International Atomic Energy Agency

INDC(NED)-1/G

323

INDC INTERNATIONAL NUCLEAR DATA COMMITTEE

PROGRESS REPORT ON NEUTRON PHYSICS WORK PERFORMED IN THE NETHERLANDS DURING 1969

April 1970

IAEA NUCLEAR DATA SECTION, KÄRNTNER RING 11, A-1010 VIENNA

REACTOR CENTRUM NEDERLAND (PETTEN)

1. RCN activities

1.1. Circular polarization of gamma radiation after capture of polarized thermal neutrons (K. Abrahams)

By means of an earlier mentioned system of 74 magnetized cobalt-iron mirrors [1) 2) 5)], a 90% polarized beam of thermal neutrons can be extracted from the High Flux Reactor at Petten. With the reactor running at 30 MW a flux of 3.10^7 $cm^{-2}s^{-1}$ has been measured at the target position.
One may assign spins to nuclear states, excited by the (n,γ) reaction, by a measurement of the polarization of the gamma radiation resulting from the capture of polarized neutrons.

Last year the $^{40}Ag(n,\gamma)$ and the $^{59}Co(n,\gamma)$ have been extensively studied [3) 4) 5)]. The first reaction was leading to unambiguous results because the sign of the polarization determines the spin of levels with $l_n(d,p) = 1$, in case of an even-even target nucleus. The interpretation of our results on the $^{59}Co(n,\gamma)$ reaction was more difficult, due to an incoherent mixture of the spins 3 and 4 in the capturing state of ^{60}Co.
By means of a careful analysis of our measurements and of measurements on radiative capture in and between resonances [6)], it is, however, possible to estimate the spin admixture for several primary γ-transitions, and to assign spins to excited states of ^{60}Co (fig. 1).

A new development is the study of the angular correlation of positon electron pairs created by circularly polarized γ radiation. A preliminary set-up of two Si(Li) detectors in coincidence yielded promising results. These measurements can test some quantum electrodynamical calculations [7)] and are of interest for the study of systematical errors in measurements on parity admixture in nuclear states [8)].

References

1) K. Abrahams and W. Ratynski, Nucl.Phys. A124 (1969) 34.
2) K. Abrahams, "Experiments with Polarized Thermal Neutrons" Thesis (1969).
3) J. Kopecký, F. Stecher-Rasmussen and K. Abrahams, Proceedings of the "International Conference on Properties of Nuclear States", Montreal 1969.

4) F. Stecher-Rasmussen, J. Kopecký and K. Abrahams, "International Symposium on Neutron Capture Gamma-Ray Spectroscopy", Studsvik 1969.
5) K. Abrahams, Atoomernergie 11 (1969) 308.
6) O.A. Wasson, R.E. Chrien, M.R. Bhat, M.A. Lone and M. Beer, Phys.Rev. 136 (1968) 1314.
7) H. Kolbenstvedt and H. Olsen, Il Nuovo Cimento XXII (1961) 610.
8) K. Abrahams, W. Ratynski, F. Stecher-Rasmussen and E. Warming, Proceedings of the 2nd International Symposium on Polarization of Nucleons (Birkhäuser Verlag Basel-Stuttgart 1965).

1.2. Integral measurements of cross sections of fission products

(M. Bustraan)

The fast-thermal coupled critical reactor facility STEK, referred to in the report over 1968, came into operation in 1969.
The actual measurements will start in early 1970.
The fissile material in the central, fast, zone is highly enriched ^{235}U, in the form of platelets. The neutron spectrum is softened by graphite, also in the form of platelets.
In order to be able to predict the neutron spectra correctly an evaluation was made of the ^{235}U fission and absorption cross section [1].
These evalueated data were condensed to a 26 group set. The resonance integrals derived from this set are 281 b (fission), 143 b (capture) compared to the experimental values of 274 b and 144 b; the α value derived from this set is 0.51, the experimental value being 0.525 (BNL 325 latest ed.).
The critical masses observed during the loading of STEK are supporting this group set.

---

1) R. Kuiken. Private communication.

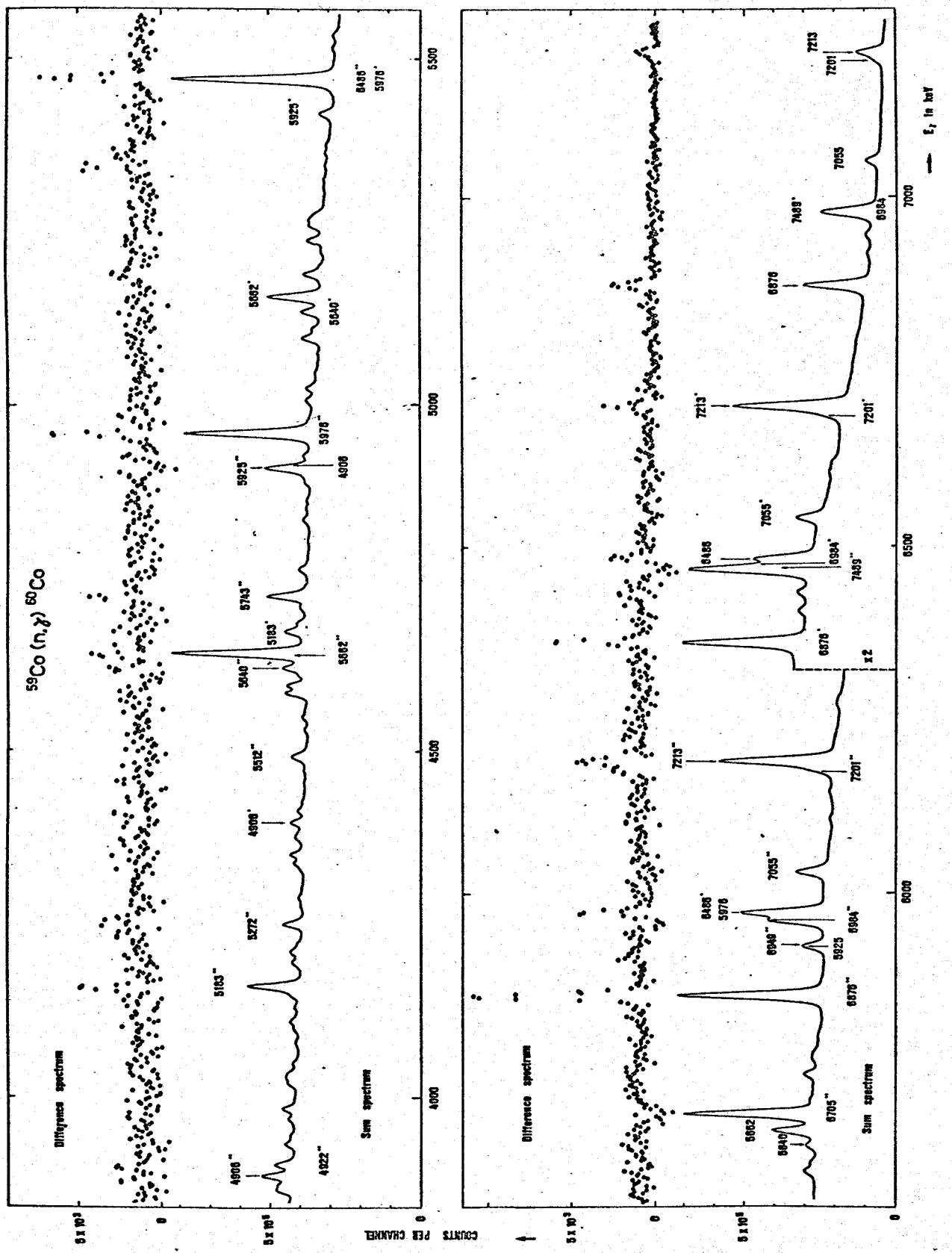
$^{59}Co\ (n,\gamma)\ ^{60}Co$
Difference spectrum
Sum spectrum
COUNTS PER CHANNEL
E_γ in keV

Figure 1

2. FOM-activities

2.1. Thermal-neutron capture γ-ray spectroscopy (G. van Middelkoop *), P. Spilling **), H. Gruppelaar ***), A.M.F. Op den Kamp and A.M.J. Spits)

A beam of thermal neutrons is obtained with a neutron filter, placed in one of the radial beam holes of the Dutch High Flux Reactor. This neutron filter consists of quartz and bismuth single crystals and is cooled down to the temperature of liquid nitrogen. The thermal-neutron flux at the target is about 10^7 cm^{-2} s^{-1}.

The capture γ-rays can be detected with a 23 cm^3 Ge(Li) detector or with a 12.7 × 12.7 cm NaI crystal. Both detectors can be used to perform γ-γ coincidence and γ-γ angular correlation measurements. The main component of the electronics is a Laben 4096-channel pulse-height analyser, which is supplied with a digital-window discriminator [1]. With this facility a maximum of 16 coincidence spectra can be measured simultaneously.

Measurements on thermal-neutron capture γ-rays started in Petten in 1964 with angular-correlation studies, using two large NaI crystals [2-4]. During the last three years a Ge(Li) detector is used, chiefly for the recording of "single" spectra. As a result γ-ray energies, excitation energies, γ-ray branchings and the reaction Q-value can be determined with high accuracy. Rather complete decay schemes have been constructed for the following final nuclei: ^{32}P [ref. 5)], ^{25,26}Mg [ref. 6)], ^{20}F, ^{13}C [ref. 7)], ^{41,43,45}Ca [ref. 8-10)]. The combination of a high neutron flux, a relatively low γ-background and a high-resolution Ge(Li) detector gives the possibility of measuring capture γ-ray spectra of samll amounts of enriched isotopes [^{42}Ca(n,γ)^{43}Ca and ^{44}Ca(n,γ)^{45}Ca]. Finally, some γ-γ angular correlation measurements with a combination of Ge(Li) and NaI detectors were performed on the γ-rays from capture in ^{44}Ca [ref. 11)]. Spins and E2/M1 mixing ratios in ^{45}Ca were derived.

Laboratory: Reactor Centrum Nederland, Petten and Physical Laboratory, State University, Utrecht.

*) Present address: Physical Laboratory, State University, Utrecht.

**) Present address: Technical University, Eindhoven.

***) Present address: Physical Laboratory, State University, Groningen.

References:

1) P. Spilling, H. Gruppelaar and P.C. van den Berg, Int. Symp. on Nucl. Electronics, Versailles, 1968, Part II, Contr. 140.
2) G. van Middelkoop and P. Spilling, Nucl. Phys. 72 (1965) 1.
3) G. van Middelkoop and P. Spilling, Nucl. Phys. 77 (1966) 267.
4) G. van Middelkoop and H. Gruppelaar, Nucl. Phys. 80 (1966) 321.
5) G. van Middelkoop, Nucl. Phys. A97 (1967) 209.
6) P. Spilling, H. Gruppelaar and A.M.F. Op den Kamp, Nucl. Phys. A102 (1967) 209.
7) P. Spilling, H. Gruppelaar, H.F. de Vries and A.M.J. Spits, Nucl. Phys. A113 (1968) 395.
8) H. Gruppelaar and P. Spilling, Nucl. Phys. A102 (1967) 226.
9) H. Gruppelaar, A.M.F. Op den Kamp and A.M.J. Spits, Nucl. Phys. A131 (1969) 180.
10) H. Gruppelaar, P. Spilling and A.M.J. Spits, Nucl. Phys. A114 (1968) 463.
11) H. Gruppelaar, Nucl. Phys. A133 (1969) 545.

2.2. Neutron capture experiments with oriented nuclei (H. Postma, E.R. Reddingius, J. Mellema and R.Kuiken, F.O.M. - Petten, Physical Laboratory State University, Leiden).

The anisotropy of the directional distribution of neutron-capture gamma rays from ^{55}Mn oriented in single crystals of $La_2Mn_3(NO_3)_{12}.24D_2O$ and $MnSiF_6.6H_2O$ has been measured with a thermal neutron beam of the high flux reactor in Petten. The necessary low temperature of 0.05 - 0.06 K has been obtained with the aid of a ^3He - ^4He dilution refrigerator. The analysis of the results is complicated since the neutron capture is related to various resonances with spins 2 and 3. Nevertheless it was possible to limit the spins of many levels of ^{56}Mn to two values. For a few levels of ^{56}Mn it was possible to arrive at a definite assignment. A similar experiment has been started with the $^{141}Pr(n,\gamma)$ reaction. The ^{141}Pr nuclei are oriented in $Pr_2Mg_3(NO_3)_{12}.D_2O$.

In a joint English-Dutch project the directional distribution of fragments from neutron-induced fission of ^{235}U has been studied, while similar experiments with ^{233}U and ^{237}Np have been started. These experiments are mainly carried out at the electron linear accelerator in Harwell.

References:

J. Mellema and H. Postma, Spin Investigation of Excited States of ^{60}Co by Means of Nuclear Orientation, Nucl. Phys. A130 (1969) 161.

E.R. Reddingius and H. Postma, Directional Anisotropy of Capture Gamma Rays from Aligned ^{149}Sm Nuclei, Proc. Int. Symp. on Neutron Capture Gamma Ray Spectroscopy, Studsvik (1969) 359 and Nucl. Phys. A137 (1969) 389.

H. Postma and J.F.M. Potters, The Change of Nuclear Orientation Parameters Related to Pseudo-continuous Neutron Capture Gamma Ray Spectra, Physica 45 (1969) 559.

INSTITUTE FOR NUCLEAR PHYSICS RESEARCH (AMSTERDAM)

Neutron cross-section data (E_n > 20 keV)

(W. Pauw)

$\sigma_{^{197}Au(n,\gamma)^{198}Au}$ $\sigma_{^{115}In(n,\gamma)^{116}In^m}$ (54 minute activity)

For these reactions all literature values have been carefully studied and renormalized in such a way that they can be represented by a smooth curve. The result of an absolute measurement of the activation cross-section of gold (σ = 692 ± 14 mb) for SbBe neutrons (22.4 keV) agrees well with this cross-section curve.
Below 100 keV the indium cross-section curve has been extrapolated through the value of σ = 577 ± 20 mb for SbBe neutrons, obtained by an absolute measurement for the 54 minutes' period.

$^{115}In(n,n')^{115}In^m$

The literature cross-section values have been renormalized. On the basis of the renormalized values the calculated average cross-section for the ^{252}Cf-neutron spectrum $\phi(E) \sim \sqrt{E} \exp\left(\frac{-E}{1.39}\right)$ (σ = 179 ± 18 mb).

(The data given in the table I will be discussed more fully in a thesis, to be submitted to the University of Amsterdam).

Table I

keV	$\sigma_{^{197}Au(n,\gamma)^{198}Au}$ (+5%, except at 22 keV)	$\sigma_{^{115}In(n,\gamma)^{116}In^m}$ (+10%, except at 22 keV)	$\sigma_{^{115}In(n,n')^{115}In^m}$ (+10%)
22.4	692 ± 14* (mb)	577 ± 20* (mb)	-
30	596	(500)	-
40	490	(435)	-
50	435	(390)	-
60	400	(360)	-
70	370	(330)	-
80	350	(310)	-
90	330	(295)	-
100	315	(280)	-
150	275	230	-
200	255	200	-
250	230	185	-
300	200	170	-
400	162	154	-
500	136	149	2
600	120	160	4.6
700	108	173	12
800	98	182	22.5
900	92	190	40.5
1000	88	194	62
1200	80	192	115
1400	74	180	160
1600	68	166	200
1800	58	150	250
2000	49	135	300
2500	31	100	310
3000	19.5	64	310
4000	14	29	310
5000	12.8	16	310
6000	-	11.3	305
7000	-	9	290
8000	-	7.4	280
9000	-	6.4	240
10.000	-	5.8	190

* values measured at I.K.O.

PHYSICAL LABORATORY OF THE FREE UNIVERSITY (AMSTERDAM)

1. Cockroft-Walton accelerator of 0.7 MeV

1.1. Neutron scattering from Bi, Sr and Na at 14.8 MeV

(P. Kuijper and C.C. Jonker)

Absolute differential cross sections for the elastic and inelastic scattering of 14.8 MeV neutrons from Bi, Sr and Na were measured with four neutron detectors placed at the same scattering angle. The associated particle time-of-flight technique with a flight parth of 2.40 m was used. The overall time resolution was 1.4 ns. The energy dependence of the detector efficiency was calculated and measured.
An optical model fit to the elastic scattering results was made.
The inelastic scattering from collective levels in Bi and Sr were compared with DWBA-calculations and the deformation parameters which are dependent on real or complex coupling were determined.

1.2. Angular correlations in the $^{12}C(n,n'\gamma)^{12}C$ reaction at 15.0 MeV

(D. Spaargaren and C.C. Jonker)

The angular correlation between neutrons inelastically scattered from the 4.44 MeV level of ^{12}C and the deexcitation gamma radiation was investigated with the gamma detector in and perpendicular to the reaction plane. The neutron spin-flip probability could be determined. By the use of two separate time-of-flight spectrometers, one coupled to the neutron detector, the other to the gamma detector, an accurate determination of the contributions of the chance coincidences was possible. Moreover the differential cross sections of the elastically and inelastically scattered neutrons and of the gamma rays could be obtained simultaneously.
The results were compared with the predictions of DWBA calculations.
The anisotropy and symmetry angle of the angular correlation in the reaction plane are in good agreement with corresponding proton data.

1.3. Scattering of 3 MeV polarized neutrons

(P.J. van Hall*, E. Zijp, C.C. Jonker)

The polarization of 3 MeV neutrons scattered elastically by Fe, Ni, Zr, Sn, Pb and Bi has been measured at 9 angles ranging from 30 deg. to 150 deg. The measured asymmetries were corrected for finite geometry and multiple scattering.
The results are compared with the optical model in which compound elastic scattering has been included. Discrepancies are found at forward angles in general and at other angles in the case of Ni and Zr.

2. A.V.F. Cyclotron (protons 33 MeV, deutons 7 MeV, alpha's 33 MeV ^{3}He 45 MeV)

2.1. Total cross section measurements

(J. Rethmeier, C. Hoekstra, C.C. Jonker)

Total neutron cross sections of C, Mg, Al, Si, Ti, Fe, Co, Ni, Cu, Zr, Nb, Ag, In, Sn, Bi, Sb and Ta were measured from 20- 30 MeV with steps of 1 MeV and an energy resolution of 0.3%.
A time-of-flight technique, based on a burstlength of the cyclotron of about 1 ns, enabled a good background subtraction. The short burstlength is obtained by a special tuning of the cyclotron. The results are in good agreement with the scarce available data. An optical model description is made.

2.2. Elastic scattering of 25 MeV neutrons

(J.G. Nijenhuis and J. Blok)

Attempts are made to measure the elastic scattering of 25 MeV neutrons from Zr with a time-of-flight technique. The time resolution is 1 ns determined by the burstlength of the cyclotron. The flight path is 2.50 m. The detector has a 40 cm collimator for γ-background reduction.
The results will be used in an optical model analysis. A determination of the symmetry term in the potential seems possible.

---

* Present adress:
Eindhoven, University of Technology.

3. New instrumentation

3.1. A CDC1700 computer will shortly be working coupled on line with the cyclotron instrumentation.

3.2. A split-pole magnetic spectrograph has been installed and will be used for the investigation of pick-up reactions with the analysed beam of the cyclotron.

3.3. An isotope separator coupled with the cyclotron by a rabbit system is in use for the spectroscopy of short living isotopes (life-times longer than one second).

INTERUNIVERSITAIR REACTOR INSTITUUT (DELFT)

Summary of activities in the field of neutron physics
(covering the period 1968 and 1969)

Using a 5 meV (4 Å) incident neutron beam incoherent inelastic neutron scattering experiments covering a range of momentum transfers between 0.6 and 2.2 $Å^{-1}$ have been carried out in globular compounds, cyclohexane (C_6H_{12}) and cyclopentane (C_5H_{10}) in the liquid and solid phase. A study is made of the molecular motions in these compounds based on line-width and intensity measurements of the quasi-elastic peaks in the time-of-flight spectra (L.A. de Graaf, Physica 40, 497-516 (1969)). In addition rotational motions of neopentane molecules (C_5H_{12}) in the plastic-crystalline phase have been studied both at Delft and in Dubna, the results of which will be published in Physica (L.A. de Graaf and J. Sciensinski).

Similar experiments have been performed in 1,1 dimethyl-, cis-1,2 dimethyl- and trans-1,4 dimethylcyclohexane in the liquid, the plastic and the solid phase. The time-of-flight spectra are analysed with a Fortran computer program (IBM 360-65) using fast fourier transforms to deconvolute the resolution function from the measured spectra. Width functions are obtained which can be interpreted in terms of various types of motions of the molecules.

Total cross sections of various organic compounds containing methyl-groups have been measured for neutrons with wavelength in the range 4.3 - 7.7 Å. The scattering cross sections per H atom for aceton (at 100 K) was found to be 11.6 ± 0.3 barn/Å H; for dimethylpolysiloxane (viscosity 1000 c stokes) 12.9 ± 0.3 barn/Å H.

Incoherent inelastic scattering of 5 meV neutrons has also been studied in strontiumdicalciumpropionate ($SrCa_2(C_2H_5(00)_6$), in order to investigate the width of the quasi-elastic peak above and below the ferro-electric curie point at 281 K. Contrary to results reported in the literature (Physics Letters 25A, 123, 1967), no significant line-broadening has been found at the ferro-electric transition.

Scattering experiments of 5 meV neutrons by an isotopically pure sample of ^{36}Ar led to a scattering cross section of 74 ± 2 barn (C.D. Andriesse and co-authors, Physics Letters 28A, 642 (1969)). From the neutron spectra obtained from gaseous ^{36}Ar in five different states close to condensation (at temperatures between 141.5 and 147 K and pressures between 26.5 and 38 atm respectively), intermediate scattering functions are derived and tabulated in a publication submitted by C.D. Andriesse to Physica. Deviations from the ideal gas behaviour of these functions are specified.

The diffraction of 0.91 Å neutrons has been studied in various tetragonal chlorides in the liquid state (CCl_4, $TiCl_4$, $SnCl_4$) in order to determine the structure factor and the radial density distribution function. For CCl_4 at room temperature the results are consistent with those reported in the literature (J. of Chem. Physics 48, 2395 (1968)).

A polarized neutron beam of 1.18 Å wavelength has been used to measure the spontaneous magnetization in nickel near the Curietemperature (H.K. Bakker, M.Th. Rekveldt and J.J. van Loef, Physics Letters 27A, 69(1968)). Further experiments have been carried out to study the domain structure in nickel foils under stress.