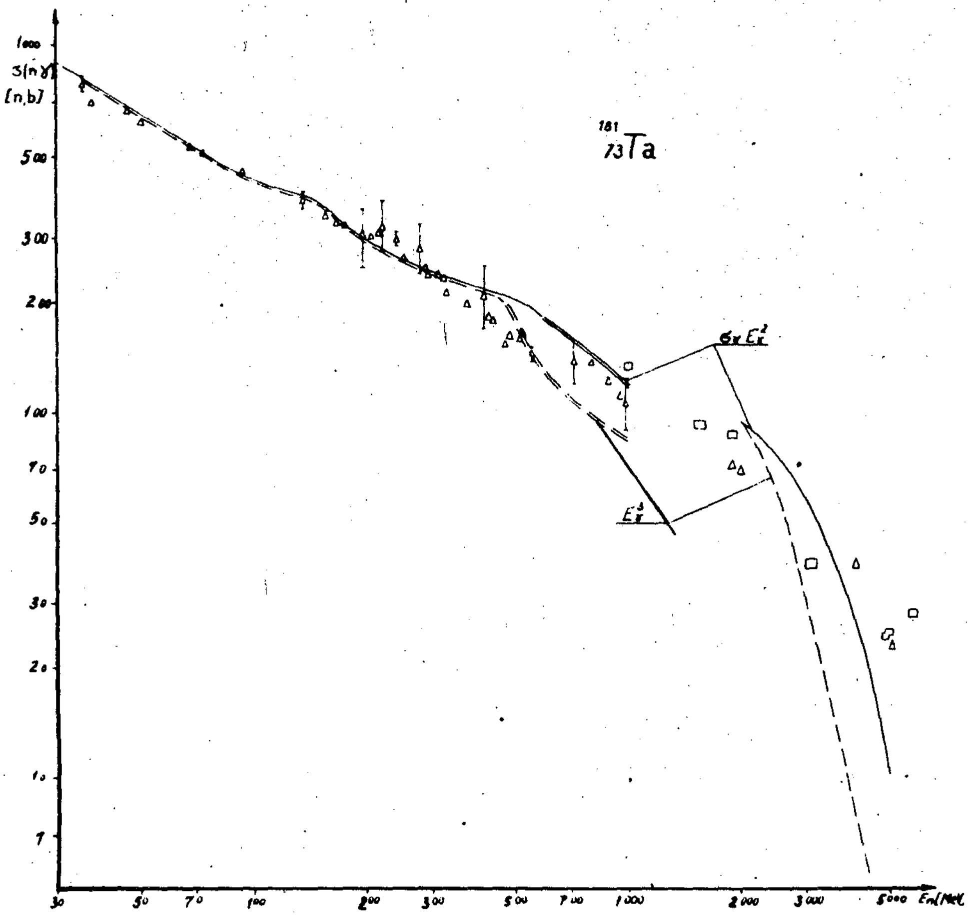

Not for publication

13. STUDY OF THE (n,γ) REACTION MECHANISM BASED ON THE STATISTICAL MODEL FOR HEAVY NUCLEI IN THE NEUTRON ENERGY RANGE FROM 0.03 to 6 MeV.

J. Brzosko, E. Gierlik, A. Sołtan jr., Z. Wilhelmi,
Institute of Experimental Physics, University of Warsaw.

In the recent years a considerable number of measurements and analysis of the γ -ray spectrum shape from (n,γ) reaction have been made [1] . In many events a distinct enhacement of high energy γ - rays is seen. It is interesting that in this neutron energy range the theoretical predictions of the γ - ray spectrum shape based on the compound nucleus model differ considerably from the experimental results. It is used to take the probability of the γ - ray emission in the form:

$$P_\gamma \sim \sum_J \int E_\gamma^3 \varrho(U,J)\, dE_\gamma \qquad (1)$$

where ϱ (U, J) describes the nuclear level density of the nucleus of spin J and excitation energy U . Starfelt has made an attempt to describe the probability of the γ -ray emission from high excited nuclei taking into account the cross section $\sigma_\gamma(E_\gamma)$ for the γ - ray absorbtion.

$$P_\gamma \sim \sum_J \int E_\gamma^2 \sigma_\gamma(E_\gamma) \varrho(U,J)\, dE_\gamma \qquad (2)$$

It was assumed that the $\sigma_\gamma(E_\gamma)$ consists of the E 1 and M 1 giant resonances having the same analytical form.

There are suggestions that the M 1 resonance exists for γ -rays energy about 5.5 MeV [2] with intensity two order smaller than the E 1 one. The agreement between the γ - ray experimental spectrum from (n , γ) reaction and predicted theoretically based on N . Starfelt's method is excellent. This fact and the weak dependence of the γ -ray spectrum shape on incident neutron energy gave us an idea to test usefulness of the compound nucleus model with assumption that M 1 resonance exists, in the case of many nuclei /^{103}Rh, ^{127}J, ^{133}Cs, ^{181}Ta, ^{197}Au/. It was interesting to verify the agreement of such measured magnitudes as the $\frac{\langle\Gamma_\gamma\rangle}{D}$ /gamma strength function in the resonance region/ γ -ray spectra from the (n, γ) reaction and the total cross section σ (n, γ) (En $<$ 6 MeV) with those predicted theoretically. In the σ (n, γ) cross section calculations it was necessary to describe precisely a competitive neutron emission because of its great contribution in the compound nucleus decay. The spin dependent nuclear level density and its parameters were taken according to Gilbert and Cameron [3] . As appeared it was possible to obtain a good agreement and consistency of the general features as well as absolute values of mentioned kinds of the experimental data with the predictions of the compound model with P_γ taken in form (2) . The values of parameters used in formulae were taken close to that obtained in other experiments. As an example, measured and calculated values of $\frac{\langle \Gamma_\gamma \rangle}{D}$ and σ (n, γ) are given in following Table.

nucleus	$\frac{\langle \Gamma_\gamma \rangle}{D}$		$\sigma(n,\gamma)$ [mb] En = 90keV		$\sigma(n,\gamma)$ [mb] En = 500 keV		$\sigma(n,\gamma)$ [mb] En = 4 MeV	
	exp	theor	exp	theor	exp	theor	exp	theor
^{181}Ta	13.6	10	450	440	160	170	25 35	30
^{197}An	8.4	6.6	350	350	125	120	20 30	25

Calculation based on (1) can merely reproduce general trend of σ (n, γ) for En < 2 MeV, agreement being hardly satisfactory and γ - ray spectrum is reproduced definitly uncorectly. Therefore it seems to suggest that statistical theory of the compound nucleus with P_γ described by (2) can give good predictions in the case of the (n, γ) reaction for En $\leqslant$ 6 MeV, and indirectly, points out the possibility of the M 1 giant resonance existence.

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Not for publication

14. $^{209}Bi(n,n'\gamma)$ SCATTERING WITH 14.8 MeV NEUTRONS USING Ge-Li DETECTOR

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Physics, Cracow.

Inelastic scattering of 14.8 MeV neutrons on a natural bismuth target was investigated. The detection of gamma rays was performed by use of Ge-Li detector in the energy range of 1 - 4.5 MeV. The observed discrete lines of the gamma-ray spectrum might be interpreted as radiative transitions from the following groups of levels:

1/ one - particle levels of 1.612, 2.833, 3.146, 3.648 MeV,

2/ the splitted octuple vibration multiplet of 2.6 MeV with energies 2.495, 2.557, 2.576, 2.592, 2.615, 2.743 MeV,

3/ some other levels which possibly could be ascribed to the higher vibrational excitations of the core.

The measurements are in progress.

Not for publication

15. HEAVY ICE AND DEUTERIUM DRIVE-IN TARGETS FOR dD NEUTRON PRODUCTION

J. Koralewski, E. Rurarz, and J. Tys, Institute of Nuclear Research, Świerk.

The neutron source from dD reaction has been constructed. It has following characteristics:

a/ possibility of work as a target with heavy ice or as self-loading target /self-loading on gold/,

b/ in the case of work with heavy ice the ice layer of reproductible thickness can be formed,

c/ convenient system of neutron flux monitoring by counting the protons from competing reaction D/dp/T by using the solid state detector,

d/ it is easy to calibrate the energetic scale of emited charged particles from the target by placing the small source of alpha particles from ^{239}Pu near the semiconductor detector.

e/ small amount of constructional materials.

Protons emerging from the target at 135^{o} with respect to deuteron beam are counted to measure the neutron yield. Our heavy ice target mean yield for an accelerating voltage 175 kV is 6×10^{5} n/s μA .

The decrease with time in neutron yield for one ice layer irradiated with ion beam current of 25 μA is shown /Fig.1/.

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From self-loading target irradiated at 100 μA , 0.6 x 10^5 n/s μA yield obtained.

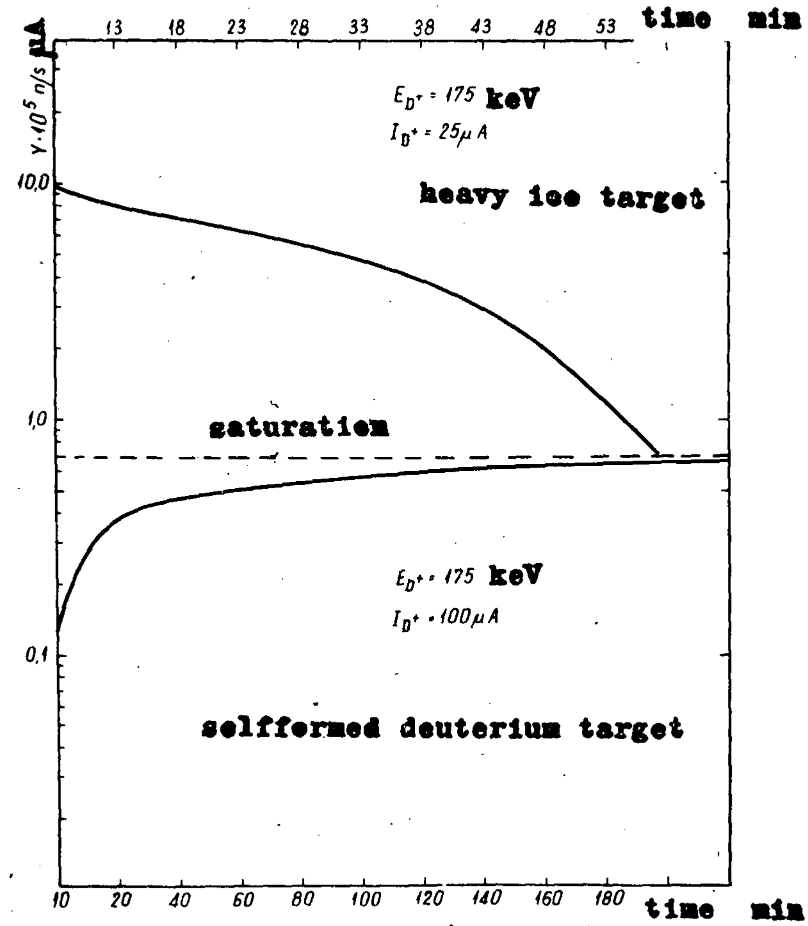

Fig. 1

Neutron yield as a function of the time of bombardment on the heavy ice target /upper curve/ and neutron yield increase with the bombardment time on a selfformed deuterium target on gold /lower curve/.

Not for publication

16. A NEUTRON POLARIMETER WITH HIGH ENERGY RESOLUTION

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Experimental Physics, University of Warsaw, Poland.

A new type of a low pressure neutron polarimeter with the detection of alpha recoils has been constructed. The neutron polarization is based on the measurement of the left-right asymmetry after the scattering of the neutrons by helium nuclei.

Neutrons originating in a target (T) /Fig. 1/ pass through a hole in a brass collimator (C) , enter a helium filled chamber (Ch) and scatter on helium nuclei. Recoiled alpha particle passes an angular filter of a special construction and is detected in one of two silicon surface barrier detectors (E_1, E_2). Neglecting the energy loss of alpha particle on its path in gas the pulses produced in (E_1) or (E_2) counter are proportional to the energy of the recoiling alpha particle and, because of the fixed angle of recoil, proportional also to the energy of the incident neutron.

In order to reduce the background caused by charged particles being emited in neutron induced reactions in silicon and detected in the semiconductor counter, recoiling alpha particles are made to pass between two horizontal plates of an ionization chamber located in the scattering region (ΔE). Pulses from ionization chamber gate the pulses from E_1

and E_2 analysed in 400-pulse analyser.

The resolution obtained for the $T(d,n)^4He$ neutrons at E_d = 420 keV amounts to about 14 %. We have also performed a preliminary measurements of the asymmetry for neutrons emited at 29° in the c.m. system under the 420 keV deuteron bombardment of tritium target. The value $\frac{R}{L} = (1 \pm 4)$ % was obtained with agreement with previous measurements.

Neutron polarization measurement in the $T(d, n)^4He$ reaction at E_d = 1.5 MeV and in the $^7Li(d,n)^8Be$ reaction are in progress.

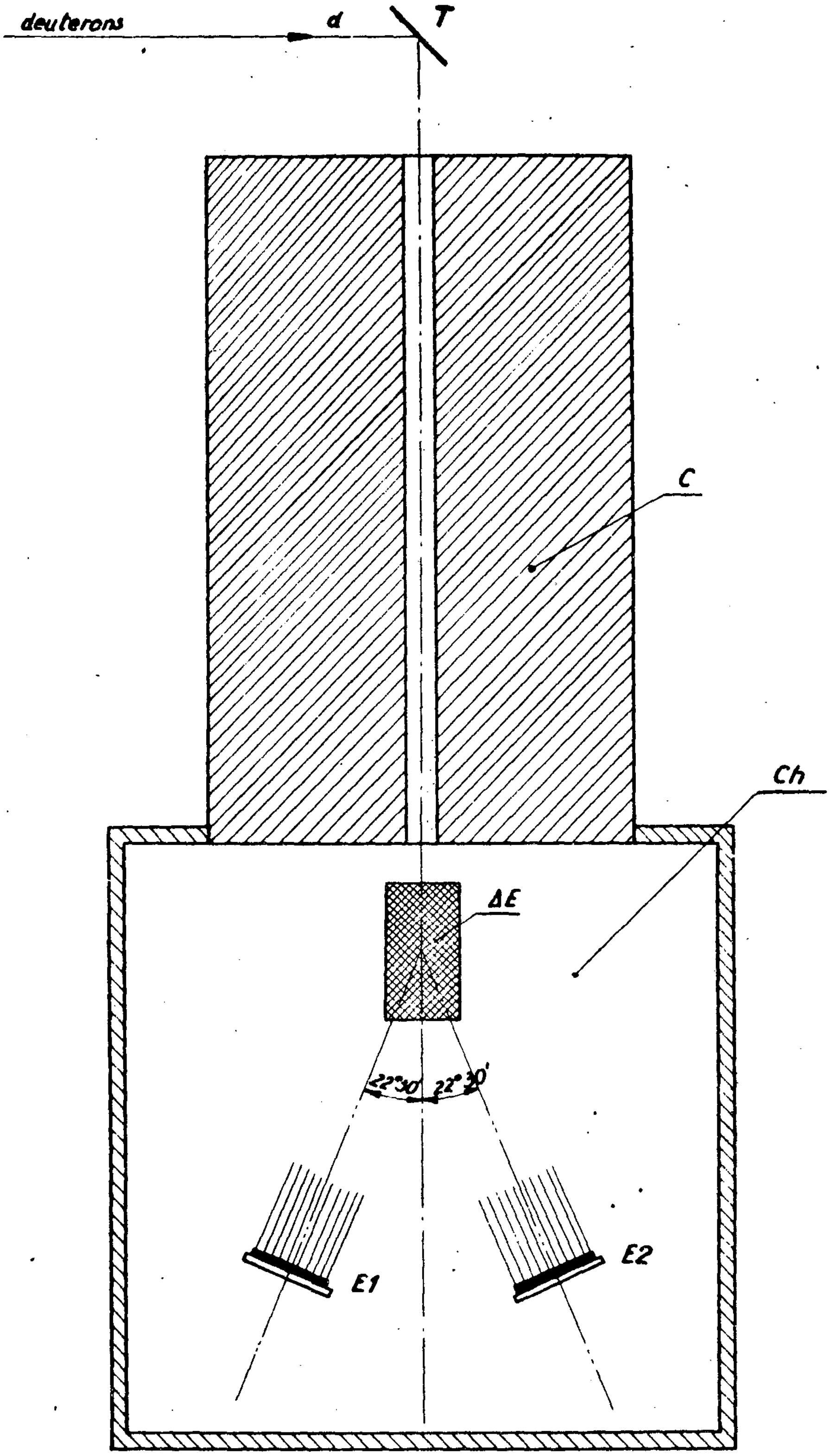

Fig. 1. Schematic diagram of polarimeter

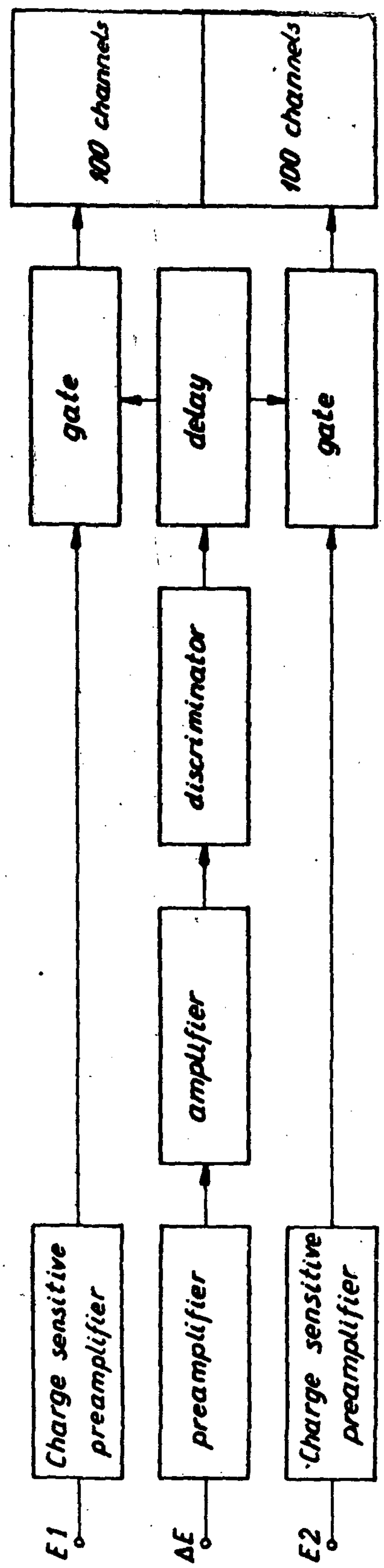

Fig. 2. Block diagram of electronic circuitry

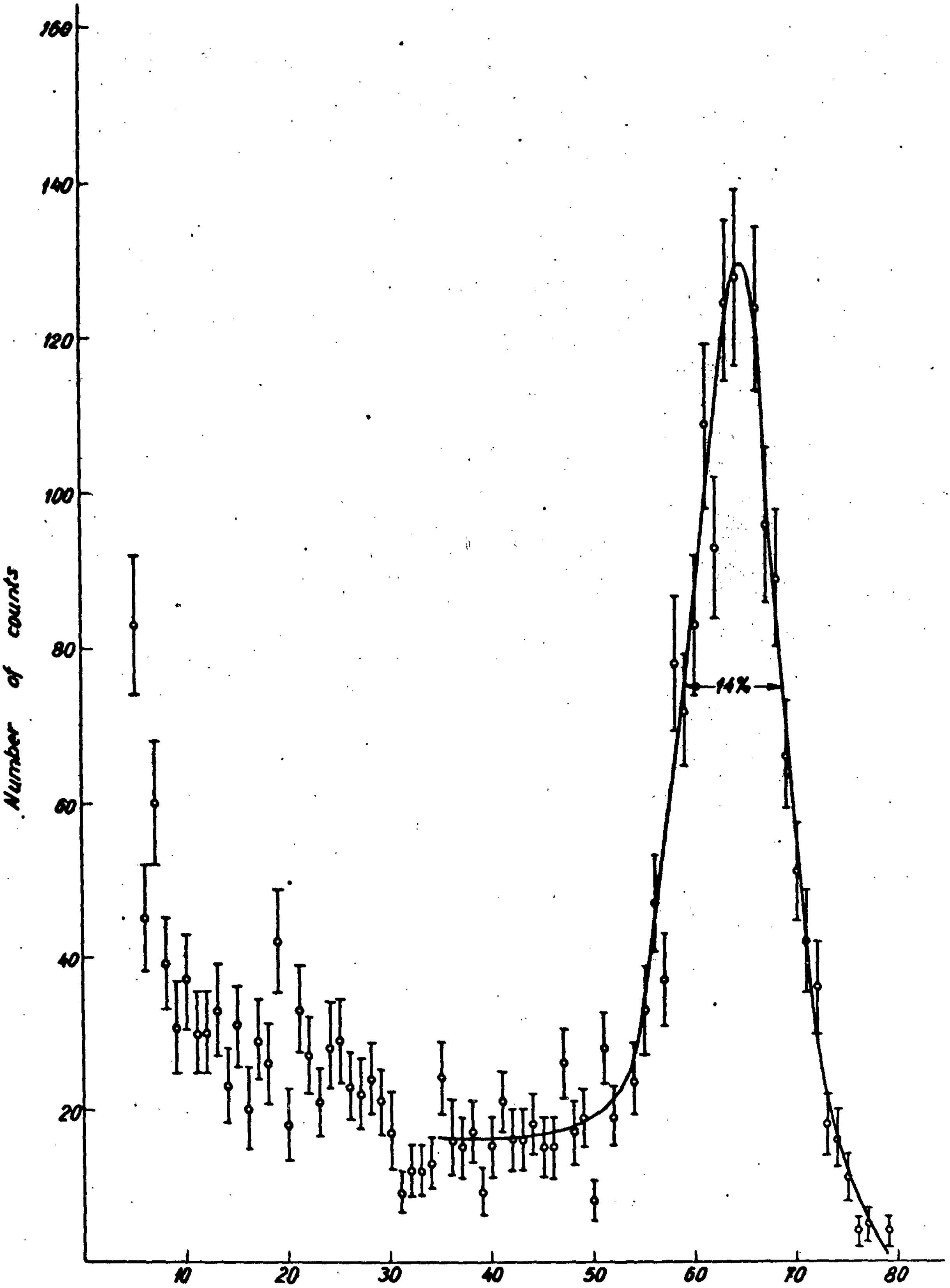

Fig. 3. Recoiled alpha particle spectrum for the (d.T) neutrons

Not for publication

17. PILE OSCILLATOR OP-2

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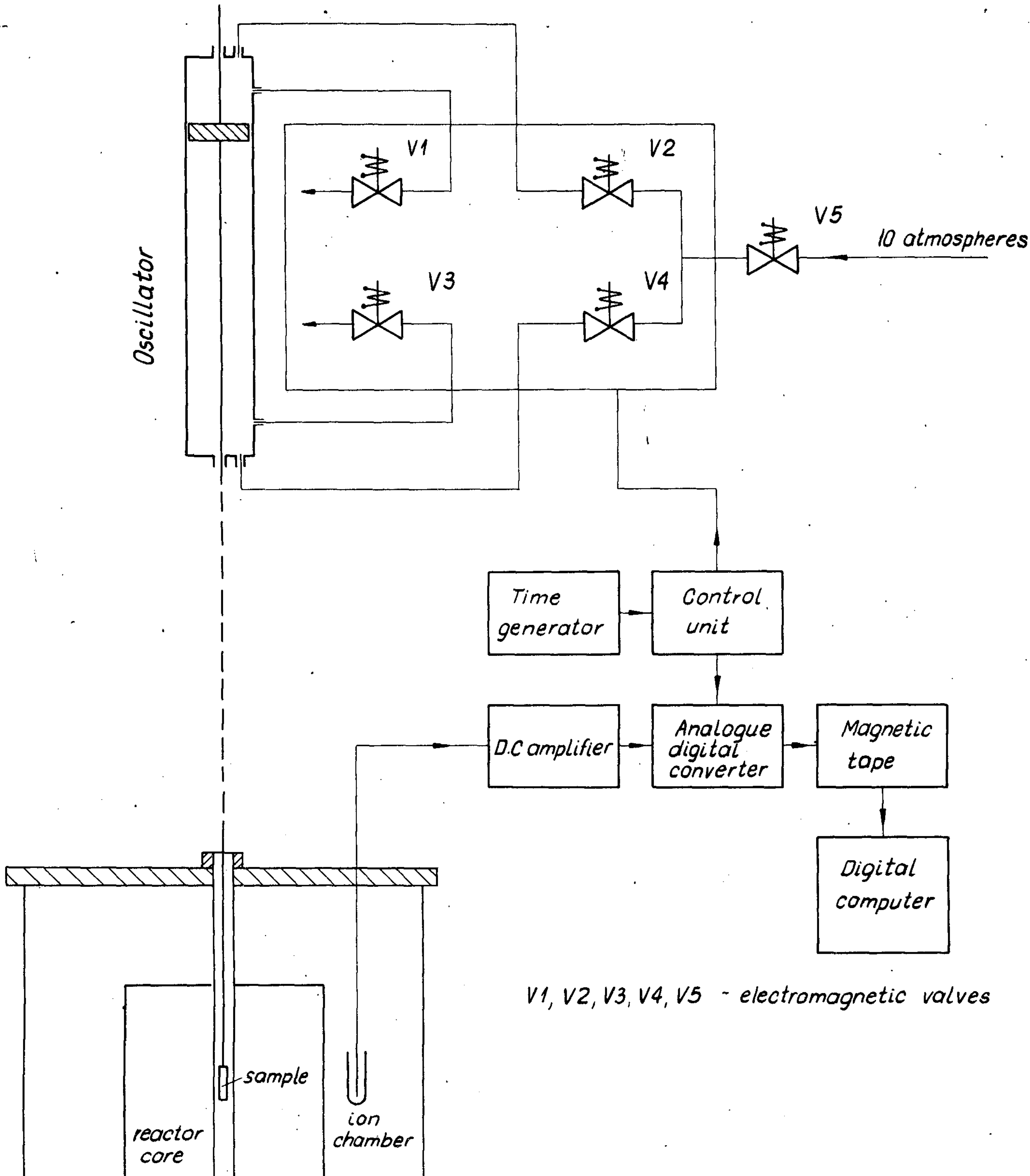
The pneumatic pile oscillator OP-2 has been constructed in the Reactor Physics Department and resonance integral experiments have been started by its means in the year 1967.

The pile oscillator OP-2 consists of a mechanical oscillator, pneumatic supplying system, pneumatic-electrical control device and analyzing equipment. The block diagram is shown in Fig. 1.

The main oscillator parameters are as follows:

- oscillation period : 4 ÷ 40 sec
- transit time : about 0.8 sec /the samples follow a nearly square wave motion/,
- stroke of the movement : 70 cm.

The system of analysis is seen from Fig. 2. The use of the analogue to digital converter allows to register the output voltage of short time intervals on the magnetic tape are processed on the Gier computer using the programmes SS-KB /in computer language/ and Fourier-1 /in ALGOL/.



Oscillator
V1
V2
V3
V4
V5
10 atmospheres
Time generator
Control unit
D.C amplifier
Analogue digital converter
Magnetic tape
Digital computer
V1, V2, V3, V4, V5 - electromagnetic valves
sample
reactor core
ion chamber

FIG. 1.

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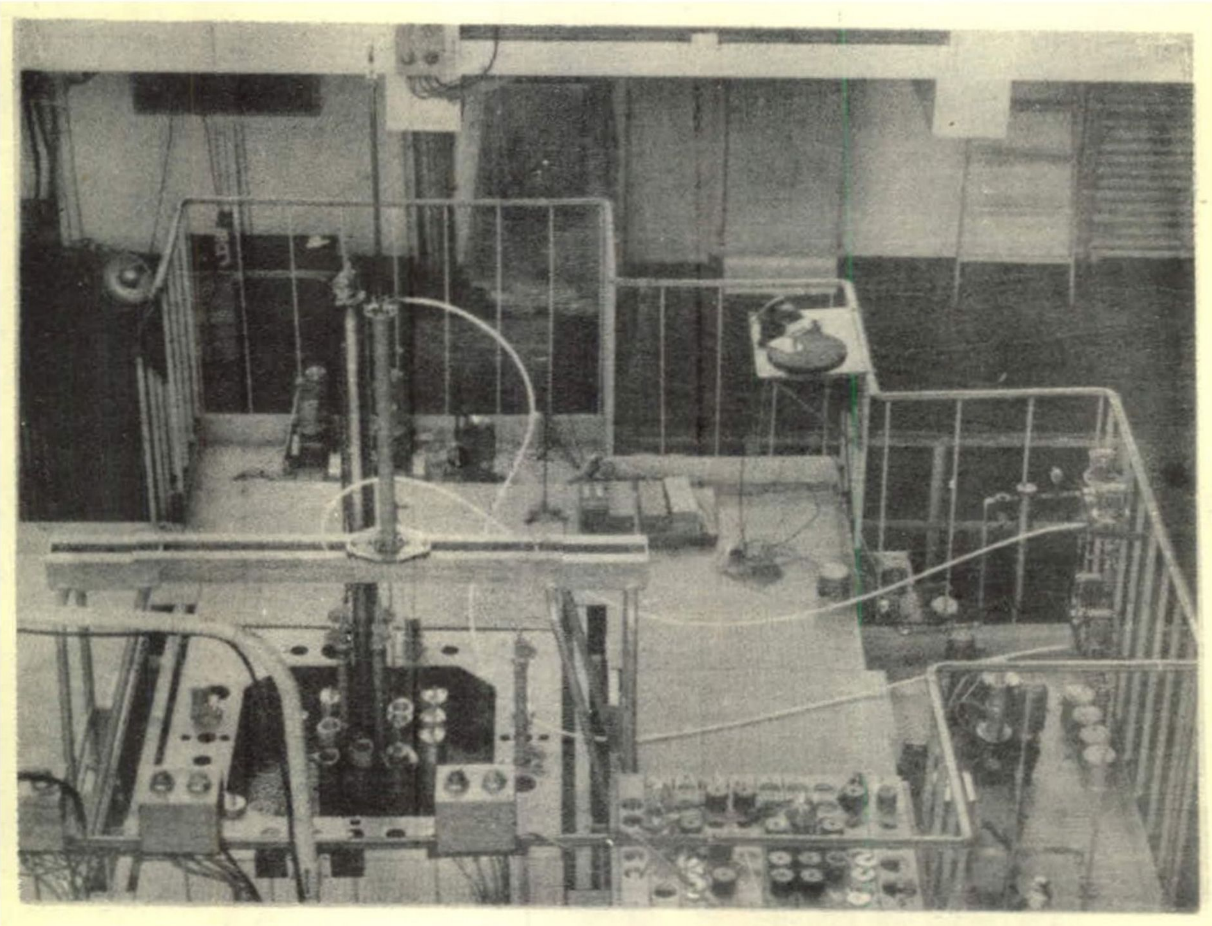

Fig. 2. General view of the pile-oscillator OP-2 assamblied on the ANNA reactor facility.

Not for publication

18. RESONANCE INTEGRALS OF SILVER AND TANTALUM

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The infinitely diluted resonance integrals /the 1/v part excluded/ of silver and tantalum have been determined in the neutron spectrum of the zero-power reactor ANNA using the pile oscillator technique.

The samples were prepared in the form of solutions /silver/ and foils /tantalum/.

Boron was used as the cross section standard /759 ± 2 b/ and gold was used for the determination of the spectral index α . A value of 1550 ± 50 b for the above - 1/v part of the resonance integral for gold has been calculated using resonance parameters quoted in BNL-325 /2nd ed. 1966/ and this value has been used as a resonance integral standard.

The resonance integrals of the materials measured here have been also estimated from the resonance parameters quoted in the recent edition of BNL-325.

The following experimental and calculated results have been obtained:

	I_{exp} /b/	I_{calc} /b/
Silver	715 ± 30	720 ± 20
Tantalum	690 ± 25	730 ± 40

The results are not corrected for the deviation of the neutron spectrum from 1/E.

Not for publication

19. THERMAL NEUTRON CROSS SECTIONS FOR CRYSTALLINE MODERATORS

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The adaptation of the GASKET code for the Gier computer is in progress. The original version of GASKET includes the calculation of the scattering function $S(\alpha, \beta)$ in incoherent approximation for four modes of the scatterer dynamics and their possible mixtures: free translation, diffusive motion, isotropic vibration with continuous frequency spectrum, and discrete isotropic vibrations. The prepared version of the GASKET code called MINIGASKET takes into account only the first and third mode being specifically tailored to meet the needs of the THERMOS code for beryllium moderator. The code is written in the ALGOL-60 language.