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PROGRESS REPORTS FROM SWEDEN AND DENMARK

(up to September 1963)

These progress reports are prepared for the information of the January 1964 INDSWG meeting, on the initiative of Dr. O. Kofoed-Hansen.

Some of the items are abstracts for papers presented at meetings - for simplicity these are copied unchanged, in spite of the occurrance of phrases like "will be presented" or "will be described".

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4 December 1963

PROGRESS REPORT FROM SWEDEN

A. PROGRESS IN NUCLEAR DATA MEASUREMENTS AT AB ATOMENERGI (STUDSVIK AND STOCKHOLM)

a) Scattering of slow neutrons

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

At the slow neutron time-of-flight spectrometer at the reactor R 1 in Stockholm the experiments on hydrogenous compounds have been continued. The measurements on water, glycerol, oleic acid and pentane have been performed in a wide temperature range thus including measurements both in the solid and the liquid phases. It has been concluded that the neutron in the scattering process has observed a more moveable entirety than the whole molecule. For such motions of molecular subgroups activation energies and life times have been obtained. For example the life time of a hydrogen bond in glycerol at room temperature has been obtained to be 9.10^{-12} seconds. A complete report of the results will be published.

Also measurements on solid and liquid aluminium just around the melting point have been performed. The results seem to support Egelstaff's ideas about coherent inelastic scattering in polycrystals and liquids.

Reports: 1) "A study of the diffusive atomic motions in glycerol and of the vibratory motions in glycerol and light and heavy water", IAEA Symposium on "Inelastic Scattering of Neutrons in Solids and Liquids", Chalk River 1963, 317-340.

2) "Cold Neutron Scattering and Diffusive motions in hydrogen bonded liquids", Phys. Letters 3, 145 (1962).

(K.E. Larsson et al.)

2. Time-of-flight measurements at the reactor R 2 (Studsvik)

The time-of-flight spectrometer at the Swedish MTR-type reactor R 2 has been in operation since the beginning of this year. It is an improvement over the conventional type of spectrometer in that the chopper is placed before the sample where it serves the double purpose of giving a narrower ingoing spectrum at the same time as it chops the beryllium-filtered beam. A detailed description of the spectrometer is to be published soon.

As a first task we have undertaken a measurement on water. Water was chosen for two reasons. Firstly because it has been studied several times before and the main features of scattering are thus well known. It would therefore serve as a test of the equipment. Secondly because there is still some disagreement about the existence of peaks close to the ingoing energy. This question is more easily studied with this set up than with a spectrometer using the full beryllium-filtered spectrum as the energy width of the latter is several times the energy changes here in question. The measurements do indicate the existence of low lying levels but they do not fully prove it. The diffusion-broadening of the quasi-elastic peak has also been studied. If the results are analysed using a Lorentzian broadening function they yield a width which is somewhat larger than that earlier reported. It might be noted that the width of the ingoing spectrum is of prime importance also here. The results of the water measurements are to be published. An investigation of argon, in the solid and liquid states, was started recently. Argon is an interesting substance to study as the forces acting between the atoms are supposed to be known. Using calculated dispersion curves and frequency spectra the experiment is hoped to give some insight into the problem of inelastic coherent scattering from polycrystals and liquids. The latter question is a possible subject for the future work with the spectrometer.

(K.E. Larsson et al.)

3. The three-axis crystal spectrometer at the reactor R 2 (Studsvik)

The spectrometer has been operating since about the beginning of the year, and has been used to determine relations between frequency and wave vector for phonons in aluminium. Difficulties have been encountered, but we feel that we now understand these, and can probably overcome them. They are mainly associated with higher-order reflections in the monochromator and analyser crystals of the spectrometer. Recent conversations with people working in the same field elsewhere have indicated that such difficulties are of greater practical significance than was at first supposed.

The results for aluminium at room temperature should soon be complete, and we will then proceed to other temperatures, in particular to lower temperatures, probably to liquid helium temperatures. A cryostat is ready to be set up on the spectrometer.

(R. Stedman)

b) (n,p)-reactions (Studsvik)

Cross section measurements of the $Fe^{54}(n,p)Mn^{54}$ reaction in the neutron energy range 2.3 - 3.8 MeV are proceeding. Solid state detectors are used to record the charged particles. Absolute cross sections are obtained by normalizing the well known neutron-proton scattering cross section.

Preliminary results are: 208 mb (3.82 MeV), and 26 mb (2.32 MeV).

(S. Malmskog, A. Lauber)

c) Experimental determination of the effective threshold energy of some (n,p)- and (n,α)-reactions (Studsvik)

The effective threshold energy E_{eff} has been determined for some threshold reactions by a relative method as well as the average fission spectrum cross sections $\bar{\sigma}$. The following results have been obtained:

$Ti^{46}(n,p)Sc^{46}$: $E_{eff} = 6.0 \pm 0.2$ MeV; $\bar{\sigma} = 15 \pm 2$ mb

$Cu^{63}(n,\alpha)Cu^{60}$: $E_{eff} = 6.7 \pm 0.2$ MeV; $\bar{\sigma} = 0.54 \pm 0.07$ mb

$Fe^{54}(n,p)Mn^{54}$: $\bar{\sigma} = 67 \pm 8$ mb (preliminary value)

The effective threshold energies 3.2 and 8.1 MeV of the reactions $S^{32}(n,p)P^{32}$ and $Al^{27}(n,\alpha)Na^{24}$, respectively, have been used as standards.

(R. Nilsson)

d) Fast Neutron reactions (Studsvik)

1. Elastic and inelastic neutron scattering from copper

Some elastic and inelastic scattering experiments have been performed on natural copper in the neutron energy range 0.7 - 3 MeV with our 5.5 MeV van de Graaff accelerator using a time-of-flight spectrometer.

Neutron elastic scattering measurements have been performed at 1.0, 1.5, 2.0, 2.5 and 3.0 MeV. Angular distribution data have been collected at nine angles from 30° up to 150° in the laboratory system. The experimental results are compared with theoretical calculations using the optical model and the Hauser-Feshback theory of elastic neutron scattering.

Natural copper consists of two isotopes, Cu^{63} and Cu^{65}. The levels studied are at 668, 961 and 1327 keV in Cu^{63} and at 770 and 1114 keV in Cu^{65} in the neutron energy range 0.7 to 1.4 MeV. Since the isotopes constituting natural copper have rather close-lying levels the inelastic scattering measurements have been done with a technique differing in some respects from the one used in the elastic scattering experiment. The inelastic process has been observed with a NaI(Tl) scintillation spectrometer by detecting the gamma rays following the neutron scattering instead of the inelastic neutrons. In this way it has been possible to observe the inelastic process down from the threshold energies of the different excited states. Time-of-flight technique has still been used leading to a considerable background reduction as compared to ordinary methods.

The primary neutron flux was measured with a long-counter as a monitor and all runs were normalized to equal number of monitor counts. As references in these copper measurements elastically and inelastically scattered neutron cross-sections from iron were used as well as the well known T(p,n)- and (n,p)-cross sections. Neutron excitation functions have been obtained for levels excited in Cu-63 and Cu-65. Theoretical curves calculated using the optical model and the Hauser-Feshbach theory of inelastic neutron scattering have been compared to the experimental results.

(B. Antolkovic, B. Holmqvist, T. Wiedling)

2. Scattering of polarized neutrons from carbon in the MeV-energy range

A series of experiments have been performed on carbon to verify the predicted (1) rather large polarization acquired by elastically scattered neutrons in the energy range between 2 and 3 MeV. The main reason for performing these experiments is to check the possible use of carbon as a polarization analyser in this energy range, and also to verify previous phase analyses on the C^{12} + n system.

(O. Aspelund)

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

The angular distributions of neutrons from the reactions $Be^{9}(p,n)B^{9}$, $B^{11}(p,n)C^{11}$, $C^{13}(p,n)N^{13}$, and $F^{19}(p,n)Ne^{19}$ have been measured, the Studsvik 5.5 MeV van de Graaff being used for the experiments. The neutrons were detected with long-counters and the measurements were carried out for 18 energies for the $Be^{9}(p,n)$ reaction, 16 energies for the $B^{11}(p,n)$ reaction, 3 energies (just above the threshold) for the $C^{13}(p,n)$ reaction, and for 7 energies for the $F^{19}(p,n)$ reaction. Comparisons with the theory proposed by Bloom, Glendenning and Moszkowsky have been performed.

(L.G. Strömberg, T. Wiedling)

B. PROGRESS IN NUCLEAR DATA MEASUREMENTS AT RESEARCH INSTITUTE OF NATIONAL DEFENCE (STOCKHOLM)

1. Absolute measurement of $\bar{\nu}$ of Cf^{252}

I. Asplund-Nilsson, H. Condé, N. Starfelt

The number of prompt neutrons per fission has been measured with a large liquid scintillator as the fission neutron detector. The average number of prompt neutrons emitted per Cf-252 fission was found to be 3.799 ± 0.034. The measurement has been published.

I. Asplund-Nilsson, H. Condé and N. Starfelt, "An Absolute Measurement of $\bar{\nu}$ of Cf-252", Nucl. Sci. and Eng. 16, 124 (1963)

(1) J.E. Wills, Jr., et al., "Scattering of fast neutrons from C^{12} and F^{19}", Phys. Rev. 109, 891-897 (1958).

2. Relative $\bar{\nu}$ measurements

H. Condé, N. Starfelt

With the same type of fission neutron detector as in the absolute measurement of $\bar{\nu}$ of Cf-252 the average number of prompt neutrons per fission has been measured relative to of Cf-252 for some different isotopes and different primary neutron energies. Preliminary results exist for U-235, U-238 and Th-232.

Nuclide	Neutron Energy in MeV	Prompt Neutrons per Fission	Standard Deviation
Th^{232}	3.6 ± 0.3	2.41	0.10
	7.43 ± 0.05	2.99	0.06
	14.9 ± 0.3	4.42	0.13
U^{235}	0.06 ± 0.01	2.442	0.032
	7.43 ± 0.05	3.48	0.06
U^{238}	1.49 ± 0.01	2.519	0.059
	2.40 ± 0.01	2.649	0.051
	3.50 ± 0.02	2.870	0.052
	4.88 ± 0.05	3.057	0.050
	5.63 ± 0.15	3.160	0.058
	6.32 ± 0.06	3.264	0.061
	6.83 ± 0.06	3.338	0.053
	7.45 ± 0.05	3.516	0.046
	14.9 ± 0.3	4.76	0.12

These results are based on $\bar{\nu}$ for spontaneous fission of Cf-252 of 3.799. The results for spontaneous fission in U-238 and Pu-240 have been published.

I. Asplund-Nilsson, H. Condé and N. Starfelt, "Average Number of Prompt Neutrons Emitted in the Spontaneous Fission of U-238 and Pu-240", Nucl. Sci. and Eng. 15, 213 (1963)

3. Distributions of fission neutron numbers

A. Bergström, H. Condé, M. Holmberg

With the large liquid scintillator used in the relative $\bar{\nu}$-measurements the distributions of fission neutron numbers are also measured. The number of neutrons following a fission is counted by a fast beam switching tube which can accumulate from zero to nine pulses.

The fission neutron number distributions are fitted to Gaussian distributions with the help of a computer program (IBM 7090). The parameters are the standard deviation, the efficiency and the mean value of the distribution. Calculations are in progress for spontaneous fission of Cf-252, U-238 and Pu-240 and neutron induced fission of U-238.

4. Fission neutron spectrum

H. Condé, G. During

A measurement of the fission neutron spectrum from neutron induced fission of U-238 is in progress using a time-of-flight technique. Measurements will be made in the energy interval from 1.5 to 7 MeV and around 14 MeV for the neutrons inducing fissions. A continuous neutron source produces fission pulses with a rise time less than 5 ns in a xenon-gas scintillation chamber. These pulses start a time-to-pulse hight converter while the stop pulses come from a neutron detector, a liquid scintillator 1 litre in volume. The discriminator bias for the neutron detector is set at about 0.5 MeV in neutron energy. Preliminary results exist at 14 MeV where a fit of the measured values to a maxwellian distribution $N(E) \sim E^{\frac{1}{2}} e^{-E/T}$ gives $T = 1.58 \pm 0.10$.

5. Elastic scattering angular distribution at 14 MeV

B. Lundberg, S. Schwarz, N. Starfelt, H-O. Zetterström

The measurements for oxygen have been completed and measurements on nitrogen are in progress.

6. Elastic scattering angular distributions in the 100 KeV region

S. Schwarz, L-G. Strömberg

Using time-of-flight techniques 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.

7. Fast neutron capture γ-rays

I. Bergqvist, B. Lundberg, N. Starfelt

The following papers have been published:

I. Bergqvist and N. Starfelt, "Gamma Rays from the Capture of Fast Neutrons in Ta, W, Au, Hg and Pb", Nucl. Phys. 39, 3 (1962)

I. Bergqvist and N. Starfelt, "Gamma Rays from the Capture of Fast Neutrons in Ag, Sn, I and Cs", Nucl. Phys. 39, 4 (1962)

I. Bergqvist and N. Starfelt, "Gamma-ray spectra from the capture of fast neutrons in Ni and Cu", Arkiv för Fysik 23, 40 (1962)

I. Bergqvist, "Gamma rays from the capture of fast neutrons in U-238", Arkiv för Fysik 23, 38 (1962)

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.

N. Starfelt, "The Influence of an M1 Giant Resonance on Neutron Capture Gamma-ray Spectra", FOA 4, A 4274-411 (January 1963)

8. Neutron capture cross section

I. Bergqvist

A paper with the following title has been published:
I. Bergqvist, "Fast neutron radiative capture cross sections in Ag, Ta, W, Au, Hg, and U", Arkiv för Fysik 23, 39 (1962)

9. Measurement with organic scintillators of continuous neutron spectra in the 0.5 to 15 MeV Range

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

A new reduction program has been written for the IBM 7090 computer. The first part of the program computes a response matrix by interpolation from experimentally measured response functions. This matrix is used in an iteration process, where the result from the old differentiation program is used as input data. The iteration is stopped when the computed pulse height spectrum is within the statistical uncertainties of the measured spectrum.

10. Neutron spectra from (p,n)-reactions in Ta and Au

B. Brunfelter, J. Kockum

Measurements of neutron spectra from the (p,n)-reaction in gold and tantalum have been made at the tandem van de Graaff, UITF, Risö, Denmark, using a stilbene scintillation spectrometer. The measurements cover a neutron energy from 1 to about 6 MeV and the proton energy was kept between 6 and 8 MeV. The results are consistent with a spectrum of the form $P(E)dE =$ const $E\ e^{-E/T}\ dE$ with a nuclear temp. $T = 0.55$ for W^{181} and $T = 0.61$ for Hg^{197}.

11. Absolute measurement of neutron flux and the $Li^6(n,\alpha)T$ cross section

H. Condé, S. Schwarz, N. Starfelt

In connection with the measurements of $\bar{\nu}$ of Cf^{252} the neutron detection efficiency of a large liquid scintillator was determined. An attempt to use this detector in an absolute measurement of neutron flux has been made. As a secondary standard the cross section of the $Li^6(n,\alpha)T$ reaction will be measured with the use of a Li^6-loaded glass scintillator.

12. Measurement of the energy dependence of the $Li^6(n,\alpha)T$ cross section

S. Schwarz

Using the fact that the emission of neutrons from the $Li^7(p,n)Be^7$ reaction is isotropic in the center of mass system at proton energies close to the neutron threshold the cross section for the $Li^6(n,\alpha)T$ reaction has been studied from 5 to 150 KeV. A Li^6-loaded glass scintillator was used as neutron detector.

13. Van de Graaff accelerator

L. Beckman, B. Lundberg

The terminal pulsing system is in operation with pulse lengths down to 5 ns. The installation of the Mobley bunching system is in progress.

PROGRESS REPORT FROM DENMARK

I. SPECIAL BEAM FACILITIES

I,1. The Performance of Reflecting Multi-channel Collimators as a Neutron Beam Filter and Polarizer **

H.B. Møller, L. Passell * and F. Stecher-Rasmussen,
Research Establishment Risø, Roskilde, Denmark

Neutrons reflected from the walls of multi-channel collimators can contribute appreciably to the total transmission particularly when the angular divergence of the collimator channels is of the same order as the critical angle for total reflection.

If two multi-channel collimators are placed at an angle large enough so that they can transmit neutrons only by reflection, the transmission of low-energy neutrons will be relatively unaffected while the transmission of high-energy neutrons will be strongly suppressed. Such an arrangement will act as a neutron filter, moreover a filter whose transmission can be varied within limits by the choice of the angle between the collimators and the angular divergence of the channels.

In addition, if the walls of the collimator are made of a magnetic material which is magnetized to saturation, the transmitted beam will be polarized.

In order to obtain information about the actual performance of angled collimators as a polarized thermal neutron source and as a neutron filter, a pair of collimators with magnetized iron plates were constructed.

Details of our results obtained until the spring of 1963 have been presented elsewhere.** The filter transmits approximately 6 pct of the flux transmitted through the collimators when alligned in parallel. Comparisons with quartz filters have been made and the degree of polarization has been measured.

I,2. Continued work on angled Soller collimators

E. Warming and F. Stecher-Rasmussen

The performance of the reflecting multichannel collimators as a neutron beam filter is being analyzed with a slow chopper and time-of-flight analyzing equipment.

The chopper, which has linear channels, gives bursts of neutrons of about 20 μsec duration and the flight path from the chopper to the neutron detector (a BF_3 counter) is 3,60m. The flight times are converted into pulse-heights by means of a linear ramp generator triggered from the chopper rotor and gated from the counter. The pulses are analyzed in a 512 channel pulse height analyzer.

** A more detailed account is given in Reactor Science and Technology 1963, Vol.17, p.227

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The flux distribution of the neutron beams emerging from the collimators has been analyzed for various angles between the collimators. When the collimators are aligned the transmitted beam consists of a distribution corresponding to a Maxwellian at 350°K (neutrons passing directly through the collimators) superposed a distribution (not Maxwellian), which has a maximum at 12 meV (neutrons transmitted by reflection in the walls of the collimator channels). As the angle between the collimators increases, the ratio between the directly transmitted beam and the reflected beam decreases, until the collimators are completely closed. It is seen from the spectra, that no direct transmission is permitted for angles greater than 32.7 min. At that angle the flux distribution of the transmitted beam has a maximum at 10 meV ($\pm$ 0,5 meV). Each collimator has an angular divergence of 10 min, and the collimators should therefore be closed at 20 min. This discrepancy in angle must be due to deviation from the expected geometry caused by the grinding of the collimator plates. In addition, the plates are not ground uniformly, so that there are small variations in the geometry of the channels from one channel to another, which means that all the channels are not closed at the same angle.

This may explain why the measured overall polarization (measured at 24,5 min) is lower (57%) than the expected (84%).

The ability of the system for suppressing second order neutrons has been computed from the measured spectra, and it has been found that $T(E)/T(4E) > 10$ for neutrons having there energies in the range 5,4-35meV (3,9A-1,5A). The first order transmission in the same energy range varies from 0,68 - 0,025 or 0,34 - 0,005 depending on the angle between the collimators.

It is possible to gain in first order transmission on the expense of $T(E)/T(4E)$ and v.v. by adjusting the angle between the collimators.

I,3. Characteristics of Quartz and Bismuth Single Crystal Filters for Reactor Beams.*

B.M. Rustad, Columbia University; and J. Als-Nielsen, A. Bahnsen, A. Nielsen, and C.J. Christensen, AEK Research Establishment Risø, Denmark.

The use of single crystal quartz and bismuth filters to obtain intense beams of subthermal energy neutrons from reactors has been reported by Brockhouse** and by Dyer and Low***. Such filters preferentially transmit low energy neutrons and strongly discriminate against fast neutrons and gamma-rays; however, detailed characteristics suitable for design purposes have not been reported. The total cross sections of representative samples of quartz and bismuth single crystals have been measured at room and liquid nitrogen temperatures over the energy range from 0.0008 eV to 2.0 eV to obtain data for optimizing filter design to meet particular experimental requirements.

* Work supported by the U.S. Atomic Energy Commission and the Danish Atomic Energy Commission

** B.N. Brockhouse, Rev. Sci. Instr. 30, 136 (1959)

*** R.F. Dyer and G.G.E. Low, AERE - R3494 (unpublished)

The cross sections for both crystals at liquid nitrogen temperature descend from above 9b. at 1.0 eV to less than 0.5b. near 0.006 eV. Bismuth has the advantage of a large gamma-ray attenuation coefficient, but many small Bragg peaks were observed above 0.003 eV, which were not found with quartz. Neutron and gamma-ray transmission curves useful for designing filters for special beam requirements will be presented, and the performance of the filter in the high intensity, subthermal beam facility at the Danish DR3 reactor will be described.

II INVESTIGATIONS OF He^3.

II,1. A Thermal Neutron Counter of Well Known Detection Efficiency**

by J. Als-Nielsen and A. Bahnsen*

A proportional counter has been developed utilizing the $He^3(n,p)H^3$ reaction (Q = 764 keV) for measuring neutron density in a thermal beam.

The counter has a rectangular cross section, and the anode wire is perpendicular to the beam, which can then traverse either the short (3 cm) or the long (5 cm) dimension of the counting chamber.

In both cases, the maximum energy loss from ionization tracks, shortened at the walls, will be $3/4$ Q - reaction particles being expelled in opposite directions. All (n,p) reactions will therefore be counted with a discriminator level below $1/4$ Q.

Detailed calculations of the wall-effect spectrum exhibit a step at $1/4$ Q, and this is clearly demonstrated by the measurements, which also show that it is possible to discriminate effectively against background. Spectra, recorded at 1 and 2 atm. of gas pressure, agree very well with the calculated, and the difference between the spectra for the two counter lengths is very close to that expected from a wall-less counter, indicating that conditions in the counter are close to ideal.

The ratio between the counting rates of the long and the short dimension of the counter, was compared to the ratio between the physical lengths, and good agreement found.

It is concluded that detection efficiency, i.e. the ratio between number of counts and number of (n,p) reactions, is equal to 1.000, with an uncertainty of $\pm$ 0.4%, for both counter orientations.

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** A detailed account of this work is given in Risø Report No.60 (1963)

II,2. Slow Neutron Cross Section for He^3, B and Au

by J. Als-Nielsen and O. Dietrich

The He^3 neutron cross section has been measured for neutron energies from 0.0003 eV to 10 eV. In this energy region no deviation from the 1/v law can be found from the data. The cross section at 2200 m/sec has been found to be $\sigma(He^3) = 5328 \pm 7$ barns. As an instrumental check the cross sections of natural boron and of gold have also been measured and the results agree with the most accurate existing data. The absorption cross sections at 2200 m/sec were found to be $\sigma_a(B) = 757.1 \pm 2.2$ barns and $\sigma(Au) = 98.61 \pm 0.18$ barns.

A detailed report has been issued as EANDC (OR).?

II,3. Direct measurement of the He^3 (n,p) cross section

V. Tarnov, J. Als-Nielsen.

By using two He^3 proportional counters with well known detection efficiency*, it is possible to determine directly the (n,p) cross section from the ratio of the two count rates:

$$\frac{C_1}{C_2} = \frac{1 - \exp(-a_1\sigma)}{1 - \exp(-a_2\sigma)}$$

where a_1 and a_2 are determined by the resp. He^3 pressures and the counter-lengths.

At present it has been verified experimentally, that the discriminator-level can be chosen so that the detection efficiency is 1.000 within approx. 0.2 %, even for a "thick" counter ($a \approx 0.5$).

III. INVESTIGATIONS OF CAPTURE GAMMA RAYS

III,1. Relative Intensities of Gamma Transitions in W 182 and W 183**

O.W.B. Schult and U. Gruber, Labor f. Techn. Phys. T.H. München

The relative Gamma ray intensities in W 182 and W 183 were determined with an accuracy of a few percent, using a curved crystal spectrometer, before it was installed for the measurement of low energy neutron capture Gamma rays at the DR-3 reactor at Risø in Denmark. The values obtained for

* See Risø Report No. 60. This report deals only with a "thin" counter ($a \ll 1$).

** Research supported by the Bundesministerium Bonn and by the Atomic Energy Commission Denmark and performed at the Research Establishment Risø.

the transitions in W 182 agree excellently with those, found by Edwards.[1] The relative intensity ratios for several Gamma lines emitted by W 183 are in extremely good agreement with the ratios calculated by Kerman[2] on the basis of a rotation particle coupling. The relative intensity for the 245,2 keV transition differs however by a factor 6,5 from the calculated value.

III,2. Low Energy Neutron Capture Gamma Rays from Rh 104 *

U. Gruber, O.W.B. Schult and B.P. Maier, Labor f. Techn. Phys. T.H. München

After the bent crystal spectrometer was set up at the DR-3 reactor at Risø, Denmark, the neutron capture Gamma ray spectrum of Rh 104 was roughly scanned. 170 transitions were found between 30 and 790 keV. The absence of a sufficiently intense line with an energy up to 1,2 MeV confirms clearly, that the strong 180,8 keV transition directly leads to the ground state, such as proposed by Buschhorn[3], whose results agree nicely with our measurement.

III,3. Low Energy Neutron Capture Gamma Ray Spectrum from U 239 **

B.P. Maier, O.W.B. Schult and U. Gruber, Labor f. Techn. Phys. T.H. München

The neutron capture Gamma spectrum of U 239 reveals 21 lines with energies from 133 to 630 keV. A part of the transitions at approximately 550 keV seem to correspond to the octopole transitions, as suggested by Fiebiger[4]. The very high conversion coefficients for low energy M1 and E2 transitions imply, that the transitions within the ground state band could not be seen. This complicates the interpretation of the results. The very strong 133 keV line can only be E1 or E2. As E1 is an unlike indication, one must conclude, that the decay of U239 cannot occure exclusively across the 74 keV transition in Np 239, the total intensity of which could otherwise be taken as 100%.

* Research supported by the Bundesministerium Bonn and by the Atomic Energy Commission, Denmark and carried out at the Research Establishment Risø.

** Work supported by the Bundesministerium Bonn and the Atomic Energy Commission, Denmark, and accomplished at the DR-3 at Risø.

1 F. Edwards, Thesis Cal. Inst. Technology, Pasadena Cal. 1960

2 A.K. Kerman. Mat. Fys. Medd. Dan. Vid. Selsk. 30, No. 15 (1956)

3 G. Buschhorn Z. Naturforschung 17 a, 241, (1962)

4 N. Fiebiger private communication

III,4. Neutron capture Gamma rays from Dysprosium and decay of Dy 165 *

O.W.B. Schult, B.P. Maier and U. Gruber, Labor f. Techn. Phys. T.H. München

130 n-capture Gamma lines were measured at Dy 162. The strongest transitions observed, belong to those within the ground state rotational band. An equal number of lines was measured at Dy 163, where the transitions in the ground state band are relatively weak, due to the large spin difference between these levels and the capturing state. At Dy 164 only 46 transitions could be clearly identified. Besides the 2+, 4+, 6+ ground state band, the 2+ Gamma vibrational state was found at 761,8 keV in excellent agreement with the value of Yoshizawa[1]. The very complex spectrum of Dy 165 revealed 225 lines. The energy of the isomeric transition was measured to be 108,160 $\pm$ 0,003 keV. The Gamma lines emitted by Ho 165, after the β-decay of Dy 165 could be determined very accurately, such as to define the energy of several states within a precision of 3×10^{-5} to $1,3 \times 10^{-4}$. The intensities of the transitions agree with the data obtained by Persson[2].

1 Y. Yoshizawa et al., private communication

2 L. Persson et al., Arkiv Fysik 23, 1, (1962)

* Research supported by Bundesministerium Bonn and by the Atomic Energy Commission, Denmark, and performed at the DR-3, Risø.

III,5. Neutron Capture Gamma Rays from Lu, Re 186 and Ho 166. *

B.P. Maier, O.W.B. Schult, U. Gruber and R. Koch
Labor f. Techn. Phys. T.H. München

Roughly 70 lines were found in the low energy part of the Lu 175 (n, γ) Lu 176 spectrum. 250 Gamma transitions were observed during the irradiation of Lu 176. The strongest of these transitions occur between the states (up to 17/2) of the (404), (514) and (402) rotational bands, the level of which could be very accurately determined. These results are in full agreement with the data obtained by Nielsen[1]. About 140 lines of the Re 186 spectrum were measured. The irradiation of Ho 165 with thermal neutrons produces a spectrum containing some 300 low energy Gamma transitions.

1 O.B. Nielsen, private communication

* Research supported by the Bundesministerium Boon and by the Atomic Energy Commission Denmark

III,6. (n, γ) Polarization Experiment

K. Abrahams**, L. Passell* and F. Stecher-Rasmussen

The measurements of the polarization of the beam emerging from the polarizing collimators set at 24.5 min angle has been repeated with a magnetic guide field installed between the end window of the exterior collimator and the polarization analyzer (a 97% Co - 7% Fe single crystal magnetized to saturation). The effect of the guide field was to increase the polarization by about 10%.

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The overall polarization computed from the flux distribution and the curve showing polarization versus energy gave 57% for the beam as a whole. The expected value is about 84%, and this discrepancy is believed to be due partly to non-uniform collimator channels (flux distribution measurements show that the angle 24.5 min some neutrons are directly transmitted) and partly to non-saturation of the iron plates making up the channel walls.

It is desirable to measure the overall polarization by means of a magnetized Co - Fe mirror (polarization measurements with Co - Fe crystal are inconvenient at low energies because of higher order contamination). A mirror has been set to reflect a 50 meV beam from a Co - Fe crystal, and the reflectivity of the mirror has been found to 85%. When the performance of the mirror has been analyzed, it will be used for measuring the overall polarization.

An improved version of the present collimators has been build, and is installed in DR2.

The collimator plates are magnetized by a coil, instead of permanent magnets as in the first collimator set; this has the advantage that one can be sure of having saturated the plates completely by increasing the current through the coil.

The new collimator set is provided with tapered channels, so that the beam is focussed. The incoming 3.5 cm broad beam is focussed down to a ca. 8 mm broad beam at 3.5 m distance from the end of the exterior collimator.

The collimators are in the process of being analyzed with respect to their performance as a neutron beam polarizer. When the measurements are finished the collimators will be transferred to DR3, where they will be used as a source of polarized neutrons for the (n, γ) polarization experiment.

On the basis of the in ormation obtained from collimator set number two, a third version of the collimators with tapered channels will be constructed using the 11.5 cm broad beam from the DR3 beamtube. The collimator parameters will be optimized with respect to (intensity) x $(\text{polarization})^2$.

A beam plug with a water scatterer has been constructed for this experiment and is inserted in the reactor. The gamma analyzing equipment is under construction at Kjeller, Institutt for Atomenergi, Norway. The magnetic guide field (a spin-turning guide field and a "field flipper") has been constructed at Kjeller and has been sent to Risø.

The experiment is scheduled to start October first.

IV. SOLID STATE INVESTIGATIONS WITH NEUTRONS

IV,1. Critical Magnetic Scattering of Neutrons in Iron for Temperatures above the Curie-Point.

L. Passell*, K. Blinowski, T. Brun and P. Nielsen

Measurements have been performed on the critical magnetic scattering of neutrons on iron. Spin-correlation-ranges and relaxation-time-constants have been determined for the magnetic fluctuations in iron at temperatures above the Curie-point.

The experiment was carried out to furnish further information about the thermodynamical mechanism of the magnetic second order transition in ferromagnets.

According to L. van Hove's theory (Phys. Rev. 95, 1374 (1954)), based on the concept of spin-correlation-functions, the magnetic fluctuations around the Curie-point give rise to a very strong scattering of neutrons at small angles.

The cross-section for this kind of scattering (valid for temperatures above the Curie-point and small scattering angles) is

$$(1)\qquad \frac{\partial^2\sigma}{\partial\Omega\partial E} = \text{const.} \times \frac{k}{k_o} \times |f(\bar{\kappa})|^2 \times \frac{1}{r_1{}^2(\kappa^2 + \kappa_1^2)} \times \frac{\Lambda_1 \kappa^2}{\Lambda_1^2 \kappa^4 + \omega^2}$$

where

$\bar{k}_o$ is the wave vector of the incident neutrons,

$\bar{k}$ is the wave vector of the scattered neutrons,

$\bar{\kappa} = \bar{k}_o - \bar{k}$

$\hbar\omega = \hbar^2(k_o{}^2 - k^2)/2m$,

$f(\bar{\kappa})$ is the magnetic form factor,

r_1 is a parameter with the dimension of a length; it is related to the strength of the correlation,

κ_1 is a range parameter for the magnetic correlation (the correlation decrease with a factor $\exp(-\kappa_1 r)/r$ with distance),

Λ_1 is a relaxation time-constant (the time decay of the correlation is given by $\exp(-\Lambda k^2 t)$).

The parameters r_1, κ_1 and Λ_1 are all temperature dependent. They can be determined by studying the scattered intensity at various angles. The experiment has been performed with the use of the triple-axis-spectrometer installed on one of the eight horizontal beam channels of the DR 3 reactor at Risø.

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Determination of κ_1

By performing the integration over the wave vectors of all scattered neutrons the cross section (1) for the critical magnetic scattering takes the form

$$(2) \quad \left(\frac{\partial\sigma}{\partial\Omega}\right)_{crit.} = \text{constant} \times \frac{1}{r_1^2} \times \frac{1}{k_o^2 \quad \theta^2 + \kappa_1^2} \times G(\theta, k_o, \kappa_1, \Lambda_1),$$

where the "constant" is independent of temperature.

θ is the scattering angle and

$G(\theta, k_o, \kappa_1, \Lambda_1)$ is a correction factor equal to 1 for $\Lambda_1 = o$.

κ_1 has been determined by measuring the integrated scattered intensity as a function of θ for small values of θ.

The experimental set-up is shown in fig. 1. For a given value of θ the Zn-crystal was removed, and the BF_3-counter was placed so that the counter was aiming at the sample. The wave length of the incident neutrons was 4.3 A.

Fig. 2 shows "integrated" intensities measured as a function of temperature for different scattering angles.

By subtraction of the background for the measured intensities one obtains the critical scattered intensity $I_{crit.}$. In fig. 3 $1/I_{crit.}$ is plotted versus θ^2 for different temperatures, and from the straight lines κ_1^2 is determined.

$C(\theta, k_o, \kappa_1, \Lambda_1)$ is assumed equal to one in fig. 3.

In fig. 4 the measured values of the correlation range $1/\kappa_1$ are shown as a function of temperature. The heavy line is for $\Lambda_1 = o$, the dashed line is obtained when corrections corresponding to $2m\Lambda_1/\hbar = 7.5$ are introduced.

Determination of Λ_1.

Λ_1 can be determined by measuring the shape of the scattered spectrum for a given temperature and a given scattering angle.

One can measure the incident spectrum and calculate the theoretically expected shape of the scattered beam by means of the cross section (1) for given value of Λ_1. By comparison of the theoretical and the measured scattered spectra one is able to determine a value of Λ_1.

Preliminary results of this experiment show, that $2m\Lambda_1/\hbar$ is about 7 at $2^{\circ}C$ above the Curie temperature.

More precise determination of this parameter is planned for the immediate future.

The oven.

The iron sample was heated up in a vacuum-oven (see fig. 5), and the temperature of the sample was kept constant by an automatic control. The magnitude of the temperature-fluctuations was of the order of $0.1^{\circ}C$, and the temperature gradient across the sample was less than $0.5^{\circ}C$ for the temperature close to the Curie-point.

IV, 2. Temperature dependence of the Debye temperature for Al.

Ole Bent Rasmussen, Ove Dietrich and Jens Als-Nielsen

At the IAEA Symposium 1960 on inelastic scattering of neutrons in solids and liquids, Walter Marshall (AERE, Harwell) pointed out that the temperature dependence of the Debye temperature, Θ, could be deduced from the temperature dependence of the elastic constant C_{44} and from the thermal expansion coefficient through

$$\frac{d}{dT} \ln \Theta = \frac{1}{2} \frac{d}{dT} \ln C_{44} + \frac{\Theta}{6}$$

This is of importance in calculation of cross sections at high temperatures, where only very few direct measurements exists. The temperature dependence given above has been confirmed by Xray technique (Chipmann: MRL Report no.67) to be valid for β-brass and lead, but Chipmann found a rather big discrepancy for Al.

It is the intention in the near future to measure the temperature dependence with neutrons. The monochromatic intensity, which is proportional to the Debye - Waller factor, from a single Al crystal placed in the poly-energetic, direct beam will be measured as function of the temperature. At present the oven is just finished and the Al crystal delivered, so the experiment is just ready to start and will be performed on the single axes spectrometer at DR 3.

V. THE NEUTRON HALF LIFE.

Axel Bahnsen*, Wilbur K. Brown, C.J. Christensen, Arne Nielsen, Brice M. Rustad**.

In this experiment the halflife of the neutron is determined by counting the number of decay-electrons per sec. from a fixed number of neutrons.

The experiment is performed at DR3 which has a thermal flux of 10^{14} u/sec.cm^2. A neutron scatterer is placed in a horizontal tangential beamtube. The scatterer is an aluminium box with 0.5 mm wall thickness. It contains a layer of water of thickness 2 mm. This scatterer is thick against thermal neutrons but thin against gammas and fast neutrons. In the following table this thin scatterer is compared with a thick scatterer.

out of beamtube	thick scatterer	thin scatterer	Ratio $\frac{\text{Thin}}{\text{Thick}}$
$\phi_{thermal}$	5.2×10^9	3.3×10^9	63%
$\phi_{fission}$	$2{,}0 \times 10^7$	0.15×10^7	7,5%
ϕ_γ	$4{,}0 \times 10^9$	$3{,}6 \times 10^7$	0,9%

As a further purification the beam passes a 32 cm long single-crystal Bi -block cooled down by liquid nitrogen. This allows 10^{-1} of the thermal neutrons, 10^{-3} of the fission neutrons and 10^{-5} of the gammas to pass.

The net result is a 5 cm^2 beam of composition:

thermal	6×10^7 n /cm^2.sec
fission	10^3 n /cm^2.sec
	25 mr/h

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V,1. The collimator

The outer half of the collimator wall consists of a mixture of epoxy resin and lead shots. The inner half is lead and stainless steel.

In order to get rid of neutron capture gammas from the inner collimator wall it is sawtooth shaped, and the front of the teeth is covered with Li^6-carbonate cast as rings of appropriate size to prevent thermal neutrons from hitting anything but Li^6-carbonate. Because of the 950 barns (n ,p) cross section almost without gamma emission, Li^6 is very well suited for this purpose. The estimated effect is that 10^{-4} of the neutrons hitting the Li-aperture gives rise to gamma emission.

V,2. Counter system

The counter system consists of two NE-102 plastic scintillators 5x10 cm2 placed at a distance of 20 cm. The beam is passing in the median region. To each scintillator is attached two 1 m long lightguides and an EM phototube. The pulses from the four phototubes are added, and after shaping and amplification, they are led into a 256 channel analyzer.

V,3. Production of "a fixed number of neutrons"

There are two problems, 1) determination of the neutron-density and 2) definition of the volume.

1) For this purpose is used a proportional counter of the type described by J. Als-Nielsen and A. Bahnsen (Risø Report No. 60). To the counter gas is added a small well-determined amount of He^3. The cross sections of He^3 – which recently has been redetermined by J. Als-Nielsen – is very accurately proportional to $\frac{1}{v}$ and thus the counter directly measures the density of the beam, or rather the number per cm.

2) The two plastic scintillators are placed in a homogeneous magnetic field in such a way that the scintillators and the direction of the field lines define a parallellepiped. An electron from a neutron decaying in the magnetic field will follow a helical path with its axis in the field direction. If the decay occurs inside the parallellepiped the electron will hit a scintillator. If the electron is backscattered it will go to the other scintillator. If the decay occurs outside the parallellepiped the field will prevent the electron from hitting a scintillator. The length of the scintillator is then equal to the length of that part of the beam, which is seen by the detector.

The strength of the magnetic field is 8000 gauss and the max. value of $H\rho$ is 4000 gauss.c.m. Thus the max. radius in the aforementioned helical paths is 0.5 cm. At the borders of the region this fact gives rise to some deviations from the picture given above, where it was tacitly assumed that the radii were zero. Perpendicularly to the beam the scintillator dimension is 5 cm, which is more than the dimension of the beam + 2 x 0.5 cm, there are therefore no troubles here. In the other direction the scintillator is 10 cm long and the end effect is therefore only a small fraction of the total number of counts. The effect can be studies experimentally by moving a point source along the beampath and plotting countrate versus position.

V,4. <u>Measuring technique.</u>

The expected countrate of decay electrons is 5 pr.sec.

The background from the beam facility (mainly capture gammas) is estimated to be 1 c/sec. The background coming from outside our facility is around 20 c/sec. This external background can be measured by closing the beam. To this end a series of shutters is built in the beampath: Two thin aluminium plates can be put in front of the scintillators, thus stopping the electrons. A Li^6 shutter stops the thermal neutrons without influencing anything else. A Boral-Jabroc shutter stops thermal and fast neutrons without reducing the gamma flux very much. A 1 m long water shutter stops everything. It is hoped that different combinations of these shutters will give information about the beam-background.

After subtraction of the background the pulse height distribution gives the decay spectrum plus small pulses from internal background plus noise spectrum. Discrimination at 100 keV shuts off the elctronic noise.

To compare the experimental spectrum with the theoretical one, this must be corrected for the finite resolution of the apparatus. A source of Bi^{207} with a conversion line of 974 keV placed in the center of the counting system shows a resolution of 40%. Furthermore there is another cause for bad resolution which in our present apparatus is even more important. When the Bi-source is moved in the direction of the beam the pulseheight near the edges of the scintillator is only half of that in the center position.

When this effect has been taken into consideration it has been possible to get a reasonable fit with the theoretical spectrum.

In the near future the efficiency will be checked by standardized sources of P^{32} and Au^{198}.

VI. NEUTRON DOSIMETRY

VI,1. Cadmium Corrections for Manganese, Cobalt, Indium and Gold

J. Olsen

Relative measurements of the epithermal activity as function of the thickness of the cadmium cover has been compared with calculated values for manganese, cobalt, indium and gold.

From the calculations it was noticed that the variation for a 1/V-absorber was even greater than the variation for indium.

A good agreement between the measurements and the calculations is obtained for manganese and cobalt when the resonance selfshielding due to resonance scattering is taken into consideration.

VI,2. Material containing Cadmium for Cd-Ratio Measurement at High Temperatures. *

J. Thomas and N. Hansen

Normally Cd-Ratio measurement is carried out with the detector foils embedded in boxes of metalic cadmium. This method, however, is limited to be used only at places where the temperature in the cadmium box does not exceed 321°C which is the melting point of cadmium.

In order to measure Cd-Ratios or to shield fast neutron detectors from the thermal flux in high flux positions (e.g. center of core DR3) a material containing cadmium has been developed. It consists of a powder of a ceramic cadmium compound kept together by a metal (e.g. CdO + Al) where the melting point is now determined by the metal. In the case of CdO + Al the melting point will be raised to 660°C. The material is easily machined since cadmium oxide itself is a soft material (i.e. it does not have the same grinding properties as e.g. boron carbide).

In addition other materials such as Samarium or Gadolinium with specific neutron cross section can be added or used solely in order to obtain other neutron shielding effects.

The material can of course be used in control rods and for other shielding purposes.

* Patent applied for.

High-Lutetium Foils for Neutron Spectrum Measurement *

by Per Knudsen

Foils containing lutetium are frequently used in the determination of neutron energy spectra. If pure lutetium was to be used, the foils would have to be extremely thin because of the self-shielding properties of lutetium. Thus, a certain dilution of the element is necessary in order to obtain foils which are thick enough to be handled without difficulty. The diluting material must of course have suitable nuclear properties, and the amount must be limited so that minimum interference with the induced lutetium activity is ensured.

Lutetium-aluminium alloys are useful in this respect to a certain degree only, since the requirement of formability sets an undesirably low limit on the lutetium content.

To circumvent this problem, a novel material consisting of a mixture of lutetium oxide and aluminium has been developed. By hot-pressing and rolling a powder-mix of the materials mentioned, foils have been manufactured with a thickness of approximately 0.15 mm (0.006 inch) containing 16 mg Lu/cm2.

Similarly, foils having a high content of europium or indium can be made by incorporating the oxide of the neutron absorber in a matrix of aluminium.

* Patent applied for.