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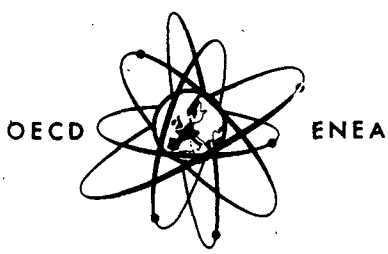
PROGRESS REPORT TO EANDC FROM SWEDEN, JUNE 1964

N. Starfelt, Editor



JUNE 1964

EUROPEAN-AMERICAN NUCLEAR DATA COMMITTEE

Progress Report to E.A.N.D.C.

from Sweden, June 1964

edited by

N. Starfelt

AB Atomenergi, Studsvik, Nyköping

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PROGRESS REPORT, JUNE 1964 FROM AB ATOMENERGI STUDSVIK AND STOCKHOLM

A. Scattering of slow neutrons

1. Time-of-flight measurements at the reactor R1 (Stockholm)

U. Dahlborg, K. E. Larsson, D. Jovic

The experiments on hydrogenous compounds like glycerol, oleic acid and pentane have been continued at the slow chopper time-of-flight spectrometer at R1 in Stockholm. A detailed interpretation of the observed scattered spectra have been performed. It has been found that a microscopic relaxation time for diffusive motions in these liquids may be defined and falls in a range between 10^{-11} and 10^{-12} seconds. In all cases there seems to be a limiting relaxation time at temperatures near the boiling point of $\sim 10^{-12}$ with the meaning that the inset of diffusion is delayed by this amount of time, which is just sufficient to permit the development of inter-molecular vibrations of the same type as in the solid phase. It also seems very possible that a cluster-formation occurs in the H-bonded liquids which is strongly temperature dependent. We have found that the cluster size tends to a single molecular size at the boiling point.

To study any possible effect of coherence in the scattering from hydrogenous samples a series of studies have been performed on partially and fully deuterated glycerol $C_3H_5(OD)_3$ and $C_3D_5(OD)_3$. Interesting changes in the above mentioned relaxation time for the inset of diffusion have been observed.

Report: K. E. Larsson and U. Dahlborg: "Proton motion in some hydrogenous liquids studied by cold neutron scattering". To appear in Physica 1964.

The cold neutron scattering experiments on poly-crystalline and liquid aluminium round the melting point of 660°C have been completed. The existence of a coherent resonance condition in liquid inelastic neutron scattering has been established with certainty. The existence of quasi-phonons in liquid aluminium was proved. The theory of Egelstaff for quasi-phonon scattering has been verified. These measurements will be extended to higher aluminium temperatures.

Report: Jovic, Larsson and Dahlborg: "A study of coherent neutron scattering in liquid aluminium". To be published 1964 in Physics of Condensed Matter.

2. Crystal spectrometer studies of liquids at R1 (Stockholm)

L. Bergsted

The crystal monochromator at R1 has been used to produce neutron lines of energy 16 and 64 millivolts which have been sent into liquid normal and fully

deuterated glycerol $C_3H_5(OH)_3$ and $C_3D_5(OD)_3$. The intention was to study the angular distribution of quasi-elastically scattered neutrons. It was found that only for small momentum transfers in the scattering process may the "elastic peak" be explained by current diffusion theories. For higher momentum transfers the scattering picture is composed of two gas model pictures super-imposed upon each other one corresponding to mass 1 and the other corresponding to mass 92. Mass 1 is the proton mass and mass 92 is the mass of the normal glycerol molecule. The value of a Debey-Waller factor may be established only in a low momentum transfer region and even then with a considerable uncertainty.

Report: Leif Bergsted: "The angular distribution of slow neutrons scattered from glycerol". Unpublished. The work continues.

3. Time-of-flight measurements at the reactor R2 (Studsvik)

G. Borgonovi, N. Kroo, K.E. Larsson, K. Sköld

For most liquids great complications occur in the interpretation of the neutron scattering picture because the liquids are not mono-atomic, or if they are mono-atomic like aluminium, it is hard to calculate their expected properties. Condensed noble gases present an exception. Therefore we have performed a cold neutron scattering experiment on solid and liquid argon with the aid of the semi-monochromatizing chopper at R2. A method has been devised to measure an average dispersion relation in the solid poly-crystalline phase and this method has also been extended to cover the liquid case. An average dispersion relation for liquid argon has been experimentally determined, thus showing the solid-like nature of this rather ideal liquid. The studies are continued on the incoherent scattering effects.

Report: Kroo, Borgonovi, Sköld and Larsson: "Inelastic scattering of cold neutrons by condensed argon". Phys. Rev. Letter 1964 and RFX-report-326.

4. The three-axis crystal spectrometer at the reactor R2 (Studsvik)

R. Stedman

Dispersion curves for phonons in aluminium have now been obtained for three principle directions, at a temperature of -195°C. Results for room temperature are partially complete. Considerable attention has been paid to the widths of the one-phonon resonances, which the spectrometer has mostly been able to resolve, even at - 195°C. Room temperature widths, and the temperature shift from -195°C t 20°C can be measured quite accurately. A search was made for small irregularities in dispersion curves which are associated with the interaction between phonons and electrons at the Fermi surface; the results were inconclusive, and it is hoped to return to this question at a later date.

B. Fast Neutron Physics

1. Elastic and inelastic neutron scattering

B. Antolkovic, B. Holmqvist, T. Wiedling

Neutron elastic and inelastic scattering experiments have been performed in the neutron energy range 0.7 - 4.6 MeV.

Angular distributions of elastically scattered neutrons on some natural elements have been collected: for carbon at 3.53, 4.03, and 4.59 MeV, for oxygen at 4.59 MeV, for iron at 3.53, and 4.59 MeV, for cobalt and copper at 1.53, 2.05, 2.53, 3.05, 3.53, 4.03, and 4.59 MeV, for nickel at 3.05, 3.53, 4.03, and 4.59 MeV, for indium at 3.05, 3.53, and 4.03 MeV, and for tantalum at 4.59 MeV. The experimental distributions are corrected for neutron multiple scattering and the corrected results are to be compared with theoretical calculations using the optical model.

Angular distributions of inelastically scattered neutrons from natural iron have been obtained for the first excited state at 0.845 MeV in Fe^{56} at the primary neutron energy of 3.53 MeV and for the first three excited states at 0.845, 2.085, and 2.658 MeV in Fe^{56} at the neutron energy 4.59 MeV. The angular distributions are isotropic within about 20%.

Neutron excitation functions for the two first excited states in Cu^{63} and Cu^{65} have been obtained by neutron inelastic scattering from natural copper in the neutron energy range 0.7 - 1.4 MeV. The levels studied are at 668, and 961 keV in Cu^{63} and at 770, and 1114 keV in Cu^{65}. The inelastic processes have been observed with a NaI (Tl) scintillation spectrometer by detecting the gamma rays following the neutron scattering. Theoretical curves have been calculated using the optical model and the Hauser-Feshbach theory of inelastic neutron scattering. Good agreement between experiment and theory has been obtained for the spin sequence of $3/2^-$, $1/2^-$ and $5/2^-$ for the ground state and the two first excited states in both isotopes.

2. Angular distributions of neutrons from (p,n) reactions in some mirror nuclei

B. Holmqvist, L. G. Strömberg, T. Wiedling

The angular distributions of neutrons from the reactions $C^{13}(p,n)N^{13}$ and $F^{19}(p,n)Ne^{19}$ have been measured for some energies close to the reactions threshold. For the reaction $B^{11}(p,n)C^{11}$ angular distributions have been measured at several proton energies below the reaction threshold of the neutrons to the first excited state in C^{11}. A 5.5 MeV Van de Graaff has been used for the experiments. The neutrons were detected with a long counter. The measurements were carried out for 16 energies for the B^{11} (p,n) reaction, 3 energies for the C^{13}(p,n) reaction and for 7 energies for the F^{19}(p,n) reaction. One of the main reasons for investigating these (p,n) reactions was to check whether the direct reaction process is important at low proton energies as well as close to reaction thresholds in nuclei consisting

of closed shells of neutrons and protons either with an extra nucleon outside the closed shell or a nucleon hole.

3. Angular distributions of neutrons from the reaction $Be^9(p,n)B^9$

B. Antolkovic, B. Holmqvist, T. Wiedling

The angular distributions of neutrons from the reaction $Be^9(p,n)B^9$ have been measured for three energies just above the threshold (and below the first resonance) and for the resonance energy at 2.56 MeV. The neutrons were detected with a Li^6-glass scintillator spectrometer in combination with time-of-flight technique. With this method it is possible to select $Be^9(p,n)B^9$ neutrons from the continuum of neutrons produced by the reaction $Be^9(p,p'n)Be^9$. The angular distributions below the resonance energy show a pronounced forward peaking.

The experimental angular distributions have been compared with a theory for direct interaction by Satchler with the improvements suggested by Rodberg.

4. Neutron polarization measurements

O. Aspelund

The experimental part of the investigation of the polarization in $n + C^{12}$ elastic scattering between 1 and 2 MeV is finished. Preliminary results of the data analysis shows that the relative contribution of even-parity scattering decreases with decreasing neutron energy, whereas the absolute admixture of odd-parity scattering stays practically constant, providing a significant non-zero polarization in the backward hemisphere over the whole energy range.

Experimental evidence for the existence of an intermediate structure in fast-neutron polarization has been found. The effect has been studied at seven scattering angles in the nuclei Cu, Mo, and Pb in the energy range 1.5 to 2.0 MeV. The persistence of correlations in the observed resonances at the scattering angles chosen has been demonstrated. Comparison with theory is presently undertaken, and the results of the computations will be released later.

Reports: L. G. Strömberg, T. Wiedling, and B. Holmqvist: Angular Distributions of Neutrons from (p,n)-Reactions in some Mirror Nuclei. AE-139.

B. Holmqvist and T. Wiedling: Inelastic Neutron Scattering Cross Sections of Cu^{63} and Cu^{65} in the Energy Region 0.7 to 1.4 MeV. (To be published).

B. Antolkovic, B. Holmqvist, and T. Wiedling: A Direction Sensitive Fast Neutron Monitor. (To be published).

B. Holmqvist and T. Wiedling: A Gas Target with a Tritium Gas Handling System. AE-127, to be published in Nukleonik.

B. Antolkovic, B. Holmqvist, and T. Wiedling: A Study of the Angular Distributions of Neutrons from the $Be^{9}(p,n)B^{9}$ Reaction at Low Proton Energies. (To be published).

C. Fission integrals for U 235 and Pu 239

E. Hellstrand, E. Johansson, E. Jonsson

The fission integrals for U 235 and Pu 239 have been measured relative to the resonance integral for gold. The measurements were made in a well collimated neutron beam originating from a graphite scatterer placed at the center of the heavy water reactor R1. The usual difficulty of finding that cadmium cut off energy which in a true 1/E flux yields the same epicadmium fission rate as that measured, was largely overcome by special studies of the neutron beam with a fast chopper. Measurements of the neutron energy distribution of the undisturbed beam - from thermal energies to 10 keV - have earlier been reported by Johansson et al. (1, 2). Besides these measurements the transmission characteristics of the cadmium sheet used was determined in a special experiment with the fast chopper. Using the experimental information and the cross section curves given in (3) the effective cadmium cut off energy could be determined with an estimated accuracy of about 0.01 eV.

The cadmium ratio technique was used (cadmium thickness 0.105 cm). The fission rates were obtained with small fission chambers that had coating thicknesses of the order of 100 $\mu g/cm^2$.

After correction to the standard cut off energy of 0.50 e.v. the following results were obtained

U(235) RI = 275 ± 9 b
Pu (239) RI = 319 ± 12 b.

References

(1) E. Johansson, E. Lampa, N. G. Sjöstrand, Ark. for Fysik 18, 513 (1960)
(2) E. Johansson, E. Jonsson: Nucl. Sci. and Eng. 3, 264 (1962)
(3) J. J. Schmidt, Neutron Cross Sections for Fast Reactor Materials, KFK 120 (1962)

D. A report containing the dilute resonance integrals of all isotopes is being compiled. The values, based upon slightly different definitions, are recalculated to comparable quantities.

R. Nilsson.

Progress Report to E.A.N.D.C., June 1964 from Research Institute of National Defence, Stockholm

1. $\bar{\nu}$-measurements in the fast neutron fission of Th^{232}, U^{235} and U^{238}

H. Condé, M. Holmberg and N. Starfelt

The average number of prompt neutrons per fission has been measured with a large liquid scintillator as the fission neutron detector. The $\bar{\nu}$ - measurements are made relative to $\bar{\nu}$ prompt of Cf^{252} spontaneous fission. A correction to the $\bar{\nu}$-value caused by the foil thickness of Th^{232} and U^{235} has been estimated.

Nuclide	Mev	Prompt neutrons per fission x)	Standard deviation
Th^{232}	1.42 ± 0.2	2.205	0.060
	1.80 ± 0.01	2.126	0.055
	2.23 ± 0.01	2.180	0.049
	2.64 ± 0.01	2.273	0.052
	3.6 ± 0.3	2.44	0.10
	7.45 ± 0.05	3.027	0.060
	1.48 ± 0.2	4.064	0.060
U^{235}	thermal	2.419	0.019
	7.45 ± 0.05	3.460	0.060

x) Based on $\bar{\nu}$ = 3.775 ± 0.000 for Cf^{252} fission

Asplund-Nilsson, Condé and Starfelt: $\bar{\nu}$ of U^{238} from 1.5 to 15 MeV. EANDC report

2. $\bar{\nu}$-measurements in the photofission of U^{238}

H. Condé, M. Holmberg

The average number of prompt neutrons from the photofission of U^{238} has been measured with a large liquid scintillator as the fission neutron detector. A preliminary result, $\bar{\nu}$ = 2.72 ± 0.12, exists at 7 Mev. Measurements at other gamma ray energies are in progress.

3. Fission neutron spectrum

H. Condé, G. During

Measurements of the fission neutron spectra from neutron induced fissions of U^{238} and U^{235} and from the spontaneous fission of Cf^{252} are in progress using a time-of-flight technique. Preliminary results exist at 14 MeV of U^{238} and for Cf^{252} where fits of the measured values to maxwellian distributions ($N(E) = E^{\frac{1}{2}}e^{-E/T}$)

give:

Nuclide	Neutron Energy Mev	Temperature MeV
U^{238}	14.5	1.58 ± 0.10
Cf^{252}	spont.	1.34 ± 0.04

4. Elastic scattering angular distributions at 14 MeV

B. Lundberg, S. Schwarz, N. Starfelt and H. O. Zetterstrom

The measurements for O^{16} and N^{14} have been completed. (to be published).

5. Elastic scattering angular distributions in the 100 keV region

L. G. Stromberg and S. Schwarz

Using time-of-flight technique and a Li^6-loaded glass scintillator as a neutron detector measurements at neutron energies around 100 keV are in progress for U^{238}. The measurements will be extended to other elements.

6. Inelastic neutron scattering from the 44 keV level in U^{238} for $50 < E_n < 200$ keV

S. Schwarz, N. Starfelt and L. G. Stromberg

Measurements are in progress by time-of-flight technique with a Li^6-glass scintillator as a neutron detector.

7. Fast neutron capture γ-rays

I. Bergqvist, B. Lundberg, N. Starfelt

Measurements at neutron energies up to 2 Mev are in progress for several elements. A method of calculating neutron capture γ-ray spectra taking into account dipole giant resonance effects on the reduced γ-ray width has been developed.

Bergqvist, B. Lundberg and N. Starfelt:

Neutron Capture Gamma-Ray Spectra and the M1 Giant Resonance ANL-6797 (1963)

B. Lundberg, N. Starfelt: γ-rays from the Capture in Ta and Au of Neutrons from 1-4 MeV, to be published.

N. Starfelt: Calculation of (n,γ) spectra: Nucl. Phys. 53, 397 (1964)

8. Measurement with organic scintillators of continuous Neutron Spectra in the 0.5 to 15 MeV Range

B. Brunfelter, J. Kockum, H-O. Zetterstrom

A new version of the reduction program has been written for the IBM 7090 computer. It is based on inversion of the response matrix which is computed by inter-

polation from experimentally determined response functions. By choosing the response function used in each energy interval suitably the induced oscillations are kept tolerably small at the same time as the end effects and the multiple scattering are taken into account.

9. Measurement with He^3-proportional counter of continuous Neutron Spectra between 0.1 and 5 MeV

B. Brunfelter, J. Kockum

The response functions to monoenergetic neutrons of a He^3-filled proportional counter has been measured between 0.1 and 5 Mev. It is intended to use the response functions in a matrixinversion program in order to make the counter useful as a neutron spectrometer.

10. A relative measurement of the $Li^6(n,\alpha)He^3$ cross section

S. Schwarz, L. G. Strömberg and A. Bergström

The $Li^6(n,\alpha)H^3$ reaction cross section has been measured with a time-of-flight technique using a Li^6-glass scintillator as a detector of neutrons produced by the $Li^7(p,n)Be^7$ reaction. In the low energy range the results are based on the assumption that the neutrons from the latter reaction are isotropically distributed in the center-of-mass system for proton energies close to the neutron threshold. In the higher energy range the measurement is based on the (n,p) scattering cross section. A fit according to the Breit-Wigner single level dispersion theory has been made for the p-wave resonance at $E_n \sim 0.25$ MeV taking into account the 1/v dependence of the cross-section at low energies, extrapolated from the thermal value.
(to be published).

11. Absolute measurement of fast neutron flux with a large liquid scintillator

H. Condé, S. Schwarz and N. Starfelt

A method of making an absolute measurement of the flux of fast neutrons has been studied. An accurately determined fraction of the neutrons in a collimated beam passing along a channel through a large liquid scintillator is scattered into the scintillator. The detection efficiency of the neutron detector has been measured in an earlier experiment. An absolute measurement of the $Li^6(n,\alpha)T$ cross section is made by placing a Li^6-glass scintillator in the calibrated neutron beam.

The experiments are continued.

H. Condé, S. Schwarz and N. Starfelt: FOA 4 report A 4350-411.

12. Neutrons from the $Li^7(p,n)Be^7$ reaction near threshold

L. G. Strömberg and S. Schwarz

Angular distributions are presented for neutrons from the reaction $Li^7(p,n)Be^7$ at proton energies between reaction threshold and about 2.3 MeV. A Li^6 glass scintillator and time-of-flight techniques were used for neutron detection. The integrated differential cross sections were normalized to published total cross section results. Legendre polynomial expansions and theoretical interpretation are in progress.

S. Schwarz and L. G. Strömberg, Tables of neutron energies from the reaction $Li^7(p,n)Be^7$ in the range $E_{th} < Ep < 2.30$ MeV, FOA 4 report A 4367-411

The nonrelativistic kinematic relationship between incident proton energy and neutron energy as a function of laboratory angle has been calculated as a help in high resolution work with monoenergetic neutrons in the range $1 < E_n < 600$ keV.

S. Schwarz and L. G. Strömberg: A method for the determination of the thickness of thin Li-targets, FOA 4 report A 4341-411

The relative position of the peaks in the time-of-flight spectrum from the $Li^7(p,n)Be^7$ reaction for proton energies close to the neutron threshold has been used for the determination of the target thickness. A Li^6-glass scintillator was applied as a neutron detector. The accuracy of the estimate is of the order of 0.1 keV for target thicknesses of a few keV.

13. γ-rays from inelastic scattering

G. During, N. Starfelt

Studies of γ-rays in coincidence with inelastic scattered neutrons from the bombardment of elements with 15 Mev:s neutrons are in progress. Experimental arrangements with time-of-flight neutron spectrometer and NaI-γ detector are developed.

14. Experimental fast neutron spectra in Al and Fe

G. During, R. Jansson, N. Starfelt

Arkiv för fysik 26, 293 (1964)

15. Experimental fast neutron spectra in U

G. During, R. Jansson

Measurements of neutron spectra from the bombardment of uranium with 3 and 15 Mev neutrons are in progress.

16. Van de Graaff accelerator

L. Beckman, R. Jansson

The Mobley bunching system for the compression of the beam pulses from 10 to 1 ns has been put to a preliminary test. Pulse lengths below 1.5 ns has been observed.

17. Monte Carlo calculations on neutron detectors

S. Schwarz, L. G. Stromberg, H-O. Zetterstrom

Monte Carlo calculations are being performed to study the influence of multiple scattering and edge effects on the detection efficiency for neutrons of organic scintillators. The non-linear response of NE 150 plastic has been determined experimentally. The spectrum forms of the Compton distributions are studied for the purpose of exact bias determination.

The multiple scattering of keV neutrons in Li^6-loaded glass scintillators has been studied by a Monte Carlo technique. The program can be used to calculate corrections to the neutron detection efficiency for scintillators of absolute flux measurement for monoenergetic neutrons in the keV range. Results are presented referring to Nash and Thompson GS 20. (to be published).