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~~NOT FOR PUBLICATION~~

INTRODUCTION

This progress report contains information of work done in the neutron cross section field at various Swiss laboratories during the last year. The information is not intended to be complete, nor does it cover all of the work in the reporting laboratories relating to nuclear cross section measurements. As some of the data, which appear in this report are of preliminary character, they must not be quoted in publications without permission of the experimenter associated with the work.

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I. Institut de Physique, Université de Neuchâtel

(Dir.: Prof. Dr. Jean Rossel)

1. Study of the 16.6 and 16.9 MeV levels of $^{8}Be^{*}$, through the reaction $^{7}Li(d,\alpha\alpha)n$ at 3 MeV

R. Corfu, C. Nussbaum

In continuation of the investigations presented in EANDC(OR) - 90 "L", 20 (1969), we have performed 11 biparametric measurements of the differential cross-section of the reaction $^{7}Li(d,\alpha\alpha)n$.

The choice of the set of angles of the two detected α's was obtained taking into account of a variation from 0^{o} to 180^{o} in CM of the emitted neutron in the first step of the reaction.

Analysis of the data and theoretical interpretation are in progress.

2. Treiman-Yang test for quasifree scattering at low energy, exchanging particles of spin 0, 1/2 and 1

R. Corfu, J.-P. Egger, C. Lunke, C. Nussbaum, J. Rossel,
E. Schwarz (Université de Neuchâtel)

J.-L. Durand and C. Perrin
(Institut des Sciences Nucléaires, Grenoble, France)

The experimental results of the study of deuteron break-up and other 3-body reactions on light nuclei indicate that the enhancement associated with the quasifree kinematic condition is very important even at bombarding energies of a few MeV. However, this does not necessarily imply that the pole graph represents a dominant contribution. The importance of this contribution can be tested with the Treiman-Yang criterion [1] which is based on the invariance of the pole graph matrix element for the reaction with respect to rotations (angle ϵ) of the second stage reaction plane about the direction of the exchanged particle. Shapiro indicates [2] that this is only true if the energy associated with the momentum transfer is lower than the binding energy [3] and if the spin of the exchanged particle is 0 or 1/2. We have studied the reactions H(d, 2p)n at 20 MeV, $^{6}Li(p,pd)^{4}He$ and $^{6}Li(p,p\alpha)^{2}H$ at 50 MeV which include the exchange of protons, neutrons, deuterons and alpha particles. The use of deuterons as projectiles in the deuteron break-up reaction is advantageous because the direction of the exchanged nucleon is defined directly in the laboratory coordinate system and the available phase space is the same for all T-Y angles. Kinematical conditions were chosen to insure high relative energies between particles in the final state, therefore final state interactions were ignored.

Absolute cross sections for the above reactions have been measured in a series of complete experiments using CH_2 and self supporting ^{6}Li targets and deuteron and proton beams from the Grenoble isochronous cyclotron. The reaction products were detected by two ΔE-E detector telescopes placed within a spherical reaction chamber of 1.2 m in diameter which allows motions out of the reaction plane. The energies and the time of flight difference of each coincident event were measured and stored on magnetic type by a PDP-9 data acquisition system.

Particle identification was done off-line.

In the case of the H(d, 2p)n reaction the T-Y distribution varies between 10.2 ± 1.3 and 17.9 ± 1.5 mb sr^{-2} MeV^{-1} for T-Y angles ranging from 0^{o} to 110^{o} for a fixed momentum transfer $\vec{q}$ such that $\frac{q^2}{2m} = 0.9$ MeV. This implies that at $E_{inc} = 20$ MeV several diagrams must be taken into account (see fig. 1 and 2). Analysis of the p + ^{6}Li data is in progress.

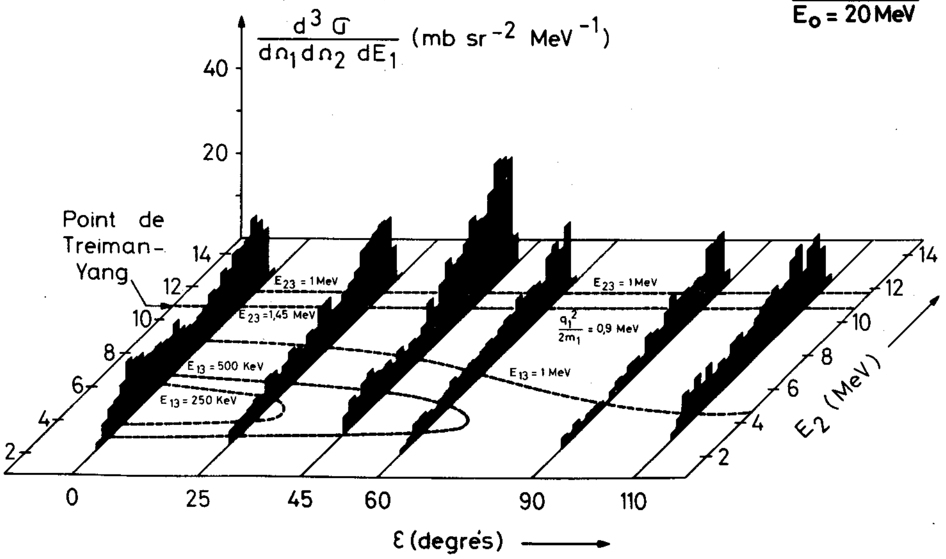

Fig. 1: Display of cross section in angle ε and energy of spectator proton.

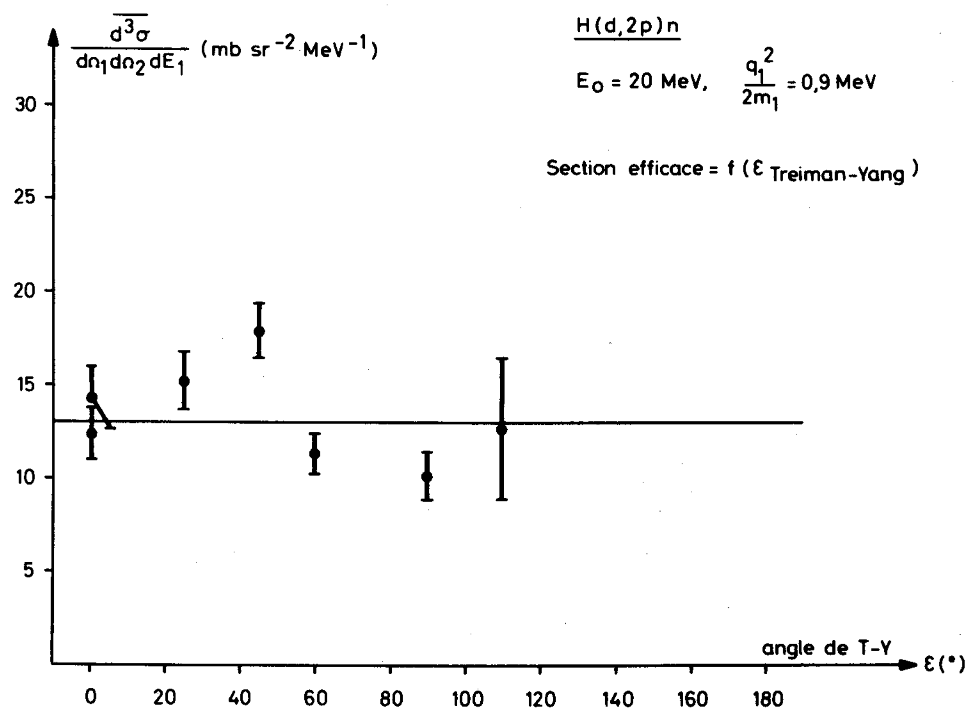

Fig. 2: Variation of cross section with T-Y angle ε.

References

[1] S.B. Treiman and C.N. Yang, Phys. Rev. Letters 8 (1962) 140

[2] I.S. Shapiro, V.M. Kolybasov and G.R. Augst, Nucl. Phys. 61 (1965) 353

[3] I.S. Shapiro, Proc. Intl. Schl. Phys. "Enrico Fermi" 38 (1967) 232

3. Polarization measurements in the D(n, n) scattering at 2.5 MeV* and in the C(d, n) reaction at 3 MeV

S. Jaccard, J.-F. Germond, J. Piffaretti and J. Weber

a) D(n, n)

Up to now, the neutron polarization has been measured at five angles θ_L : 40°, 45°, 46°, 60° and 120°. The experimental asymmetries have been corrected for multiple scattering by the Monte Carlo method. The results are:

θ_{Lab}	40°	45°	46°	60°	120°
P_1P_2	-0.0042 ±0.0039	-0.0039 ±0.0049	-0.0132 ±0.0041	-0.0164 ±0.0037	-0.0048 ±0.0075
P_2 % (P_1=40±2%)	+1.0±1.0	+1.0±1.2	+3.3±1.0	+4.10±0.95	+1.2±1.8

The errors are statistical + instrumental.

The angular distribution is being completed by measurements between 70° and 110° Lab and around 30° Lab.

A description of the polarimeter of a new type which we used and a detailed study of possible false asymetries are soon to be published [1] .

It is now being studied whether it is possible to use the $^9Be(\alpha, n_1)^{13}C$ [2] polarized neutron source to measure the $P_2(\theta)$ angular distribution at $E_n \approx 3.3$ MeV.

Based on the work of R. Viennet [3] , predictions of the values of the Wolfenstein's parameters in function of angle and energy are presently computed and will be published shortly [4] .

Triple scattering experiments are presently planned and should be in progress by the end of the year.

b) $^{12}C(d,n)$*

We have measured, with a liquid He polarimeter, the polarization of the neutrons from this reaction at 2.75 and 3 MeV.

The results are in good agreement with earlier measurements by Walter et al. [5, 6] and are being published in detail elsewhere [7].

$$\theta_L = 20^o \quad \overline{E_d} = 2.71 \text{ MeV} \quad P_1 = (-36.5 \pm 2.2)\ \%$$
$$\overline{E_d} = 2.96 \text{ MeV} \quad P_1 = (-37.0 \pm 1.8)\ \%$$

The errors are statistical + instrumental, the asymmetries have been corrected for multiple scattering.

* EANDC (OR) - 93 "L" (1970)

References

[1] J. Piffaretti,
Thesis 1971, Helv. Phys. Acta, to be published

[2] T. Stammbach, G. Spalek, J. Taylor and R.L. Walter,
N.I.M. 80, 304 (1970)

[3] R. Viennet,
Thesis 1971, to be published

[4] S. Jaccard and R. Viennet,
to be published

[5] J.R. Savers Jr, F.O. Purser Jr and R.L. Walter,
Phys. Rev. 141, 825 (1966)

[6] M.M. Meier, L.A. Schaller and R.L. Walter,
Phys. Rev. 150, 821 (1966)

[7] S. Jaccard, J.-F. Germond, J. Piffaretti and J. Weber,
Helv. Phys. Acta, to be published

4. Measurement of angular distribution for (n, p) and (n, α) reactions on ^{19}F, ^{29}Si, ^{32}S and ^{40}Ca at 5.8 MeV

F. Foroughi

We report there some results which have been obtained with a system of simultaneous detection and E-ΔE selection of charged particles for differential cross section measurements of (n, α) and (n, p) reactions on targets of CaF_2, S (natural isotopic composition) and ^{29}Si(95.3 % enriched). The incident neutron beam of 5.85 MeV had a mean resolution in energy of 75 keV. The experimental results have been corrected for geometric effects and for neutron attenuation in the intervening parts of the telescope.

In the following figures (1 to 9) the measured angular distributions are given and table I presents the values of total cross sections evaluated from the angular distribution histogrammes.

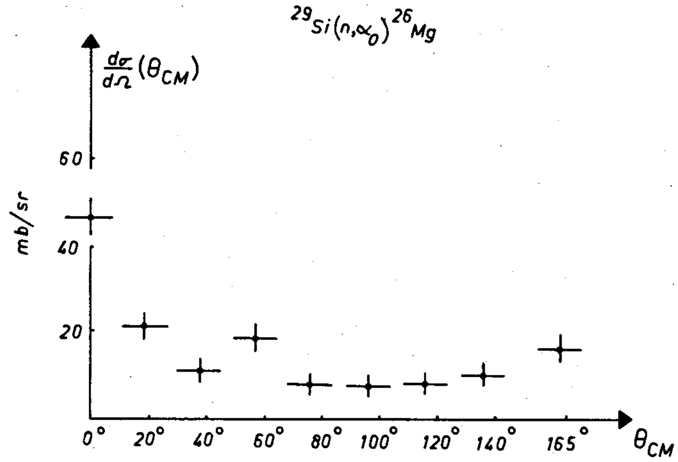

Fig.1

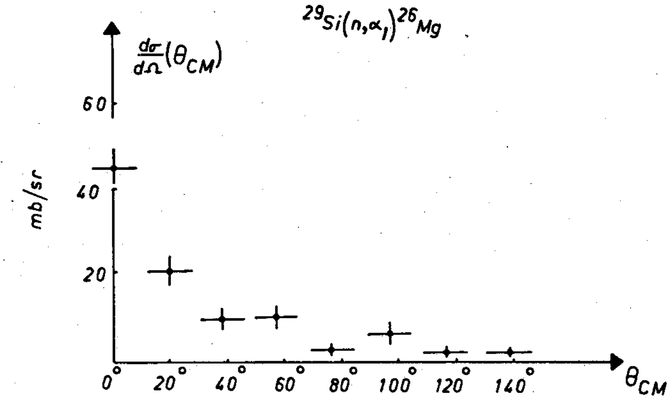

Fig.2

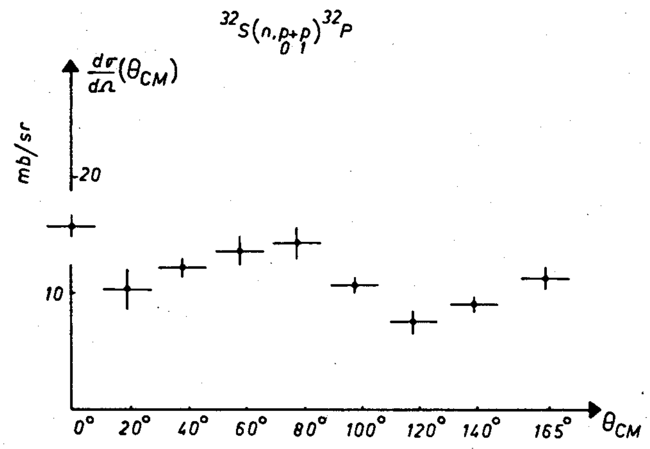

Fig.3

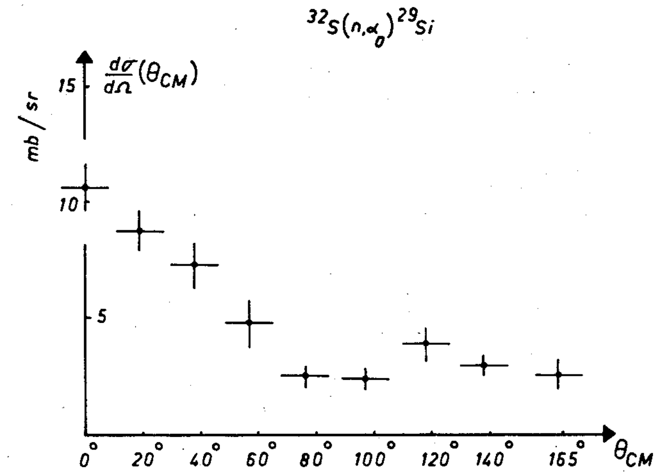

Fig.4

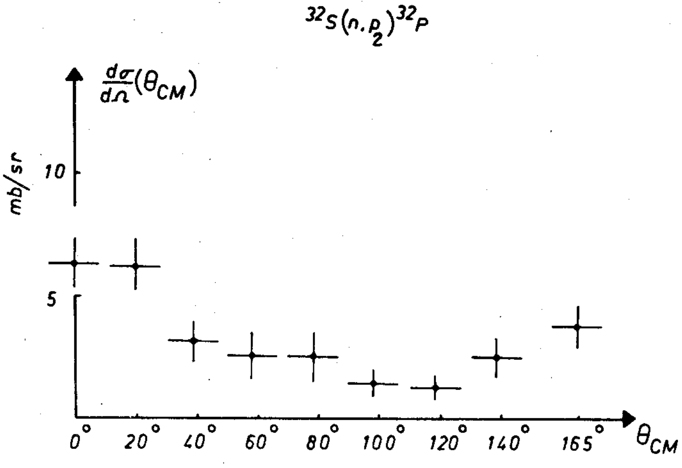

Fig. 5

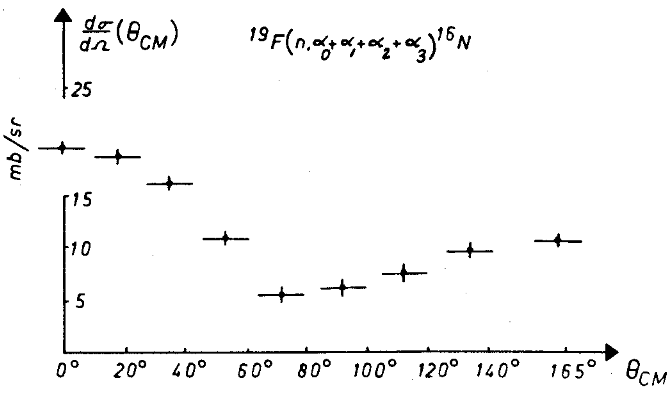

Fig. 6

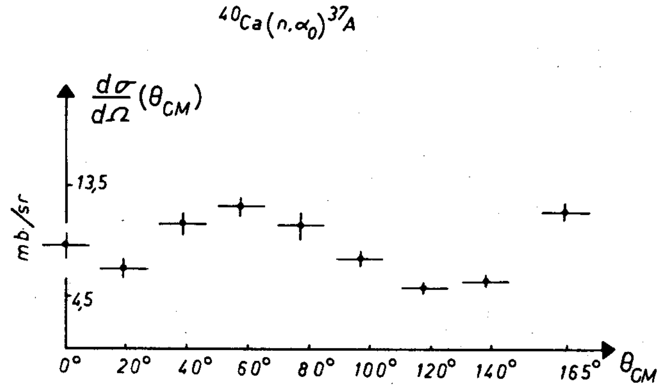

Fig. 7

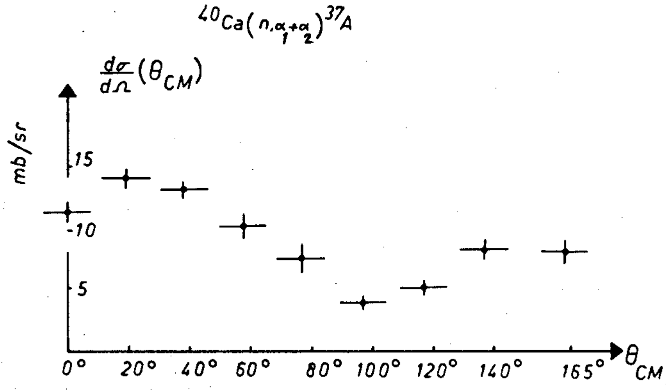

Fig. 8

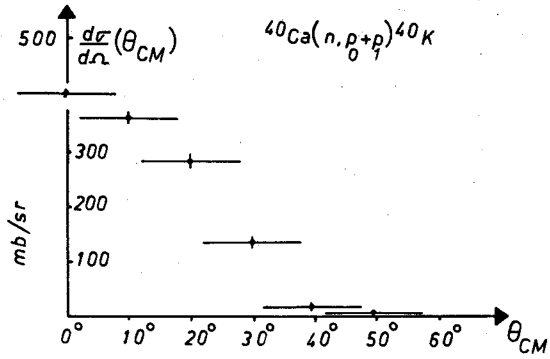

Fig. 9

TABLE I

	Reactions	σ
^{40}Ca	(n,α_0)	116 ± 12 mb
	$(n,\alpha_1+\alpha_2)$	110 ± 12 "
	(n,p_0+p_1)	365 ± 27 "
^{19}F	(n,α)	135 ± 17 mb
^{32}S	(n,α_0)	51 ± 7 mb
	(n,p_0+p_1)	150 ± 20 "
	(n,p_2)	82 ± 9 "
^{29}Si	(n,α_0)	140 ± 20 mb
	(n,α_1)	90 ± 10 "

II. Institut de Physique Nucléaire, Université de Lausanne

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

(n, Charged Particles) Reactions at 14.0 MeV

J.P. Perroud, Ch. Sellem

The complete angular distribution of the reaction $^{9}Be(n,\alpha)\,^{6}He$ (10 angles) and the angular distribution of the reaction $^{9}Be(n,t)\,^{7}Li$ in forward direction (up to 60^{o}Lab.) have been measured with the spectrometer described in [1].

The measured spectra show perfectly resolved peaks, which can be attributed to the following particles and reactions:

- 2 alpha rays emitted by $^{9}Be(n,\alpha)\,^{6}He$ leading to the ground and first excited (1.80 MeV) state of ^{6}He.
- 1 ^{6}He peak originating from the $^{9}Be(n,\alpha_{o})\,^{6}He$ reaction.
- 2 tritium lines from $^{9}Be(n,t)\,^{7}Li$, leaving the final nucleus ^{7}Li in the ground and first excited (0.478 MeV) state.

The preliminary analysis of the data for the reaction $^{9}Be\,(n,\alpha_{o})\,^{6}He$ gives an angular distribution, which form is in good agreement with previous measurements [2]. The integrated cross section is somewhat lower than the one given by [2] but agrees very well with activations measurements of [3]. The cross section for the reaction $^{9}Be\,(n,\alpha_{1})\,^{6}He$ leaving the ^{6}He nucleus in its first excited state shows clearly forward peaks. The search for excitation at higher levels in ^{6}He and the analysis of data for the reaction $^{9}Be(n,t)\,^{7}Li$ have not yet been performed.

The measurement of the angular distribution of the reactions $^{10}B(n,p)\,^{10}Be$, $^{10}B(n,d)\,^{9}Be$, $^{10}B(n,t)\,^{8}Be$, $^{10}B(n,\alpha)\,^{7}Li$ are in progress.

References

[1] J.F. Loude, J.P. Perroud and Ch. Sellem, EANDC(OR)-90"L", p 15 (1969) and HPA 42 (1969) 905.

[2] G. Paic, D. Rendic and P. Tomas, Nucl. Phys. A96 (1967) 476.

[3] M.E. Battat and F.L. Ribe, Phys. Rev. 89 (1953) 80.

III. Eidg. Institut für Reaktorforschung, Würenlingen

(Dir.: Dr. W. Zünti)

1. Reaction Cross-Section and Resonance Integral for $^{18}0(n,\gamma)^{19}0$ *)

W. Blaser, A. Wyttenbach and P. Baertschi

The cross-section for the reaction $^{18}0(n,\gamma)^{19}0$ has been measured with reactor neutrons on targets of $^{18}0$-enriched Na_2CO_3 relative to the cross-section for $^{23}Na(n,\gamma)$ ^{24}Na. The samples were irradiated with a fast pneumatic transfer system without and with Cd-covers and the $^{19}0$ and ^{24}Na-activities determined by γ-spectroscopy with a Ge(Li)-detector. Assuming $\tau_{1/2}$ ($^{19}0$) = 27 s and $\hat{\sigma}$ (^{23}Na (n,γ) = 0.534 b, the following values were found:

effective cross-section	$\hat{\sigma} = (1.7 \pm 0.1) \cdot 10^{-4}$ b
2200 m/s cross-section	$\sigma_0 = (1.6 \pm 0.1) \cdot 10^{-4}$ b
excess resonance integral	$I' = (7.4 \pm 0.4) \cdot 10^{-4}$ b
resonance integral (including the 1/v contribution and with a lower energy of 0.5 eV)	$I = (8.1 \pm 0.4) \cdot 10^{-4}$ b

The only previously published value is $\hat{\sigma} = 2.2 \cdot 10^{-4}$ b [1] and is suspected to be seriously in error due to obsolete counting techniques and to the use of an erroneous half-life for $^{19}0$.

*) Full paper in J. Inorg. Nucl. Chem. (in press)

Reference

[1] L. Seren, W.E. Moyer, W. Sturm, Phys. Rev. 70 (1946) 561

2. Multiple Scattering Effect in Neutron Capture Cross-Section Measurements

F. Widder

In the class of neutron capture cross-section measurements by means of liquid scintillator tanks or Maxon-Rae-Detectors the effects of single and multiple neutron scattering can be large, even for thin, high-transmission samples. The evaluation of high precision cross-section curves by means of Monte Carlo calculations are very expensive. For this reason H. W. Schmitt [1] has derived an analytical expression for the average path length for the case of plane parallel neutrons axially incident upon a thin disk of material whose scattering and capture cross-sections are considered to be nearly constant over several neutron collisions. Later Monte Carlo calculations for a finite neutron beam diameter produced essentially identical results. The formula given by Schmitt is only valid for $n\sigma_T t \leq 0.2$ and $t \leq r/2$. Moreover it contains an error which fortunately has little influence within the given limits of validity. Nevertheless this formula was used by several authors [2, 3].

In order to improve the capture cross-section data of Vanadium, Manganese, Cesium, Europium, Dysprosium and Lutetium in the energy range from 0.01 eV to 20 eV ($Z \gg 1$, little energy change in scattering) we needed an improved expression. The formula we derived is valid to $\leq$ 1 % for $n\sigma_T t \leq 1$ and $t \leq r$.

The total number of capture events per incident neutron f_c is

$$f_c = (\sigma_c / \sigma_T)\,(1 - \exp(-n\sigma_T t))\,/\,(1-X)$$

with $X = (\sigma_s / \sigma_T)\,(1-E)$

and
$$E = F(1-\exp(-n\sigma_T t)+\exp(-n\sigma_T\sqrt{r^2+t^2})-\exp(-n\sigma_T r)+G(n\sigma_T\sqrt{r^2+t^2})$$
$$-G(n\sigma_T t)-G(n\sigma_T r)+n\sigma_T(\sqrt{r^2+t^2}-r(\exp(-n\sigma_T r(1+t^2/12r^2)))$$

with $F = 0.25(1+2n\sigma_T t\exp(-n\sigma_T t)-\exp(-2n\sigma_T t))\,/\,(1-\exp(-n\sigma_T t))^2$

and $G(x) = 0.5\,(1-(1+x)\exp(-x)-x^2\mathrm{Ei}(-x))$

$$-\mathrm{Ei}(-x) = \int_x^{\infty} \frac{e^{-t}}{t}\,dt$$

The value of the radius r in the formula must be replaced by

$$r_{eff} = \frac{4}{\pi r} \int_0^r \rho \int_0^{\pi/2} \sqrt{1 - (\ \ /r)^2 \sin^2 \varphi} \, d\varphi \, d\rho \cong 0.85\, r$$

References

[1] H. W. Schmitt,
Phys. Rev. 122 (1961) 182, App. 2.,
ORNL-2883 (1960).

[2] M. C. Moxon and E. R. Rae,
Nucl. Instr. Meth. 24 (1963) 445.

[3] R. L. Macklin et al,
Nucl. Phys. 43 (1963) 353
Nucl. Instr. Meth. 26 (1964) 213.

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(Dir.: Prof. Dr. P. Marmier)

Determination of the analyzing powers iT_{11}, T_{20}, T_{21} and T_{22} of the reactions $D(d,n)^3He$ and D(d,p)T at 10 and 11.5 MeV

V. König, W. Grüebler, R.E. White, R. Risler, A. Ruh,
P.A. Schmelzbach and P. Marmier

Measurements on the polarization of the nucleons emitted from the mirror reactions $D(d,n)^3He$ and D(d,p)T give essentially higher values for protons [1] than for neutrons [2]. The purpose of the present experiments has been to investigate whether such inexplicable differences also exist in the analyzing powers of these two reactions.

The experimental method applied in determining the analyzing power of a reaction using a polarized deuteron beam has been described in earlier publications [3, 4]. For the reaction D(d,p)T, the vector and the three tensor analyzing powers have been determined at 6 energies ranging from 4 to 11.5 MeV for c.m. angles lying between 10^o and 165^o. For the reaction $D(d,n)^3He$, the recoil ^3He-particles were used for the measurements. The range of these particles in Si surface-barrier detectors is only one-fourth to one-sixth the range of tritons emerging from the reaction D(d,p)T or that of elastically scattered deuterons, whereas the range of protons is essentially larger. By the application of a very low bias, the sensitive layer of the detectors could be made so thin that the ^3He-particles suffered the largest energy loss in this layer and therefore could be observed selectively. Due to the detectors available for the experiment, this method was applicable only for deuteron energies larger than 10 MeV and for scattering angles of the ^3He-particles between 10^o and 32^o; hence the reaction could be observed only for c.m. angles ranging from 95^o to 156^o.

Filled with deuterium at a pressure of 4.5 atm, the same gas target was used for both the reactions. For the tensor polarization of the polarized deuteron beam the $^{3}He(d,p)^{4}He$-reaction served to monitor each measurement [5], whereas the vector polarization was determined by comparison with the scattering reaction $^{4}He(d,d)^{4}He^{3}$ [6].

The figure depicts the measured analyzing powers at 10 and 11.5 MeV for the c.m. angular range of 90^{o} to 160^{o}; closed dots represent the reaction D(d,p)T, open circles the reaction $D(d,n)^{3}He$. The errors shown are purely statistical and, where not indicated, are smaller than the size of the dot. Good agreement is obtained for the two components iT_{11} and T_{21} of both the reactions. In the angular range under consideration, the extremely small values of T_{22} render a comparison practically impossible. However, at both energies, the T_{20} component shows definitely larger values for the D(d,p)T-reaction than for the reaction $D(d,n)^{3}He$.

References

[1] L.E. Porter and W. Haeberli,
Phys. Rev. 164 (1967) 164

[2] G. Spalek, J. Taylor, R.A. Hardekopf, Th. Stammbach and R.L. Walter
Proc. 3rd Int. Symp. on polarization phenomena in nuclear reactions, eds. H.H. Barschall and W. Haeberli (University of Wisconsin Press) to be published.

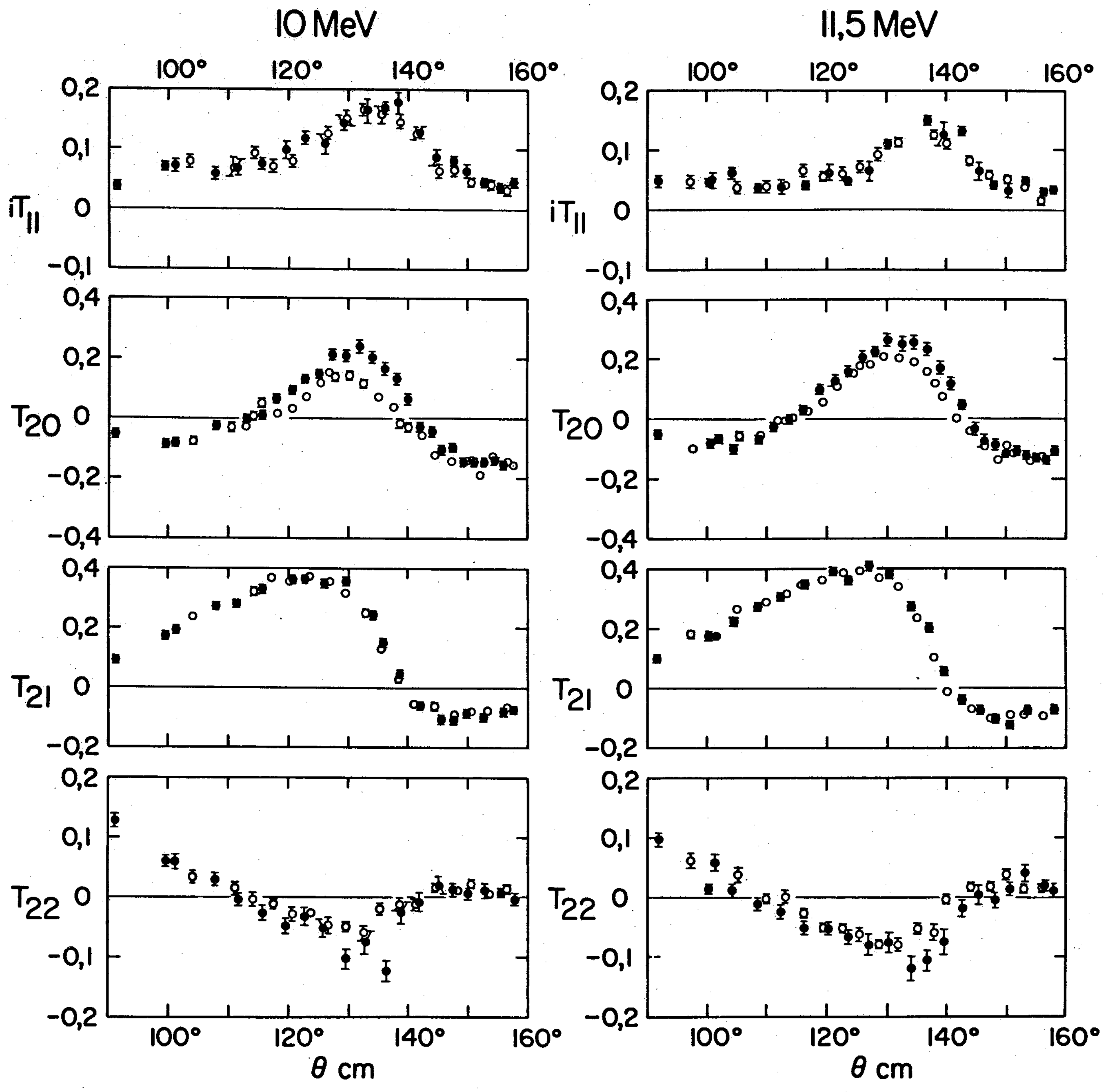
[3] W. Grüebler, V. König, P.A. Schmelzbach and P. Marmier,
Nucl. Phys. A134 (1969) 686.

[4] V. König, W. Grüebler, P.A. Schmelzbach and P. Marmier,
Nucl. Phys. A148 (1970) 380

W. Grüebler, V. König, P.A. Schmelzbach and P. Marmier,
Nucl. Phys. A148 (1970) 391

[5] W. Grüebler, V. König, A. Ruh, R.E. White, P.A. Schmelzbach, R. Risler and P. Marmier,
Nucl. Phys. A165 (1971) 505

[6] V. König, W. Grüebler, A. Ruh, R.E. White, P.A. Schmelzbach, R. Risler and P. Marmier
Nucl. Phys. A166 (1971) 393,



Analyzing powers iT_{11}, T_{20}, T_{21}, T_{22} of the reactions D(d, p)T (closed dots) and D(d, n)^{3}He (open circles) at deuteron energies of 10 and 11.5 MeV

Investigation of the Nuclear Level Densities of Cerium and Strontium

J. Schacher, P. Huber † and R. Wagner

Neutron spectra resulting from 14-MeV-neutron bombardment of Cerium and Strontium have been observed with a time-of-flight spectrometer. A computer program was developed to calculate evaporation spectra containing (n, n')- and (n, 2n)-contributions.

These calculations are based on the statistical model [1], according to which the probability that a compound nucleus decays into a residual nucleus with excitation energy E under emission of a neutron with energy ε is given by

$$W(\varepsilon) \propto \varepsilon \, \sigma_c(\varepsilon) \, \rho(E).$$

The cross section $\sigma_c(\varepsilon)$ for the inverse reaction can be approximated by optical model absorption values. For the level density $\rho(E)$ of the residual nucleus we used predictions of the superconductor model and, in the energy range above the phase transition, of the shifted Fermi gas model [2]:

$$\rho(E) \propto \begin{cases} U^{-n} \exp(2\sqrt{a_p U}) & \text{for} \quad E \gg E_{ph} \\ \exp(E/T_s) & \text{for} \quad E \leqslant E_{ph} \end{cases} \qquad (*)$$

with $n = 2$ or $5/4$.

E_{ph} is the phase transition energy, $U = E + P$ the effective excitation energy, a_p the Fermi gas level density parameter and T_s the nuclear temperature in the lower excitation energy region. P is the pairing energy of the nucleus.

The calculated energy distributions well describe the measured spectra for Cerium and Strontium which contain mainly magic nuclids. Fermi gas level density parameters a_p have been obtained from least square fitting of the data.

In figures 1 and 2 experimental and theoretical neutron spectra are compared for the two elements. In the cases shown we took the expression (*) with n = 2 (a'_p) for the nuclear level density.

For more details see reference [2].

References

[1] W. Hauser and H. Feshbach,
Phys. Rev. 87, p. 366 (1952)

[2] J. Schacher, P. Huber and R. Wagner,
Helv. Phys. Acta 44, p. 487 (1971)

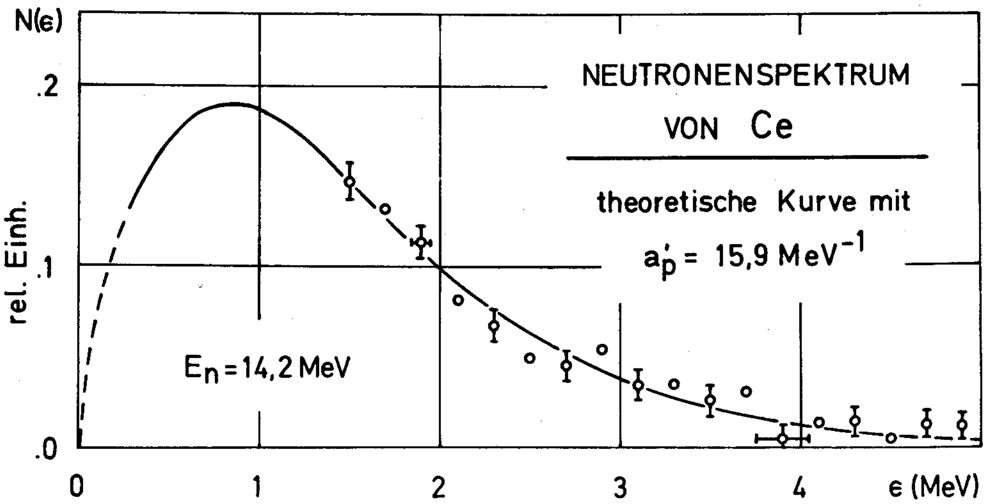


Fig. 1: The energy distribution of neutrons emitted from Cerium at a neutron bombardment energy of 14.2 MeV is compared with a fitted theoretical spectrum. The calculation is based on the statistical, the Fermi gas and the superconductor model (see eq. (*) with n = 2).

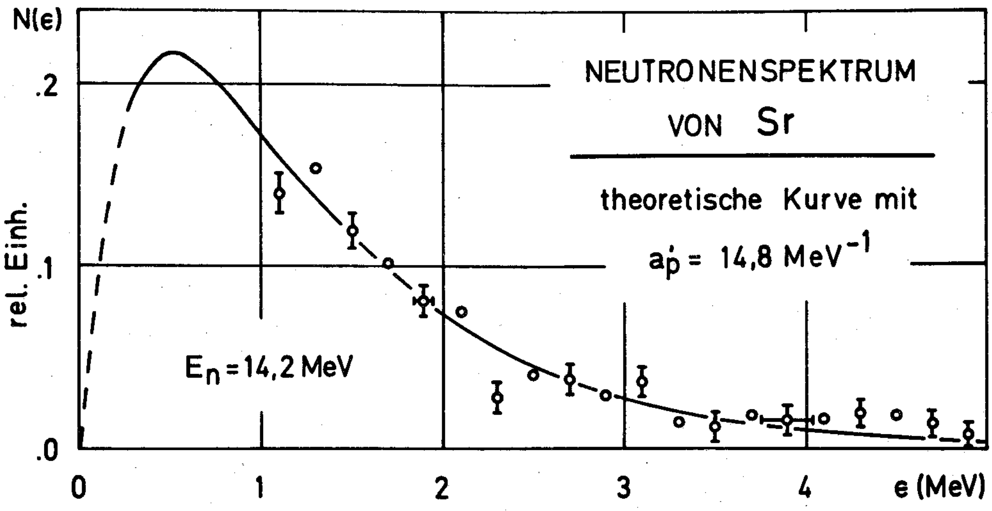


Fig. 2: The energy distribution of neutrons emitted from Strontium at a neutron bombardment energy of 14.2 MeV is compared with a fitted theoretical spectrum. The calculation is based on the statistical, the Fermi gas and the superconductor model (see eq. (*) with n = 2).