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PREFACE

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CONTENTS

I. Institut de Physique Nucléaire, Université de Lausanne

(Dir.: Prof. Dr. Ch. Haenny)

1. (n, t) and (n, α) reactions on ^{9}Be at 14 MeV

J.P. Perroud and Ch. Sellem

The measured $^{9}Be(n, \alpha_{o})$ ^{6}He cross section agrees to -20% with the results of Paic and coll. [1]. The angular distribution can be well interpreted in terms of a HPS mechanism in PWBA calculation, in which ^{9}Be has been considered as a α-^{6}He cluster with L = 0 relative angular momentum.

The angular distribution of the differential cross section for the reaction leading to the first excited state in ^{6}He has been measured up to $145^{o}{}_{CM}$. Its shape, characteristic of a direct reaction process, could not be interpreted by simple calculation. The integrated cross section is 17.5 $\pm$ 1 mb.

No ^{6}He level higher than 1,8 MeV up to 10 MeV is excited appreciably ($\sigma < 5$ mb).

The $^{9}Be(n, t_{o})$ $^{7}Li_{GS}$ and $^{9}Be(n, t_{1})$ $^{7}Li^{*}$ differential cross sections were measured up to $90^{o}{}_{CM}$. The integrated cross section, assuming the hypothesis of a compound nucleus reaction, is 5.5 $\pm$ 0.46 mb for the second reaction in agreement with the results of Benveniste and coll. [2].

A paper has been submitted to Nuclear Physics and another one on "Identification of charged particles in reactions induced by 14 MeV neutrons" will be submitted to Nuclear Instruments and Methods.

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2. ^{10}B(n, Charged Particles) Reactions at 14 MeV

Ch. Sellem, J.P. Perroud

Results of the simultaneous measurements of the angular distribution of light and heavy particles emitted in reactions induced by 14,0 MeV neutrons in ^{10}B were reported last year [1].

The analysis of the experimental results has been continued. It shall give the angular variation of the differential cross sections for the following reactions:

(n, t_0) ; (n, t_1)
(n, d_0) ; (n, d_1)
(n, p_0) ; (n, p_1) ; $\left[n, (p_2\ p_3\ p_4)\right]$; $\left[n, p_5\right]$
$(n, (\alpha_0 + \alpha_1))$; (n, α_2)

The difficult separation between α_0 and α_1 will be attempted.

Besides the differential cross sections also the corresponding integrated cross sections will be obtained.

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II. Institut de Physique, Université de Neuchâtel

(Dir.: Prof. Dr. Jean Rossel)

Depolarisation factor D in the D(nn) Elastic scattering at 2.45 MeV and phase shift analysis*

D. Bovet, S. Jaccard, J. Piffaretti and J. Weber

D has been measured at two angles and at an incident neutron energy of 2.45 MeV. The preliminary results are

θ_{cm} : 90° D : (46,0 ± 8.4) %
θ_{cm} : 40° D : (39,2 ± 8.0) %

The errors are statistical and experimental.

Phase shift analysis in the framework of the J-degenerate model [1] have been made, each one using as a "starting point" one of some of the many phase shift sets published up to now. Fig. 1 shows that, without inclusion of any experimental values of D, the results of these phase shift analysis are widely scattered especially with regards to the doublet phases. The situation improves a lot when one includes in the analysis our two preliminary results, as it is shown in Fig. 2.

The measurements of an angular repartition of D at 2.45 MeV and other energies are currently being prepared for the purpose of solving the problem of the doublet phases at low energy, below the breakup threshold.

* A more detailed paper has been submitted for publication in Helv. Phys. Acta.

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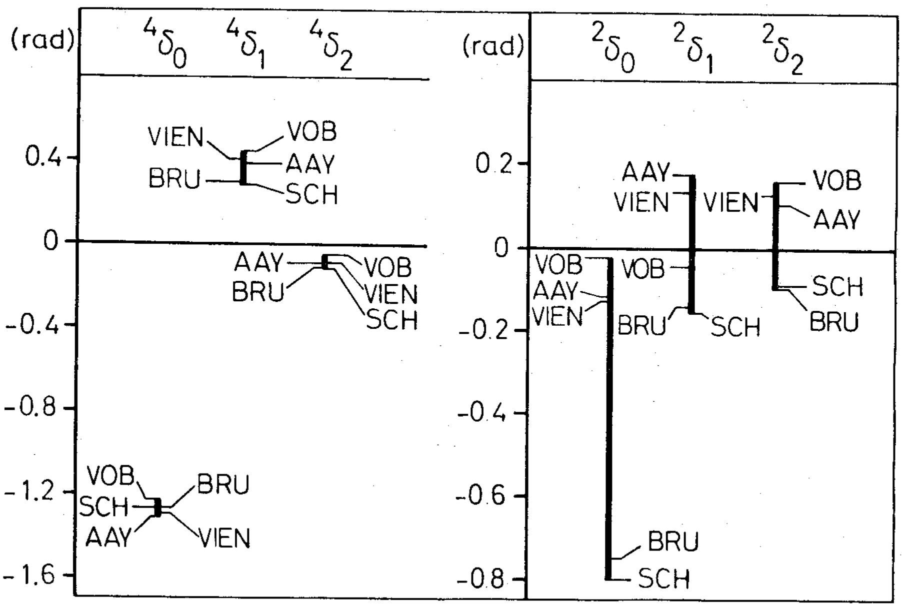

Fig. 1: Ranges of variation of our phase shift analysis results without any D values included in the analysis starting points (see text):

AAY	Aaron et al [2]
VOB	Van Oers et al [3]
BRU	Brüning [4]
VIEN	Viennet [5]
SCH	Schmelzbach et al [6]

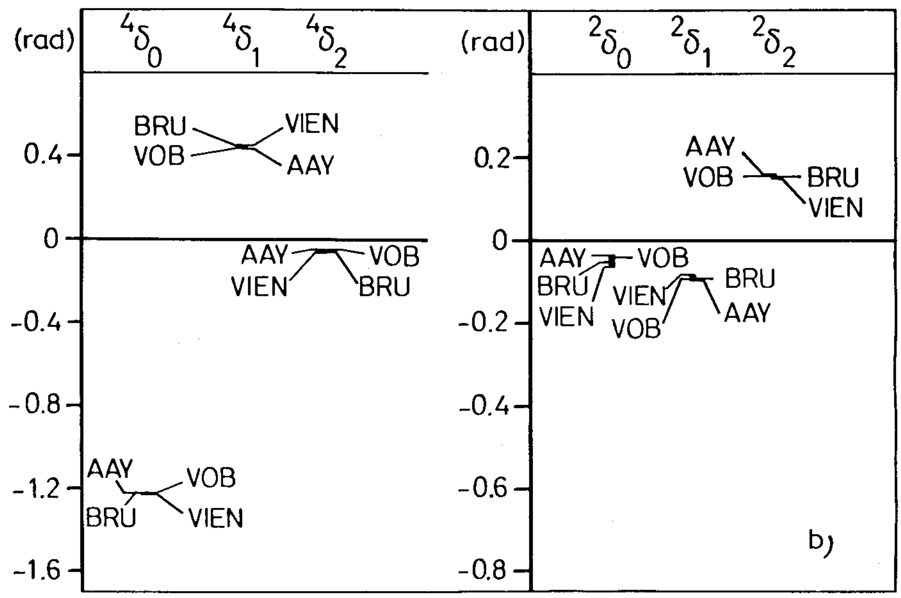

Fig. 2: same as Fig. 1 but with our two experimental values of D included in the analysis.

III. Laboratorium für Kernphysik, Eidgenössische Technische Hochschule, Zürich

1. Deuteron Breakup in the Fields of Heavy Nuclei

J. Lang, D. Balzer, L. Jarczyk*, R. Müller,
P. Viatte and P. Marmier
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Switzerland

Measurements of cross sections of the deuteron breakup in the fields of heavy nuclei at bombarding energies, where off-shell effects may be neglected, can be useful in testing the quality of different 3-body reaction theories. Such experiments were carried out using the ETH Tandem Van de Graaff accelerator to bombard gold and lead targets with deuterons of energies between 7 and 12 MeV. Outgoing protons and neutrons were detected simultaneously in a semiconductor counter and a liquid scintillator respectively, recording for each coincidence event the proton energy and the flight time difference. By monitoring with the well known Rutherford scattering at 20°, absolute cross sections $d^5\sigma/d\Omega_n d\Omega_p dE_p$ were obtained [1]. An example of an angular correlation, calculated by integration over the proton energies, is depicted in fig. 1.

To date, no exact 3-body calculations on deuteron breakup with realistic potentials have been published. Landau and Lifshitz [2] have shown 25 years ago that an analytical expression for the transition matrix element in the post representation can be obtained by assuming a zero range approximation for the n-p-potential, pure Coulomb wave functions for the proton and the deuteron and a plane wave for the neutron. The results of such a calculation, given in the form of a dashed curve in fig. 1, show unexpected big discrepancies. (The theory of Gold and Wong, which is even worse, shall not be discussed here.) As these differences cannot be due to the zero range approximation, they must result from neglecting the nuclear interaction. Also the experiments were performed below the Coulomb barrier. Therefore, the influence of the nuclear field was included by calculating the d-, p- and n-wave functions using a simple optical potential [3] . The agreement achieved with this method [4] (solid line) is excellent.

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* On leave from Jagellonian University, Cracow, Poland

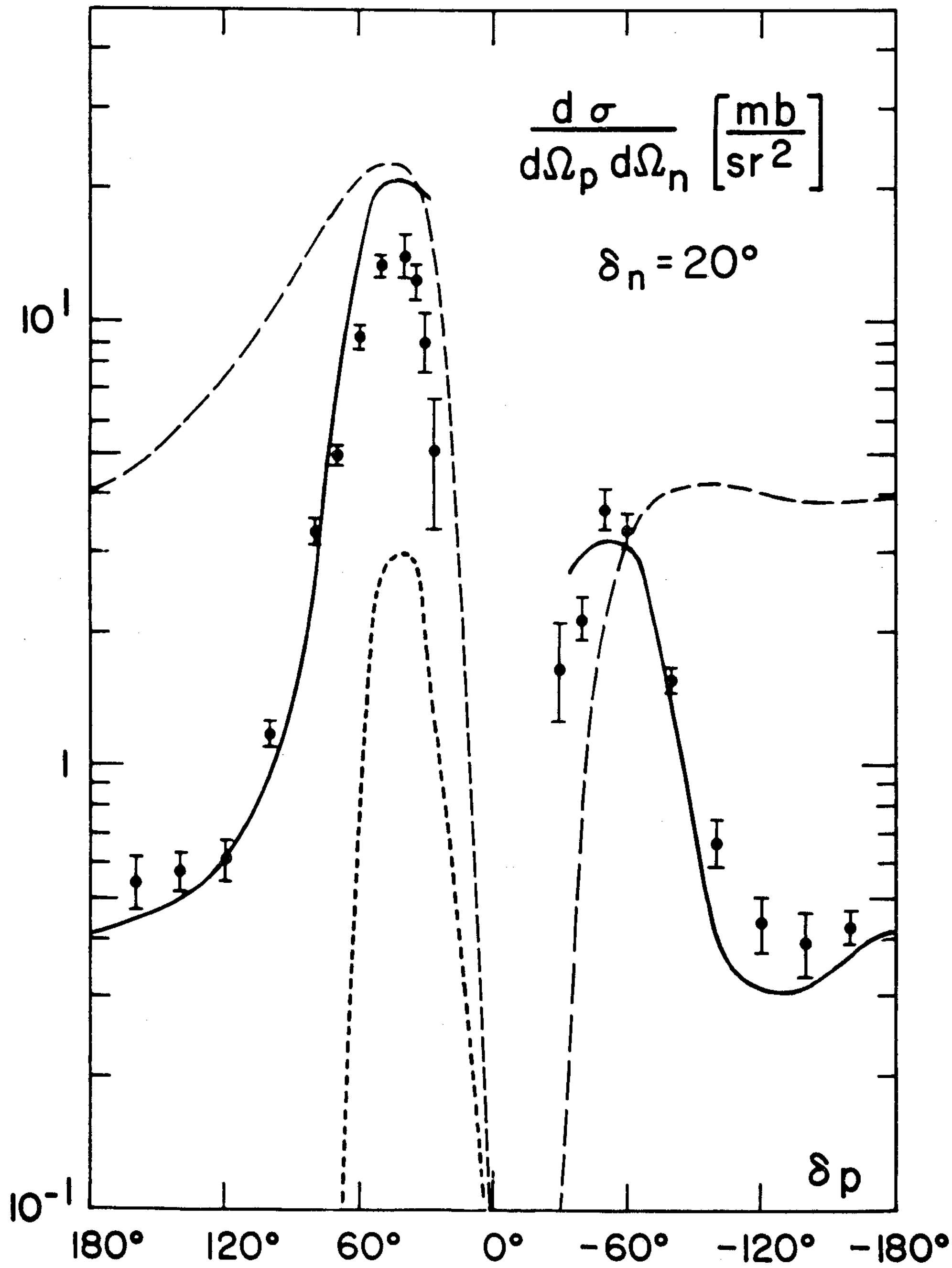

Figure Caption

Fig. 1: Angular correlations $d^4\sigma/d\Omega_p\ d\Omega_n$ for the reaction Au(d, pn) with E_d = 12 MeV and neutron emission angle $\delta_n = 20^o$ as a function of the proton emission angle δ_p. The curves show different theoretical calculations: ——— present paper; ------ Landau and Lifshitz; ······ Gold and Wong.

2. Measurements of the Tensor Analysing Powers in the $T(\vec{d},d)T$ Elastic Scattering

A.A. Debenham, V. König, W. Grüebler, D.O. Boerma,
R. Risler and P.A. Schmelzbach

Work is in progress to measure angular distributions of the deuteron tensor analysing powers in the $T(\vec{d},d)T$ elastic scattering in the energy range from 5 to 11.5 MeV for the incident deuterons. The aim of this work is to provide further experimental information on the five nucleon system. Specifically, it is hoped that these results, together with those obtained for the $He^3(\vec{d},d)He^3$ scattering [1], could be used in conjunction with theoretical work on the five nucleon system [2] to provide conclusions about Coulomb effects in the system. At present, preliminary results have been obtained at 6, 8 and 10 MeV for the moments T_{20}, T_{21} and T_{22}.

Two types of target* have been used for this experiment. The first consisted of a 1.2 mg/cm^2 gold foil 10 mm in diameter with a 0.3 mg/cm^2 layer of titanium evaporated onto it. The titanium layer was then loaded with tritium at a temperature of around 400° C. The second target was similar except that a 0.2 mg/cm^2 aluminium backing was used in place of the gold. This was found to be advantageous especially at forward angles where the elastic scattering of deuterons from gold was very high. Both elastically scattered deuterons and recoil tritons were detected although, owing to hydrogen contaminant in the target, the latter were mixed with recoil protons from d-p scattering at laboratory angles greater than about 32°.

Use of a particle identification system would therefore solve this problem as well as allow the possibility of measuring the tritons at angles less than 17° lab. The method of particle identification proposed in [3] and carried out on line with the PDP 15 computer [4] was found to be successful for this purpose.

Recently, Heiss [5] has furnished polarization equations for two particle reactions, treating the long ranged part of the Coulomb interaction separately. As a result, it is apparently now possible [6]to make theoretical computations of our observables.

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* Provided by Nuklearchemie und -metallurgie, Hanau.
We are grateful to Dr. D. Balzer for preparing the gold foils.

IV. Eidgenössisches Institut für Reaktorforschung, Würenlingen

1. Spontaneous-fission decay constant of ^{235}U

A. Grütter, H.R. von Gunten and V. Herrnberger
B. Hahn*, U. Moser* and H.W. Reist*
G. Sletten**

The partial spontaneous fission half-lives of odd-A and doubly-odd actinides are observed to be orders of magnitude longer than for even-even nuclides with the same fissility parameter. For ^{233}U and ^{235}U, however, this difference in half-life is reported to be much smaller than for other even-odd actinides. This deviation from systematics could be due to inaccuracies in the measurements or special features of the fissioning systems.

An attempt was made to remeasure the spontaneous fission decay constant for ^{235}U using the "spinner" technique. The principle of this detector is based upon producing negative pressure by centrifugal forces in a liquid containing the fissionable material. The metastable state created in this way in the solution can be destroyed as in normal bubble chambers. Very low background and a one hundred percent efficiency even for gram quantities of fissionable material are the main features of this fission counter.

About 8 grams of uranium with an isotopic composition of 99.7% ^{235}U were dissolved in ethyl alcohol. Since (α,n)-reactions in the alcohol influence the fission rate, "spinner" vessels with different diameters were used in order to enhance the escape probability for neutrons. In chambers of 8 cm and 4 cm diameter count rates of $(2.43 \pm 0.05)/h$ and $(0.98 \pm 0.03)/h$, respectively, were obtained. These count rates are compared to those predicted by neutron transport calculations for the contribution of the (α,n,f)-reaction. Since the spinner was operated 15 m below rock, the contribution by cosmic interactions is estimated to be negligible.

After correction for the contribution of the spontaneous fission of ^{234}U, ^{236}U and ^{238}U (using the published values for the decay constants) an upper limit for the decay constant of ^{235}U of $3.65 \cdot 10^{-19}\ y^{-1}$ was obtained. This limit is about 10 times lower than the value of Segrè (Phys. Rev. 1952) whose determination dates back to pre 1945. It is about 6 times lower than a more recent measurement performed by Aleksandrov et al in 1966 (Atomnaya Energiya 1966). Therefore, we conclude that the deviation in fission hindrance of ^{235}U compared to other even-odd actinides was at least partly due to an inaccuracy in the measurements.

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2. Independent yields of ^{150}Pm in the thermal neutron fission of ^{233}U, ^{235}U and ^{239}Pu

H. Gäggeler* and H.R. von Gunten

The recent availability of fast separation procedures for rare earth elements makes these elements accessible for determinations of independent fission yields. The rare earth region is of special interest in the investigation of charge distribution because it is complementary to the region of light fragments which are influenced by the 50 neutron shell. Furthermore, the rare earth fission products furnish results for charge distribution in very asymmetric fission.

The shielded nuclide ^{150}Pm is very suitable for such measurements due to its half-life and well known gamma-ray spectrum. It has already been determined indirectly in the thermal neutron fission of ^{235}U through a measurement of stable ^{150}Sm (Chu, 1959, unpublished) and in the spontaneous fission of ^{252}Cf by radiometric techniques (von Gunten, 1969). The distribution of charge for ^{233}U and ^{239}Pu is very poorly known in the region of the 50 neutron shell.

Promethium was separated from irradiated targets by a carrier-free ion exchange procedure followed by two reversed phase chromatographic separations with di-(2-ethylhexyl) orthophosphoric acid (HDEHP) on a diatomaceous silica column. The promethium fraction was counted on a calibrated GeLi-gamma spectrometer. Three photopeaks of 1165 keV, 1324 keV and 1736 keV, respectively, were used to compute the absolute activity of the ^{150}Pm formed. The decay of these photopeaks was followed for radiochemical purity. The activity of the peaks of ^{150}Pm was compared to the activity of the 340 keV photopeak of ^{151}Pm in the same sample.

The independent fission yields for ^{150}Pm in the thermal neutron fission of ^{233}U, ^{235}U and ^{239}Pu were found to be $(7{,}3 \pm 0{,}4)\cdot 10^{-4}$ $(5{,}4 \pm 0{,}3)\cdot 10^{-4}$, $(1{,}10 \pm 0{,}05)\cdot 10^{-3}$, respectively. The corresponding fractional chain yields lead to empirical Zp (most probable charge) values of 58,67 ± 0,18, 58,62 ± 0,18 and 58,75 ± 0,17 for ^{233}U, ^{235}U and ^{239}Pu, respectively, if a Gaussian charge dispersion function with a σ of 0,59 ± 0,06 is used. The Zp-value for ^{235}U is in agreement with the Zp-function proposed by Wahl. However, for ^{233}U and ^{239}Pu the Zp-values calculated for ^{150}Pm, using ν_A-values of 1,7 neutrons, deviate significantly from the Zp-function constructed with the light fragments available in this region.

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3. ^{153}Eu(n,p), (n,α) and n,2n) Cross-Sections for 14.5 MeV Neutrons

H.S. Pruys, E.A. Hermes, H.R. von Gunten

Cross sections for the ^{153}Eu(n,p)^{153}Sm, the ^{153}Eu(n,α)^{150}Pm and the ^{153}Eu(n,2n) ^{152m2}Eu reactions have been measured relative to the ^{153}Eu(n,2n) ^{152m1}Eu reaction cross section.

Neutrons were produced by the ^{3}H(d,n)^{4}He reaction in the EIR 150-kV accelerator. The decrease in the intensity of the neutron flux due to burn-out of the target was monitored and the decay curve was fitted to an exponential to obtain the neutron flux decay constant Δ. Samples consisting of 350 mg of Eu_2O_3 (enrichment 98.8% ^{153}Eu; obtained from ORNL) were irradiated for about 3 hours. After the end of the irradiation, the γ-ray activities were counted with a 40 cm^3 coaxial Ge(Li) detector, and successive γ-ray spectra were recorded by a 4096-channel analyser. The irradiations were repeated three times. In Fig. 1 a typical γ-ray spectrum is given.

The following equation was used to calculate the cross sections:

$$\sigma = \sigma_m \cdot \frac{\lambda - \Delta}{\lambda_m - \Delta} \cdot \frac{1 - e^{-(\lambda_m - \Delta)t}}{1 - e^{-(\lambda - \Delta)t}} \cdot \frac{\lambda_m}{\lambda} \cdot \frac{A}{A_m}$$

where subscript m stands for the monitor and σ is the cross section under investigation. A is the activity at the end of the irradiation; λ is the decay constant and t is the duration of the irradiation. The activity A is given by:

$$A = \frac{C \cdot s\ (1 + \alpha)}{\varepsilon \cdot p}$$

where C is the photopeak counting rate at the end of the irradiation; s is the self-absorption correction; ε is the photopeak detection efficiency; p is the decay probability for the transition under investigation and α its internal conversion coefficient. The counting rate C was calculated from an exponential fit to the measured decay curve.

The following decay parameters were used for the reactions [1],[2]:

$^{153}Eu(n,p)^{153}Sm$ (47 h);	E_γ = 103 keV, p = 77 %, α = 1.8
$^{153}Eu(n,\alpha)^{150}Pm$ (2.7 h);	E_γ = 334 keV, p = 74 %, α = 0
	E_γ = 1165 keV, p = 17 %, α = 0
	E_γ = 1324 keV, p = 19 %, α = 0
$^{153}Eu(n,2n)^{152m2}Eu$ (1.6 h);	E_γ = 90 keV, p = 100 %, α = 0.34
$^{153}Eu(n,2n)^{152m1}Eu$ (9.3 h);	E_γ = 842 keV, p = 11.1%, α = 0
	E_γ = 963 keV, p = 9.9%, α = 0

For the monitor reaction $^{153}Eu(n,2n)^{152m1}Eu$ cross section values of 750 ± 200 mb [3] and 652 ± 90 mb [4] are reported in the literature. A value of 650 mb was used.

Table I lists the results of the cross section measurements. The error limits quoted in Table I are composed of the error in the neutron flux decay constant, the error in the photopeak detection efficiency, the statistical error in the counting rate and the error in the self-absorption correction. The errors in the monitor cross section and in p,α and λ of the decay data are not included in the reported error.

Table I

Results of cross section measurements

Reaction	Cross-Section (mb)		Refs.
	Measured	Literature values	
$^{153}Eu(n,p)^{153}Sm$	9.2 ± 1.8	7.4 ± 0.7	[5]
$^{153}Eu(n,\alpha)^{150}Pm$	2.6 ± 0.3	9 ± 2	[6]
$^{153}Eu(n,2n)^{152m2}Eu$	140 ± 40	91 ± 12	[4]

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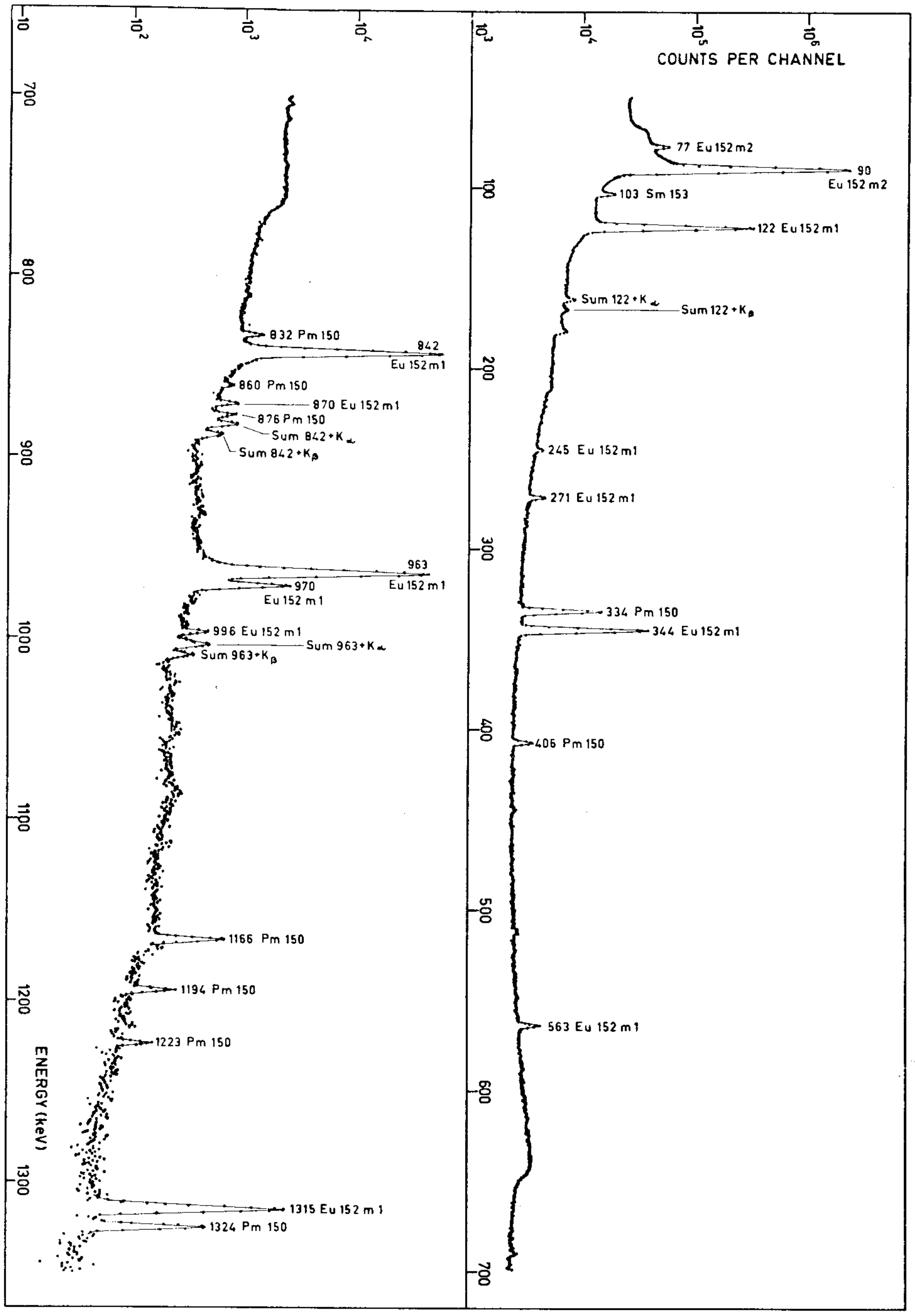

<u>Fig. 1</u>

Gamma ray spectrum of 14.5 MeV neutron irradiated ^{153}Eu measured with a Ge(Li) detector.

V. Physikalisches Institut der Universität Basel

1. $^{238}U(n,2nf)$-reaction time at 14.3 MeV

U. Noelpp*, R. Abegg and R. Wagner

The $^{238}U(n,2nf)$-reaction time has been measured with the technique presented in EANDC (OR)-116"L". An UO_2 single crystal** is cut, ground and etched in a (110)-plane. The quality and orientation of the surface is checked by means of proton-blocking patterns [1]. In the arrangement shown in Fig. 1 the crystal is irradiated by 14.3-MeV neutrons with a total flux of $1.7 \cdot 10^{14}$ n in 4 π. Fission fragments emerging from a circular surface of 1 mm diameter (defined by a 40 μ thick Al-mask) are registered in two glass plates [2]. After etching in HF, the track-density is measured under an optical microscope***. Fields through the center of the shadows of the two <111> -axes are integrated over azimuthal angles, giving the angular distribution of Fig. 2. The difference in shadow-depth can be deduced to $\Delta_\chi = .16 \pm .07$. Considering the relatively short reaction time of $^{238}U(n,f)$ and $^{238}U(n,nf)$ ($1.0 \cdot 10^{-17}$s and $5.0 \cdot 10^{-17}$s respectively) and applying the formulas presented by Gibson and Nielsen [3], we obtain as the final result for the $^{238}U(n,2nf)$-reaction time

$$\tau = (4.9 \begin{matrix} +\ 3.4 \\ -\ 2.8 \end{matrix}) \cdot 10^{-16} s$$

As the prefission neutrons deteriorate the depth of the blocking shadows recoiling the compound nucleus, the upper limit of the reaction time can be estimated. The mean recoil distances resulting from the two emerging prefission neutrons are calculated by a simple Monte Carlo-program as a function of the displacement of the compound nucleus.

In Fig. 3, semiempiric calculations on the base of reaction width ratios (---) and a theoretical approach (Hauser-Feshbach calculation [4], -.-.-) are compared with results from Moscow [5] and Aarhus-Studsvik [6] for the $^{238}U(n,f)$-reaction in a similar excitation energy range as our result.

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** We are grateful to Dr. J.L. Whitton, Chalk River Nuclear Laboratories, Canada, for loaning us such crystals

*** Dr. Schaefer of Wild AG, Heerbrugg, Switzerland, made us the M501-sampling-microscope disposable.

Fig. 1

Experimental arrangement for the measurement of the $^{238}U(n,2nf)$-reaction time. 14.3-MeV neutrons are produced by the $T(d,n)\,^4He$-reaction. The distance between the T-target and the UO_2-crystal is 12 mm, the distance between the crystal and the glass plates 200 mm.

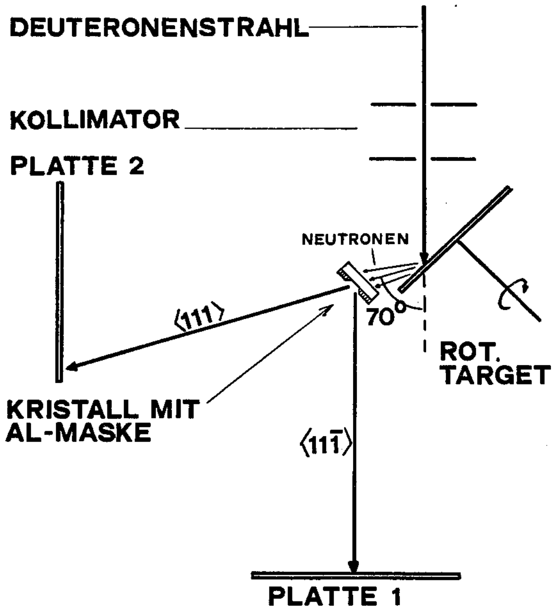
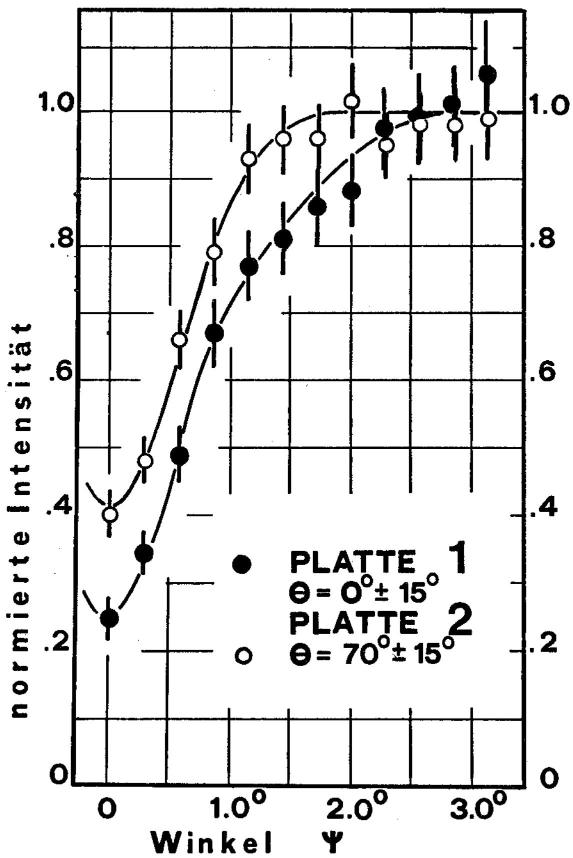


Fig. 2

Angular distribution of the fission fragments emerging from the UO_2-single crystal bombarded with 14.3-MeV neutrons, integrated over azimuthal angles near two < III >-axes and normalized for large emission angles.



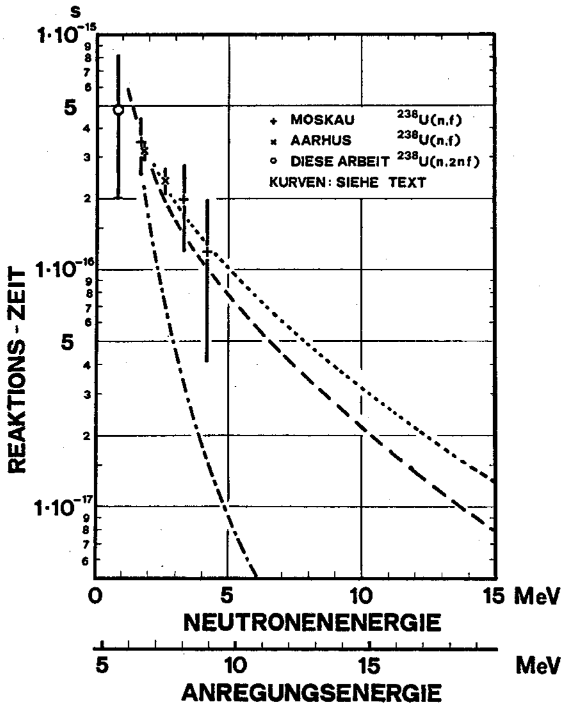


Fig. 3

Comparison of measured and calculated reaction times for neutron-induced fission of ^{238}U. For literature and curves see text.