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T. Hürlimann

Swiss Federal Institute for Reactor Research
Würenlingen

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PREFACE

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CONTENTS

I. Institut de Physique, Université de Neuchâtel

(Dir.: Prof. Jean Rossel)

1. $D(\vec{n}\ \vec{n})D$ elastic scattering at low energy

M. Ahmed†, D. Bovet, P. Châtelain, S. Jaccard††,
R. Viennet and J. Weber

The depolarization factor $D(\Theta)$ at $E_n = 2.45$ MeV has been measured at the Lab. angles: 30^o, 40^o, 55^o, 70^o, 90^o. The data processing is in progress. The experimental set up has been described elsewhere {1}.

A phase shift analysis has been performed at 2.45 MeV, fitting the differential cross section data of Seagrave {2} as well as our complete set of measurements of the polarisation $P(\Theta)$ and our two preliminary results of $D(\Theta)$ {1}. The analysis was done for two distinct situations:

a) Mixing parameters and J-degenerate phase shifts

b) Splitting of the quartet phase shifts.

The angular distribution of the Wolfenstein's parameters predicted by these two kinds of analysis do not show any significant differences.

An ERA analysis below the deuteron break-up threshold, in the framework of the diagonal-J degenerate model is in progress.

A fast neutron-gamma discriminator {2} is being tested which should be included in our experimental set-up.

A sophisticated supra-conducting magnetic system is also under test. It will be used in the near future in the measurements of the Wolfenstein's parameters.

†Present address: Birmingham University, England
††Present address: TRIUMF, Columbia University, Vancouver, Canada

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{1} S. Jaccard, thèse, Université de Neuchâtel 1972

{2} Seagrave et al. Phys. Rev. 105 (1957) 1816

{3} P. Betz et al. Nucl. Instr. Meth. 119 (1974) 199

2. Study of three models for the quasifree scattering of two neutrons in the d(n,nn)p reaction*

E. Bovet and F. Foroughi

We have made a systematic study of n-n quasi-free scattering in the d(n,nn)p reaction, with the aid of three models: the impulse approximation, the Cahill model {1} and the Ebenhöh Code {2}. We have obtained interesting results. For example, the "Chew-Low Plot" for all three models is a straight line, while the Cahill model satisfies the Treiman-Yang {3} criterion and gives a considerable improvement in the absolute value of the differential cross-section, over that obtained with the impulse approximation.

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{2} W. Ebenhöh, Nucl. Phys. A191 (1972) 97

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* An article has been submitted to H. P. A. for publication

3. Checking the alignment of a scattering chamber and measuring angular resolution with the aid of a position sensitive detector*

E. Bovet, F. Foroughi, G. Pauletta, C. Nussbaum and S. Tchiguir†

In the non relativistic case, the relation between the coincidence angles of two elastically scattered particles does not depend on the incident energy. For relativistic energies such as are obtained from a cyclotron, there is a weak correction in the angle. For example the variation is of the order of 0.01^{o}/MeV for elastic scattering of 70 to 80 MeV protons on deuterium. Consequently, the energy of the incident beam need not be known accurately.

Two signals are obtained from our surface barrier position sensitive detector (SBPSD); one proportional to the energy E deposited in the detector and the other to $E \cdot X$, where X is the distance from one end of the detector at which the particle is incident. The ratio X of these two signals is independent of E. Thick targets and a beam having a poor energy resolution can therefore be used, and this leads to an important reduction in the machine time. It should also be noted that since it is not necessary to stop the particles in the SBPSD, a thin SBPSD can be used.

In order to check the alignment of a scattering chamber with respect to the beam direction, or to measure the angular resolution of a detector mounted at an angle Θ_b, one centres a SBPSD at an angle Θ_a (where Θ_a and Θ_b correspond to the coincidence angles). Signals from the SBPSD are passed if they are in coincidence with those from the detector, and X is obtained as described above. The angular displacement of the chamber axis from the beam direction is directly related to the mean value of X, and the angular resolution of the detector at Θ_b to the width of the X distribution. It should be noted that one should not use particles of the same mass because, in the non-relativistic case, their angular separation is always 90^{o} and therefore does not depend on the direction of the incident beam, while at relativistic energies, the dependence is slight.

†On leave from the Moscow Physical Engineering Institute

The angular resolution depends on the defocalisation of the beam. Thus this method also represents a good way of finding the compromise between good focalisation and beam current best suited to ones particular requirements. It has been used successfully for our scattering chamber {1} at SIN (Swiss Institute for Nuclear Research) with a proton beam and a deuterated polyethylene target.

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II. Institut de Physique, Université de Fribourg

(Dir.: Prof. Dr. O. Huber)

Study of the $^{191}Ir(n,\gamma)$ and $^{193}Ir(n,\gamma)$ reactions with a curved crystal spectrometer*

W. Beer, J.-C. Dousse, J. Kern, A. Raemy and W. Schwitz

The thermal capture gamma rays from the $^{191}Ir(n,\gamma)$, $^{193}Ir(n,\gamma)$ and $^{nat}Ir(n,\gamma)$ reactions have been observed with the Fribourg curved crystal spectrometer of DuMond type {1}. The targets were placed in the tangential through-tube of the reactor SAPHIR in Würenlingen.

The gamma rays from the above reactions had been previously observed with semiconductor detectors by Krüger et al. {2} and by the present authors in the energy range 40 - 600 keV. It was obvious from the spectra that many peaks were unresolved. A new measurement with a spectrometer of higher energy resolution was thus felt necessary. Fig. 1 shows two portions of the same spectrum observed with a Ge(Li) detector of good resolution and with the crystal spectrometer.

In fig. 2 are compared three spectra from the above reactions, showing how the lines can be assigned to one or the other isotope. About 100 transitions have been observed in ^{194}Ir and over 200 in ^{192}Ir. For the more intense peaks an energy precision of the order of one eV has been achieved. Most lines have been observed in several orders of reflection. The number of orders at which a particular line can be seen is limited by the decreasing crystal reflectivity with increasing order of reflection.

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{1} O. Piller, W. Beer and J. Kern, Nucl. Instr. Meth. 107 (1973) 61

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* Work supported in part by the Fonds National Suisse de la Recherche Scientifique

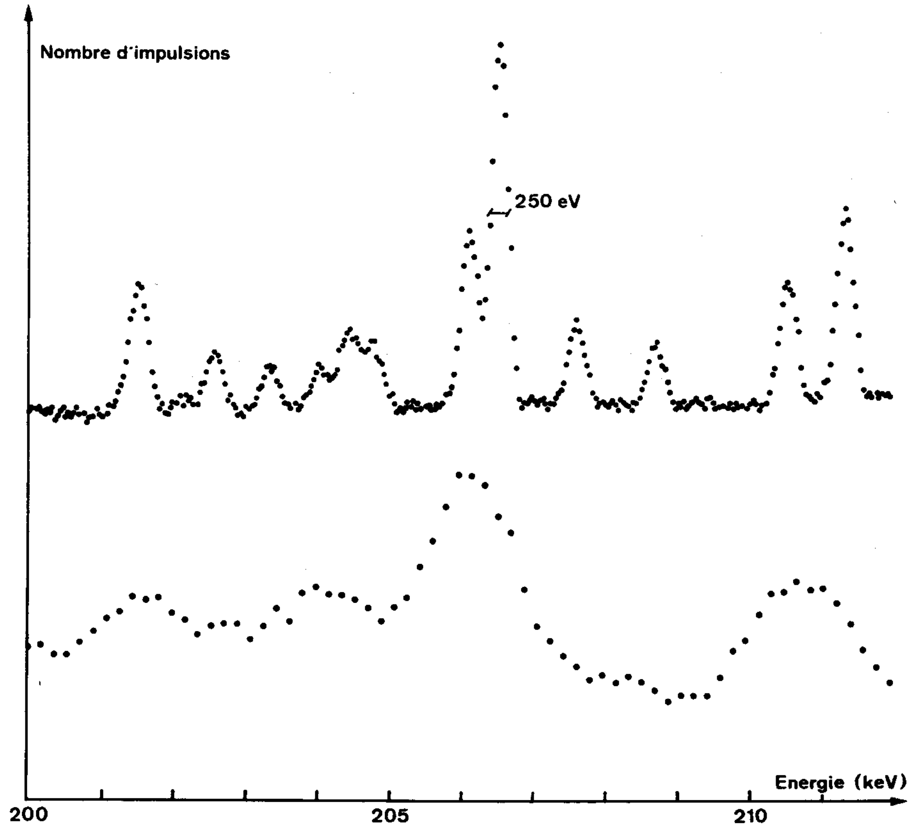

Fig. 1: Comparison of two portions of the $^{nat}Ir(n,\gamma)$ spectrum observed with a 2.4 cm^3 Ge(Li) diode (lower spectrum) and with the curved crystal spectrometer (upper spectrum) in 2^{nd} order of reflection.

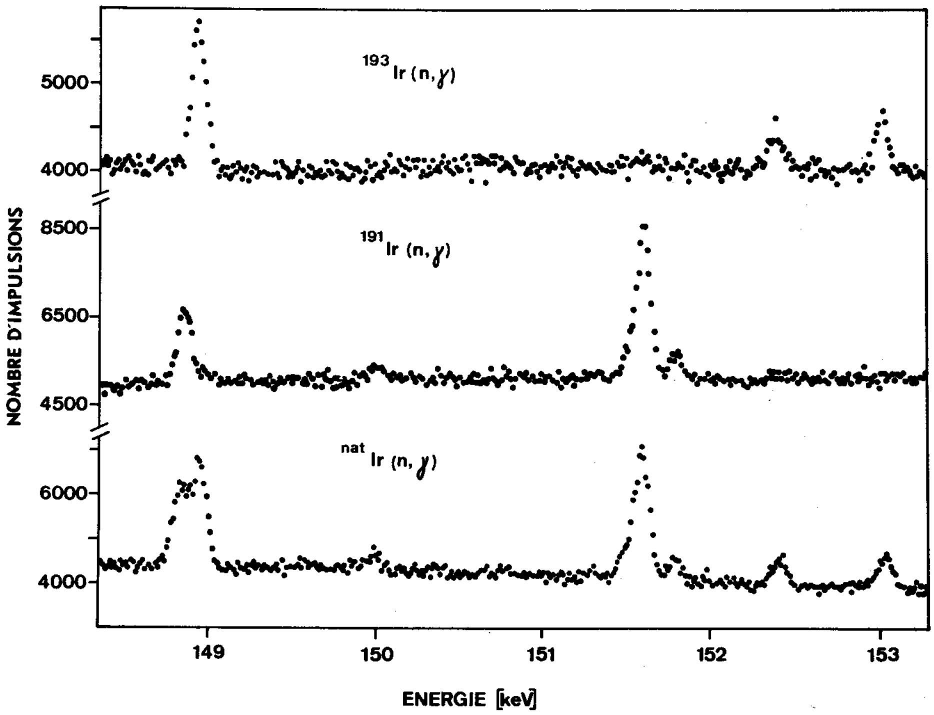

Fig. 2: Three portions of the $^{191}Ir(n,\gamma)$, $^{193}Ir(n,\gamma)$ and $^{nat}Ir(n,\gamma)$ spectra observed in 3^{rd} order of reflection.

III. Physik-Institut der Universität Zürich

(Dir.: Prof. Dr. Verena Meyer)

Eleastic and inelastic scattering of protons from ^{54}Fe

H. Brändle, V. Meyer, M. Salzmann

The cross sections for elastic and inelastic scattering of protons from ^{54}Fe leading to the compound nucleus ^{55}Co have been measured at proton energies between 3.1 and 4.4 MeV at angles of 90°, 125°, 141° and 165° with respect to the beam. The results for 165° are shown in fig. 1, together with an R-matrix fit. The resonant levels, their eleastic and inelastic widths are given in table 1.

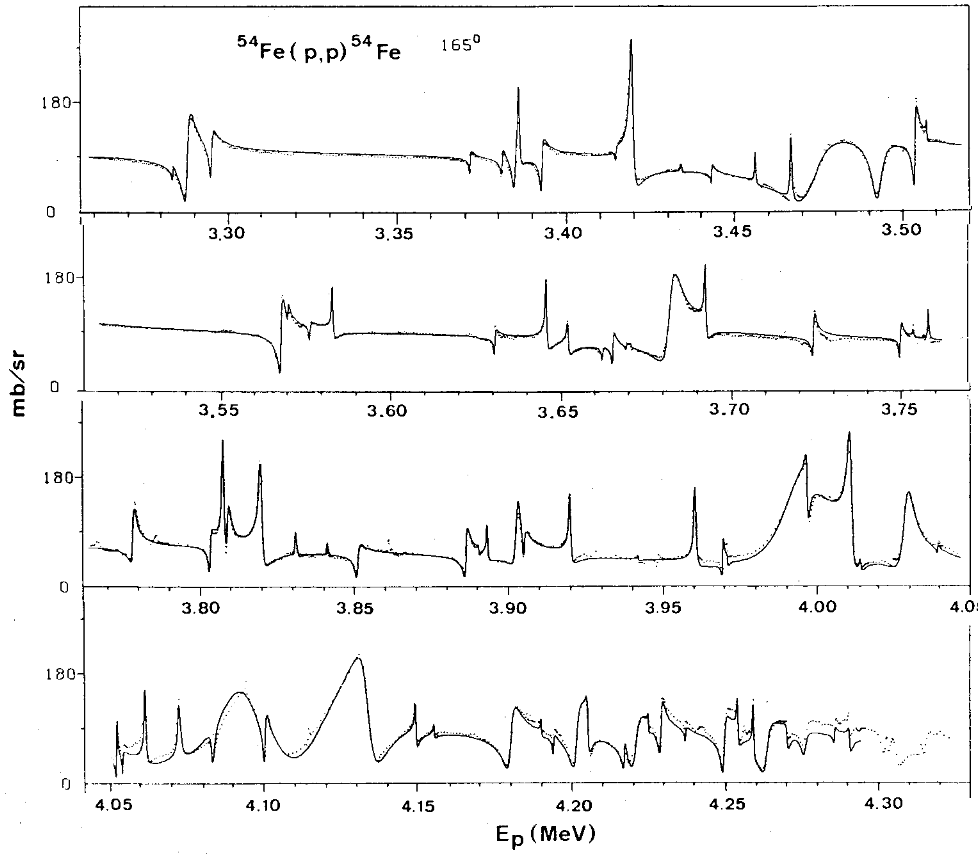

Fig. 1: Elastic scattering cross section at Θ_{lab} = 165°. The solid curve is a fit to the data with the parameters given in table 1.

Table 1

$^{54}Fe(p,p)$ and $^{54}Fe(p,p')$ resonance parameters

E_p^{lab} (MeV)	ℓ_p	J^π	Γ_p (eV)	γ_p^2 (keV)	$\Gamma_{p'}$ (eV)	$\gamma_{p'}^2$ (keV)	E_p^{lab} (MeV)	ℓ_p	J^π	Γ_p (eV)	γ_p^2 (keV)	$\Gamma_{p'}$ (eV)	$\gamma_{p'}^2$ (keV)
3.2834	1		60	0.36			3.9420	2	$(3/2^+)$	30	0.22	10	1.49
3.2876	1	$3/2^-$	1400	8.31	30	11.03	3.9481						
3.2948	1	$1/2^-$	500	2.93			3.9603	2	$5/2^+$	500	3.50	30	0.43
3.3715	1	$3/2^-$	100	0.52			3.9693	1	$(3/2^-)$	150	0.34		
3.3810	0	$1/2^+$	170	0.46			3.9710	2	$(5/2^+)$	100	0.69	150	2.12
3.3846	1	$1/2^-$	1100	5.57			3.9894	0	$1/2^+$	20000	26.66		
3.3861	2	$5/2^+$	300	5.36			3.9968	2	$3/2^+$	400	2.66	10	0.13
3.3927	1	$3/2^-$	350	1.75	100	22.78	4.0109	2	$5/2^+$	1300	8.49	120	1.53
3.4147	1	$(3/2^-)$	60	0.29			4.0141	2	$(3/2^+)$	200	1.30	70	0.88
3.4195	2	$5/2^+$	750	12.95	10	0.86	4.0244						
3.4342	2	$(5/2^+)$	20	0.31			4.0254						
3.4432	1	$3/2^-$	95	0.44			4.0282	0	$1/2^+$	3800	4.88		
3.4561	2	$(5/2^+)$	50	0.78			4.0392	0	$1/2^+$	50	0.06	10	1.11
3.4667	(2)	$(5/2^+)$	200	3.08	30	25.60	4.0524	1	$3/2^-$	200	0.42	10	0.25
3.4724	1	$1/2^-$	14000	61.57			4.0543	1	$(1/2^-)$	160	0.33	30	0.73
3.4930	1	$1/2^-$	3600	15.39			4.0615	2	$5/2^+$	400	2.44	10	0.11
3.5036	1	$3/2^-$	350	1.47	15	2.16	4.0726	2	$5/2^+$	750	4.50	90	0.98
3.5072	2	$(5/2^+)$	60	0.86	10	0.61	4.0834	2	$5/2^+$	400	2.37	400	39.26
3.5663	1	$(1/2^-)$	50	0.19	15	1.70	4.0850	0	$1/2^+$	25000	30.47		
3.5678	1	$3/2^-$	600	2.30	15	1.69	4.1005	1	$3/2^-$	500	0.99	35	0.76
3.5700	0	$1/2^+$	80	0.17	40	22.19	4.1210	0	$1/2^+$	30000	35.39		
3.5764	1	$3/2^-$	60	0.23	25	2.51	4.1340	2	$5/2^+$	6000	33.22	200	1.89
3.5831	2	$(5/2^+)$	140	1.76	5	0.23	4.1497	2	$(5/2^+)$	180	0.98	80	6.52
3.6308	1	$3/2^-$	110	0.39	15	1.34	4.1556	2	$(5/2^+)$	40	0.22	20	1.61
3.6459	2	$5/2^+$	220	2.49	25	0.93	4.1805	0	$1/2^+$	2600	2.91		
3.6524	2	$3/2^+$	220	2.46	10	0.36	4.1904	2	$(5/2^+)$	40	0.21	10	0.08
3.6623	1	$(1/2^-)$	120	0.40			4.1943	1	$3/2^-$	100	0.18	40	0.69
3.6654	1	$3/2^-$	160	0.53	20	1.58	4.2018	0	$1/2^+$	2500	2.75		
3.6694	1	$3/2^-$	30	0.10	5	0.39	4.2055	2	$3/2^+$	600	3.03	120	0.97
3.6707	2	$(3/2^+)$	15	0.16	3	1.13	4.2172	1	$(3/2^-)$	250	0.44	20	0.33
3.6820	0	$1/2^+$	3800	7.03			4.2206	1	$1/2^-$	3300	5.78		
3.6928	2	$5/2^+$	220	2.31	15	0.48	4.2252	2	$(3/2^+)$	100	0.49	15	0.12
3.7244	0	$1/2^+$	300	0.53			4.2292	0	$1/2^+$	700	0.75		
3.7497	1	$3/2^-$	700	2.09			4.2372	1	3/2	50	0.09	25	0.39
3.7499	2	$5/2^+$	400	3.83	15	0.40	4.2432						
3.7537	3	$(5/2^-)$	10	0.55	20	1.18	4.2496	1	$3/2^-$	800	1.36	220	3.32
3.7581	3	$(5/2^-)$	25	1.37	40	2.32	4.2542	2	$(5/2^+)$	170	0.81	60	0.44
3.7782	0	$1/2^+$	800	1.33	90	23.02	4.2592	2	$(5/2^+)$	200	0.95	50	3.04
3.8032	1	$3/2^-$	400	1.12	100	5.03	4.2632	1	$1/2^-$	3000	5.04		
3.8076	2	$5/2^+$	500	4.38	50	1.11	4.2703	2	$(3/2^+)$	200	0.93	400	2.81
3.8090	1	$3/2^-$	800	2.22	80	3.95	4.2757	1	$1/2^-$	700	1.16	900	12.82
3.8198	2	$5/2^+$	800	6.88	80	1.72	4.2856	0	$1/2^+$	100	0.10	60	0.34
3.8311	3	$(7/2^-)$	30	1.44	50	2.31	4.2907	2	$(3/2^+)$	180	0.82	200	11.26
3.8412	3	$(7/2^-)$	15	0.71	30	1.34	4.3024						
3.8509	1	$1/2^-$	900	2.37			4.3051						
3.8611							4.3142						
3.8624							4.4132	0	$1/2^+$	2500	2.32		
3.8861	1	$3/2^-$	600	1.51	60	2.34	4.461	0	$1/2^+$	2000	1.79		
3.8903	2	$(5/2^+)$	30	0.23	50	0.88	4.526	0	$1/2^+$	2400	2.04		
3.8931	2	$(5/2^+)$	150	1.16	35	0.61	4.576	0	$1/2^+$	1500	1.25		
3.9023	0	$1/2^+$	1700	2.47			4.671	0	$1/2^+$	20000	15.53		
3.9049	1	$1/2^-$	500	1.23	30	1.11	4.748	0	$1/2^+$	1500	1.12		
3.9199	2	$(5/2^+)$	350	2.60	50	7.99	4.83	0	$1/2^+$	50000	34.32		

IV. Laboratorium für Kernphysik, Eidg. Technische Hochschule, Zürich

(Dir.: Prof. Dr. J. Lang)

Investigation of the $^{2}H(\vec{d},p)^{3}H$ reaction with polarized deuterons

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

For several years the reaction $^{2}H(d,p)^{3}H$ has been among the favourite reactions used in investigating the ^{4}He nucleus. Not only the cross section, but also the polarization of the outgoing protons have been measured over a wide energy range {1}. The production of polarized deuterons by polarized ion sources has permitted this reaction to be studied in more detail. A series of analysing power measurements have been performed at low energy up to about 0.5 MeV by the Basle group {2}, Franz and Fick {3}, and Ad'yasevich et al. {4}. Measurements in the energy range between 3 and 11.5 MeV have been performed some time ago {5} in this laboratory. The analysis in {5} suffers from the fact that between 0.5 and 3.0 MeV no analysing power data were available. The installation of a more powerful polarized ion source at the 12 MeV EN-tandem accelerator made it possible to measure the necessary data in the energy range between 1.0 and 3.0 MeV. At these low energies the transmission through the accelerator was quite low, but the target current was still sufficiently high (a few n A). Measurements of the differential cross section σ_0, the vector analysing power iT_{11}, and the three tensor analysing powers T_{20}, T_{21}, and T_{22} have been carried out in energy steps of 0.5 MeV.

The experimental method and the general procedure for measuring the vector and tensor analysing powers of nuclear reactions with the polarized deuteron beam has been discussed in previous papers {6}. The Madison convention {7} has been used in the representation of the tensor components T_{kq}.

The results of the differential cross section measurements are shown in fig. 1. The vector and tensor analysing powers are represented in figs. 2

and 3. For comparison, the result of ref. {2} at 0.46 MeV is shown too. In all three figures most of the statistical errors are smaller than the dots; the solid lines are the result of a Legendre polynomial analysis.

The results of analysing the differential cross section data in term of Legendre polynomials can be used to calculate the total cross section at the various energies measured. The results are represented in fig. 4. The open circles at lower energy are from {8}; the results at higher energy are from {5}. At 3 MeV the results of the analysis of the present data and of {5} are shown. A curve has been drawn by hand through the dots representing the data.

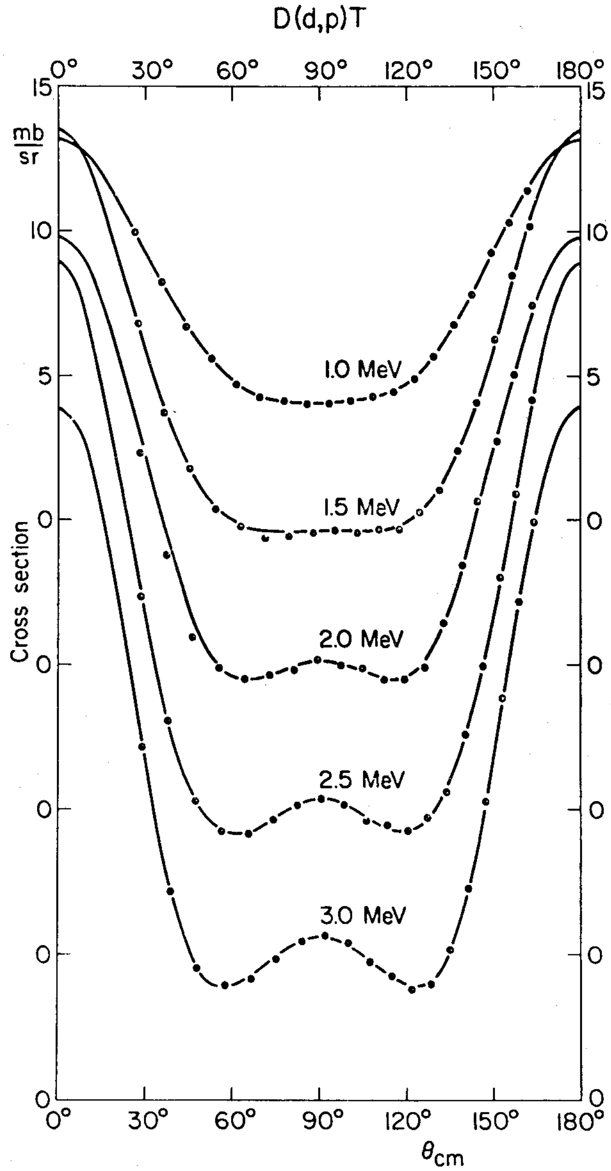

Fig. 1: Angular distributions of the cross section for the $^2H(d,p)^3H$ reaction. The dots are larger than the statistical error. The solid lines are Legendre polynomial fits.

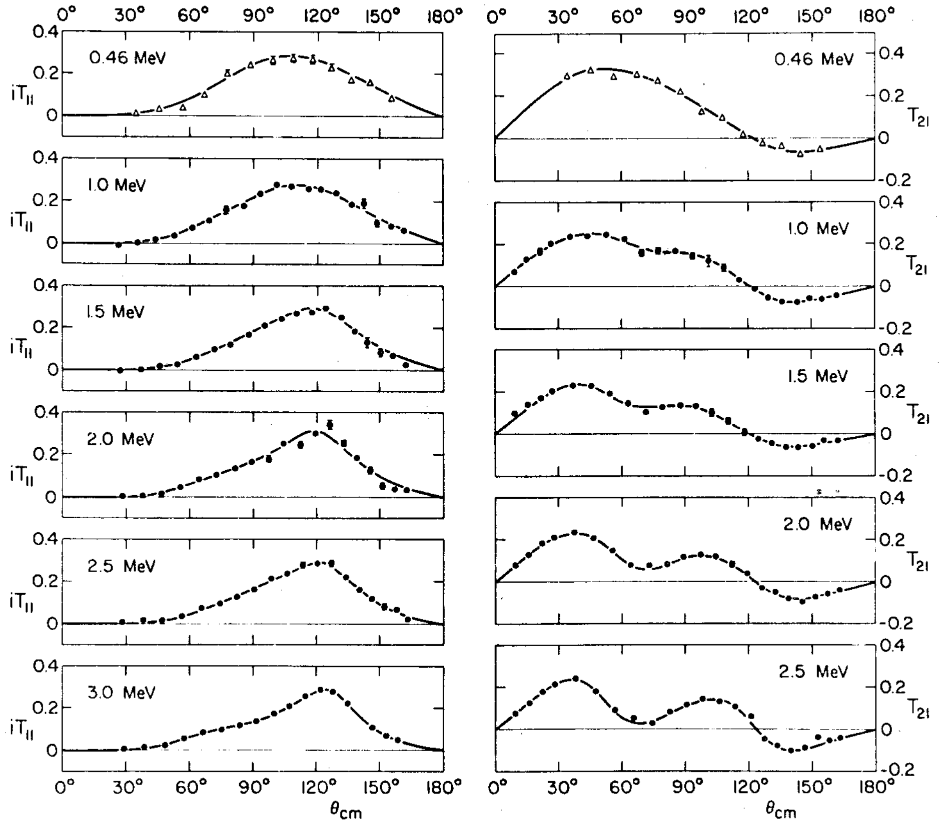

Fig. 2: The analysing powers iT_{11} and T_{21} between 0.46 and 3.0 MeV. Where no error bars are shown the statistical error is smaller than the dots. The solid lines are Legendre polynomial fits. The results at 0.46 MeV are from ref. {2}.

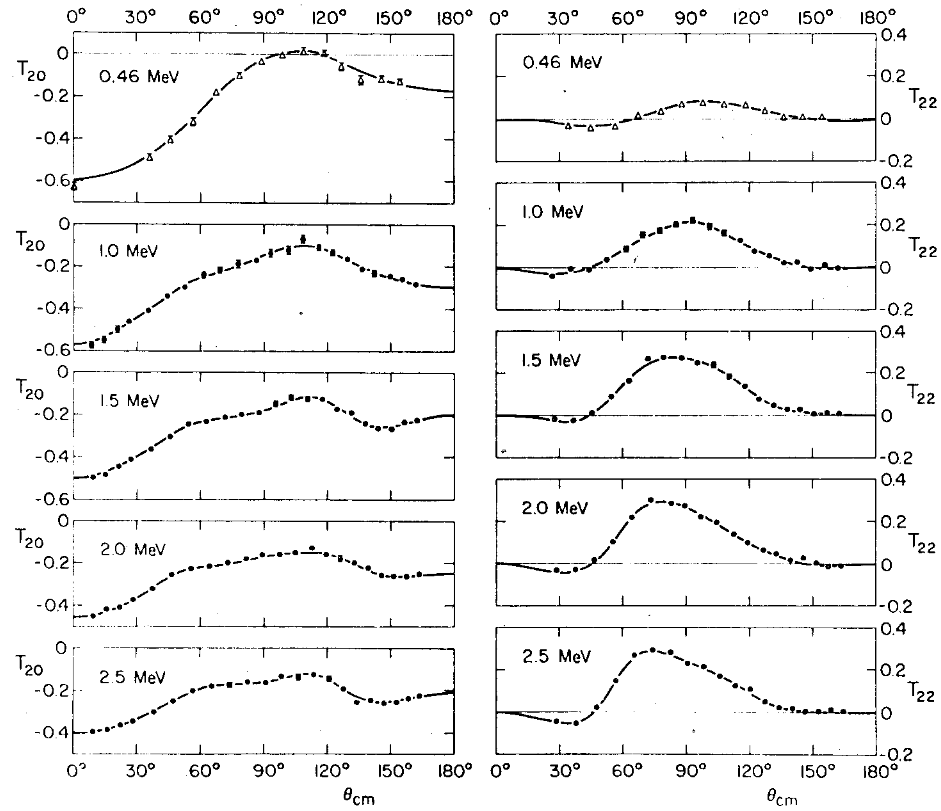

Fig. 3: The tensor analysing powers T_{20} and T_{22} between 0.46 and 2.5 MeV. Where no error bars are shown the statistical error is smaller than the dots. The solid lines are Legendre polynomial fits. The results at 0.46 MeV are from ref. {2}.

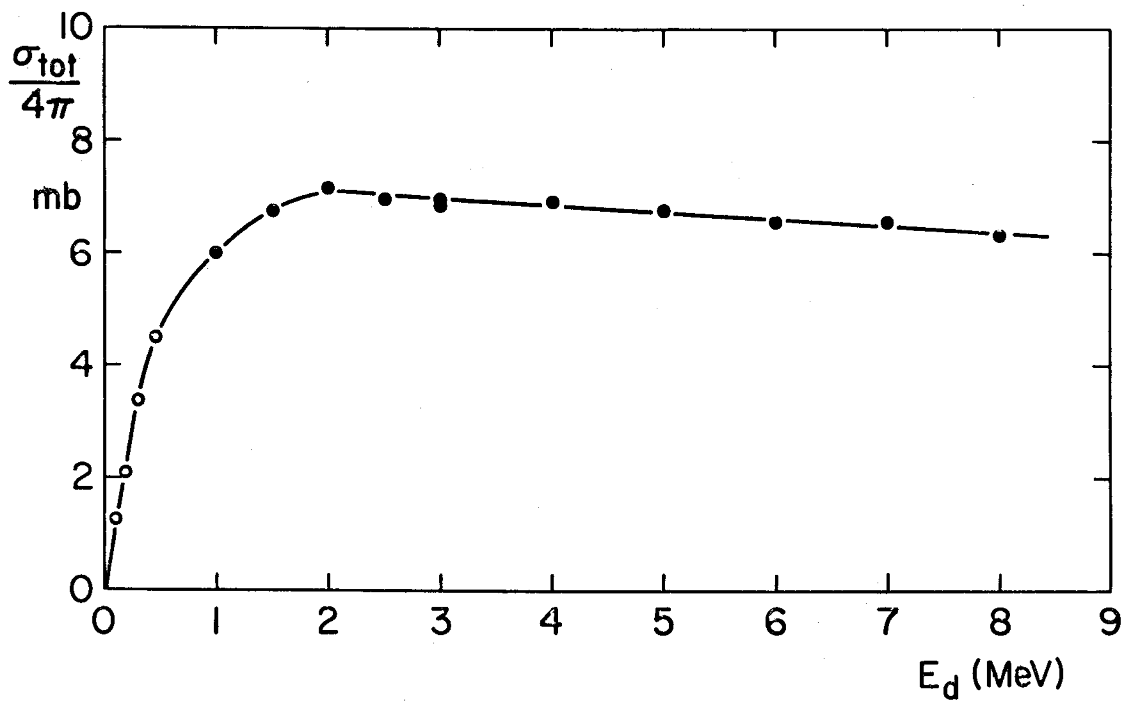

Fig. 4: Total cross section $\sigma_T/4\pi$ of the $^2H(d,p)^3H$ reaction. The open circles are from ref. {8}; the results at energies higher than 3 MeV are from ref. {5}.

The normalized Legendre polynomial coefficients {5}

$$d_{kq}(L) = \frac{4\pi\, ƛ^2\, a_{kq}(L)}{\sigma_{tot}} = \frac{a_{kq}(L)}{a_{oo}(0)}$$

are presented as a function of the incident deuteron energy in fig. 5. The dots are the results of the calculations; the solid lines are drawn by hand for the sake of clarity. The size of the dots are in all cases larger than or equal to the error found in the fit. Legendre coefficients which are too small to appear different from zero at all energies on the scale used in fig. 5 are not shown. At low energy the results of the Basle group {2} and at energies higher than 2.5 MeV the results of {5} are indicated. The most prominent variation in the value of the coefficients occurs in the energy range up to about 3 MeV. The present experimental data were needed to determine the behaviour in this energy region quantitatively. A search for one or more resonances in ^{4}He in this energy region, as well as the assignment of spin and parity can only be done in a careful, detailed analysis, which is in preparation in this laboratory.

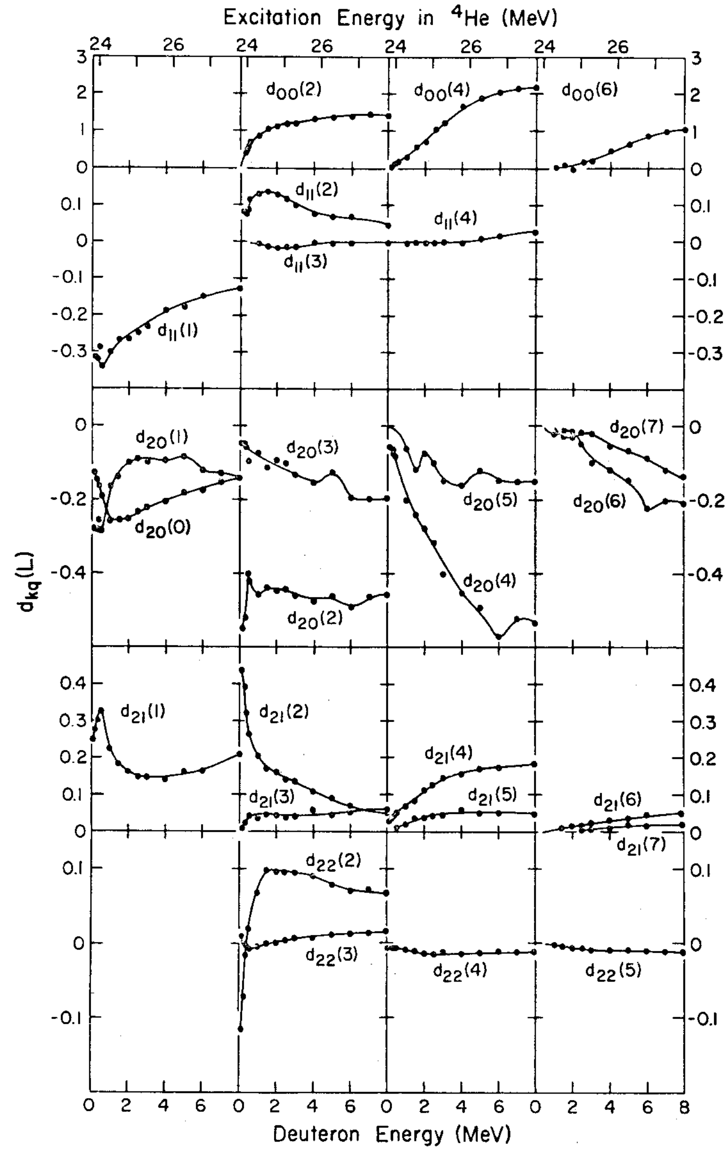

Fig. 5: Normalized Legendre polynomial expansion coefficients $d_{kq}(L)$ for the differential cross section, and the vector and tensor analysing powers. The dots are larger than the uncertainties of the fits. At energies below 0.5 MeV the results are from ref. {2}.

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V. Eidg. Institut für Reaktorforschung, Würenlingen

(Dir.: Prof. Dr. H. Gränicher)

1. Neutron capture cross sections of ^{151}Eu, ^{153}Eu, ^{175}Lu and ^{176}Lu in the energy region from 0.01 to 10 eV

J. F. Widder

Neutron capture cross sections in the thermal and epithermal energy region are still required for several elements and isotopes. These cross sections are needed for different purposes such as detector applications, fission product poison calculations, burn-up calculations, flux measurements and others.

In order to fulfill requests for neutron data the capture cross sections for the elements Europium and Lutetium have been measured in the energy range from 0.01 through 10 eV using conventional time-of-flight techniques and a Moxon-Rae detector. The cross sections of the isotopes ^{151}Eu, ^{153}Eu, ^{175}Lu and ^{176}Lu were determined by means of additional measurements on samples enriched in ^{153}Eu and ^{175}Lu, respectively.

The requests compiled in special NEANDC-Reports (WRENDA) are characterized by high accuracy requirements. Though the experimental techniques for the measurement of such cross sections by means of prompt capture gamma-rays are well known for years, difficulties may occur if high precision is required. For this reason we had to develop new improved methods for the determination of the absolute neutron flux, of background and dead time corrections as well as for the calculation of multiple neutron scattering and gamma-ray attenuation effects in samples in order to reduce the systematic errors.

The accuracy attained in our measurements for the capture cross section values is 2 - 4 % from 0.01 to 1 eV (2 % in the thermal region) and 3 - 5 % above 1 eV. For some resonance cross sections above 4 eV the total error increases up to 10 %.

All data (including systematic and statistical errors) have been transmitted to the NEA Neutron Data Compilation Centre in Saclay, France, and are available on request.

A detailed description is given in EIR-Report No. 217 (1975) (NEANDC(OR)-143) which will appear in the near future.

2. Cross sections important to molten salt reactor studies

E. Ottewitte

Recent studies have indicated the following reactions to be important to the formation of corrosive and radioactive impurities in a molten chloride fast reactor:

(n,γ) for Cl-35, Cl-36, Cl-37, P-32 and S-35,
(n,p) for Cl-35,
(n,α) for Cl-35.

The absorption cross section of Cl-37 is also critical to the breeding gain in a Cl-37 enriched MSBR.

In this vein EIR personnel are undertaking a complete evaluation of neutron cross sections for pertinent Cl isotopes in ENDF/B format.

To date this work has revealed the need for measurements

(a) to determine the isotopic identity of some of the measured natural Cl resonances,

(b) to determine Γ_p for most of the resonances, and deduce the associated degrees of freedom.

3. Reaction cross section for protons in the energy range of 10 - 70 MeV for Rb, Cs, Cd, Tl and Pb

F. Hegedüs, S. Chakraborty

In connection with the radioisotope production at the SIN injector cyclotron we are measuring reaction cross sections for protons in the energy range of 10 - 70 MeV for Rb, Cs, Cd, Tl and Pb.

Applying the "stacked foil technique" 25 - 30 thin foils of 30 mm in diameter were irradiated simultaneously. The thickness of the foil stack was 4 - 6 g/cm^2 corresponding to a degradation of the incident proton energy of 72 MeV to 40 - 10 MeV. The proton current was measured by means of the $^{65}Cu\ (p,pn)^{64}Cu$ reaction induced in thin copper foils placed between target foils. In order to avoid systematic errors the measurements will be repeated with lower incident proton energy and other target arrangement.

After bombardment the gamma spectra of the produced radionuclides in the different target foils were measured. In order to distinguish between (p,xn) and (p,p(x-1)n) type reactions sometimes chemical separation was performed. The evaluation of the spectra allows the determination of the reaction cross sections in function of the proton energy.