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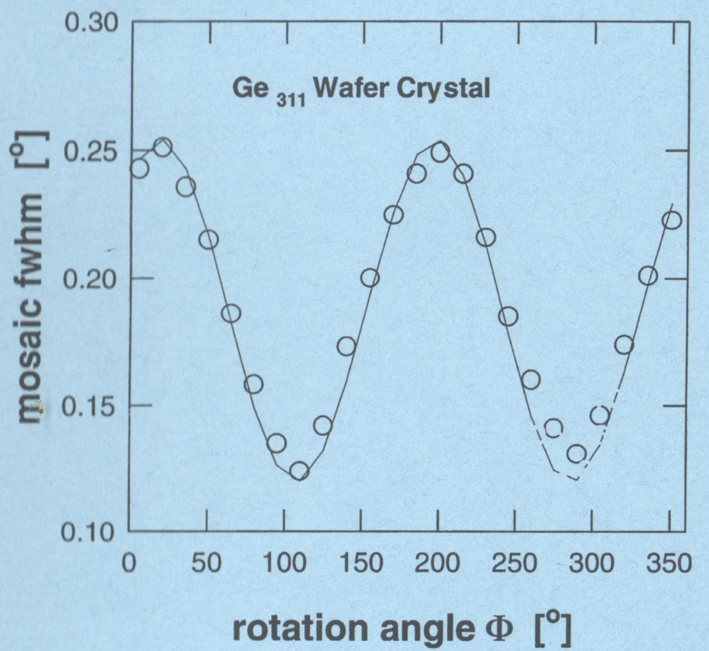
SWISS NEUTRON NEWS



Schweizerische Gesellschaft für Neutronenstreuung
Société Suisse pour la Diffusion des Neutrons
SGN / SSDN

Cover illustration:
Germanium wafer showing an anisotropic mosaic ideal for focusing monochromators. Wafers have been processed at PSI for the SINQ diffraction instruments. Neutron measurement at ILL: Martin Böhm, Graz.

Impressum:

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Inhaltsverzeichnis

Editorial

Das Hochplateau des Vercors-Massivs bei Autrans ist seit vielen Jahren all jenen als Eldorado des Ski-Langlaufs bekannt, die im Winter am Institut Laue-Langevin (ILL) Grenoble experimentieren. Seit Januar 1996 ist der Name Autrans zusätzlich mit der Zukunft der Neutronenstreuung in Europa verknüpft. Es trafen sich dort 80 Wissenschaftler aller Disziplinen (die Hälfte waren keine Neutronen-Spezialisten), um über die Bedeutung und Trends der Neutronenstreuung im nächsten Jahrtausend ("a forward look beyond the year 2005"), unter Berücksichtigung komplementärer Techniken wie Synchrotronstrahlung, nachzudenken. Der Autrans-Workshop wurde von der European Science Foundation (ESF) geleitet und vom ILL perfekt organisiert.

Die wesentlichen Schlussfolgerungen lassen sich wie folgt zusammenfassen (ein detaillierter Report kann beim Sekretariat der SGN/SSDN verlangt werden):

(1) Die Bedeutung der Neutronenstreuung ist weiterhin zunehmend, sowohl in den traditionellen Disziplinen als auch in "neuen" Forschungsgebieten (Erdwissenschaften, Pharmakologie, Biologie, Materialwissenschaften, Engineering). Dieser Trend beruht wesentlich auf der Mannigfaltigkeit neuer Materialien, die immer wieder entdeckt werden.

(2) Die Technik der Neutronenstreuung muss sich weiter entwickeln, weil das Potential quellseitig mit den kommenden Spallationsneutronenquellen der 3. Generation (1-5 MW) nahezu ausgeschöpft sein dürfte. Insbesondere sind neue Ideen und Konzepte der Instrumentierung vordringlich.

(3) Die Zahl der Neutronenquellen wird in den nächsten 10 Jahren drastisch absinken (Stilllegung alter Reaktoren). Zur Vermeidung der sich abzeichnenden "Neutronenlücke" werden folgende Massnahmen empfohlen:
- Verbesserung der Ausnützung der bestehenden Hochflussquellen;
- Förderung nationaler Projekte für neue Neutronenquellen;
- Realisierung einer Europäischen Spallationsneutronenquelle der 3. Generation (ESS, 5 MW).

Wir Schweizer Neutronenstreuer sind in der privilegierten Lage, nach der Inbetriebnahme der SINQ am PSI wesentlich zu einer erfolgreichen Strategie der Neutronenstreuung in Europa beitragen zu dürfen. Nutzen wir diese Chance!

Albert Furrer
Präsident der SGN

4th Summer School on Neutron Scattering

NEW INSTRUMENTS AND SCIENCE AROUND SINQ

18-24 August 1996, Lyceum Alpinum, Zuoz, Switzerland

The main purpose of the Summer School is to give participants an introduction to the basic principles of neutron scattering and its application to the study of condensed matter. The lectures will cover both theoretical and experimental aspects, with particular emphasis on the utilisation of the first-generation neutron instruments installed at the spallation neutron source SINQ at PSI. (SINQ will produce the first neutrons in October 1996). No previous knowledge of the subject is required, but an honours degree in natural sciences (equivalent to the diploma) is essential. A poster session will be organized for participants who wish to present their own results. The ***list of topics and invited lecturers*** *includes:*

Introduction to neutron scattering	*W.E. Fischer, Villigen*
Four-circle diffractometer SC3	*J. Schefer, Villigen*
Quasicrystals	*W. Steurer, Zürich*
Optical information storage systems	*Th. Woike, Köln*
Residual stress	*G.A. Webster, London*
Powder diffractometers HRPT and DMC	*P. Fischer, Villigen*
Magnetism: a supramolecular function	*S. Decurtins, Zürich*
Metal-insulator transitions in perovskites	*M. Medarde, PSI*
Triple-axis spectrometer DrüchaL	*W. Bührer, Villigen*
Incommensurate phase transitions	*R. Currat, Grenoble*
Martensitic phase transitions	*W. Petry, München*
Polarized triple-axis spectrometer TASP	*P. Böni, Villigen*
Identification of magnetic modes by polarization analysis	*B. Dorner, Grenoble*
The INVAR problem	*P.J. Brown, Grenoble*
Time-of-flight spectrometer FOCUS	*S. Janssen, Villigen*
Dynamics of polymers	*U. Buchenau, Jülich*
Magnetic excitations studied with time-of-flight spectroscopy	*B.D. Rainford, Southampton*
Small-angle diffractometer SANS	*W. Wagner, Villigen*
Porous materials	*S.K. Sinha, Argonne*
Polymers and colloids	*P. Schurtenberger, Zürich*
Reflectometer	*D. Clemens, Villigen*
Layered magnets	*H. Zabel, Bochum*
Polymer surfaces, interfaces and thin films	*M. Stamm, Mainz*
Non-diffractive methods	*E. Lehmann, Villigen*
Neutron radiography	*G. Bayon, Saclay*
Prompt gamma analysis	*J. Kern, Fribourg*
Isotope production facility, neutron activation analysis, etc.	*H.W. Gäggeler, Villigen*
Sample environment	
Dynamic nuclear polarization	*H. Stuhrmann, Geesthacht*
Extreme conditions (p,T,H)	*J. Mesot, Villigen*
Data acquisition software and hardware	*D. Maden, Villigen*
Summary	*S.W. Lovesey, Villigen*

Organization: R. Bercher (Secretary), W.E. Fischer (School Chairman), A. Furrer (Programme Chairman)

Residential accommodation will be available at the Lyceum Alpinum in Zuoz (costs: approximately 580 Swiss Francs, including full board, excursion, banquet, and Proceedings). The number of participants will be limited to 100. The language of the School is English. Closing date for applying is ***30 June 1996****. For further information and application forms, contact Renate Bercher, Paul Scherrer Institut, CH-5232 Villigen PSI, Tel.: +41-56-310 34 02, Fax: +41-56-310 32 94.*

The School is not yet booked out! Please apply immediately!

THE EUROPEAN NEUTRON SCATTERING ASSOCIATION (ENSA) AND THE PAUL SCHERRER INSTITUTE (PSI)

Second Announcement and Call for Abstracts

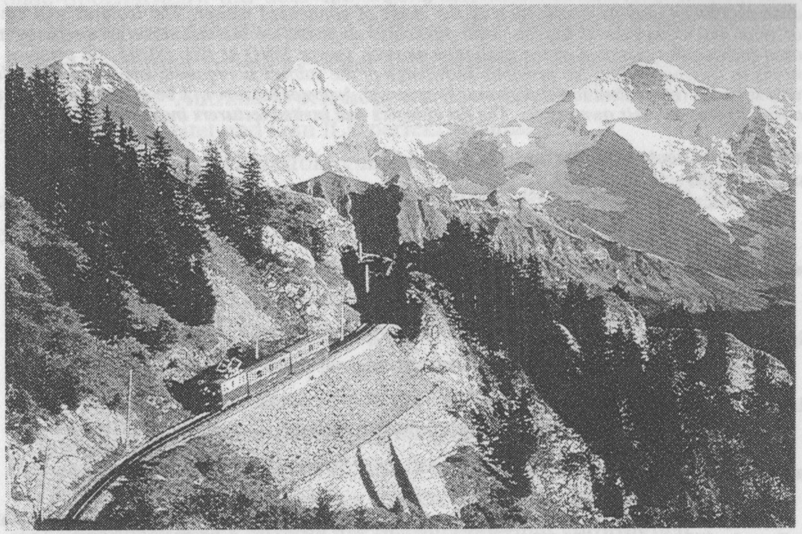


Photo: Tourismus Organisation Interlaken

ECNS'96

1st European Conference on Neutron Scattering

(Introductory Course: October 6-7, 1996)

8 - 11 October 1996 Interlaken Switzerland

The European Neutron Scattering Association (ENSA) will hold the 1*st* European Conference on Neutron Scattering (ECNS'96) at Interlaken, Switzerland, October 8-11, 1996. ECNS'96 will be organized by the **Paul Scherrer Institute (PSI), Villigen**, assisted by the **Swiss Society for Neutron Scattering.** ECNS'96 will cover the whole range of relevant subjects in neutron scattering from condensed matter, including significant applications and technical developments of the field.

The organizers are delighted about the overwhelming response to ECNS'96. Up to June 1996 more than 600 abstracts have been received. It is likely that **ECNS'96 will be the largest gathering of neutron scattering scientists anywhere in the world to date**. This underlines the importance of the technique and gives confidence in the future development and spread of neutron scattering in Europe.

Being the host country for ECNS'96 it is important that the Swiss activities in the field of neutron scattering are visible at the Conference, also in view of forthcoming evaluations in this field with respect to future international collaborations. We therefore encourage all the members of our Society strongly to participate at the Conference. We particularly encourage the **participation of young scientists**, since a large number of grants will be available for qualified Ph.D. and postdoctoral students. In addition, a few prizes for the best contributed papers by young authors will be provided. Also, the programme will start with a two-days' introductory course (October 6-7, 1996) on neutron scattering, particularly for participants with little or no knowledge of the field.

For further information please contact the Conference Secretary:

Dr. J. Mesot, Laboratory for Neutron Scattering ETHZ & PSI
CH-5232 Villigen PSI, Switzerland; e-mail: ECNS@psi.ch
phone: +41 - 56 - 310 40 29; fax: +41 - 56 - 310 29 39

******** Important Notice for Members of the SGN/SSDN ********

In a recent letter we informed our members that the General Assembly of our Society will be take place after the official inauguration of the spallation neutron source SINQ at PSI in November 1996. Since this SINQ event has been postponed to the year 1997, the **General Assembly 1996 of the SGN/SSDN** will take place during ECNS'96 at Interlaken (a special invitation will follow later).

Gratulationen

Wir gratulieren herzlich den folgenden Mitgliedern unserer Gesellschaft, die im letzten halben Jahr mit einem Preis ausgezeichnet worden sind:

Joël Mesot gewann den **ETH - SEU Award Preis 1996** (SEU = Southeast University, formerly Nanjing Institute of Technology). Die Preisverleihung basierte auf seinen Arbeiten, die wesentlich zum Verständnis der physikalischen Eigenschaften von Hochtemperatur-Supraleitern beigetragen haben.

Wolfgang Henggeler wurde an der 15*th* General Conference of the Condensed Matter Division of the European Physical Society (April 1996, Baveno-Stresa, Italien) ein **Young Scientist Award** zugesprochen. Die Preisverleihung basierte auf "high-level research results as well as excellent performance in the presentation" (magnetische Anregungen im "heavy-fermion" Hochtemperatursupraleiter Nd_2CuO_4).

Mitteilungen

1. Das Beispiel der SGN/SSDN macht weiterhin Schule! Im April 1996 haben unsere holländischen Kollegen die **Nederlandse Vereniging voor Neutronenverstrooiing** (NVNV) gegründet. Erster Präsident ist Dr. A.A. van Well (TU Delft). Wir wünschen der NVNV viel Erfolg.

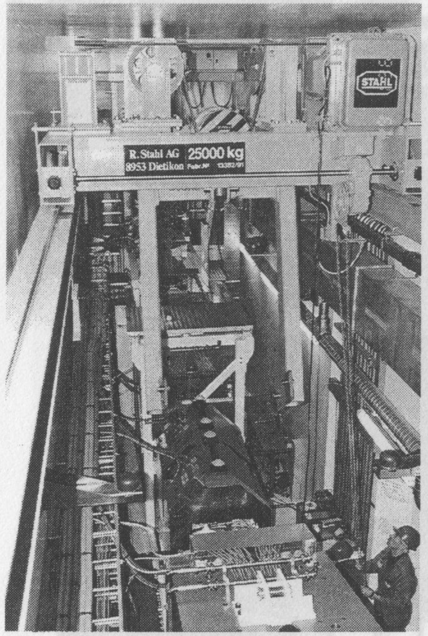
2. Eine Kopie des **Autrans Reports** (siehe dazu auch das Editorial) über "Scientific Prospects for Neutron Scattering with Present and Future Sources" kann beim Sekretariat der SGN/SSDN angefordert werden.

3. Die von der European Neutron Scattering Association (ENSA) im Jahre 1995 bei allen Mitgliederorganisationen durchgeführte Umfrage wurde ausgewertet, und die Resultate liegen im Report **"The ENSA Survey of the European Neutron Scattering Community"** (an analysis of the responses to a questionnaire circulated by the European Neutron Scattering Association) vor. Eine Kopie dieses Reports kann beim Sekretariat der SGN/SSDN angefordert werden.

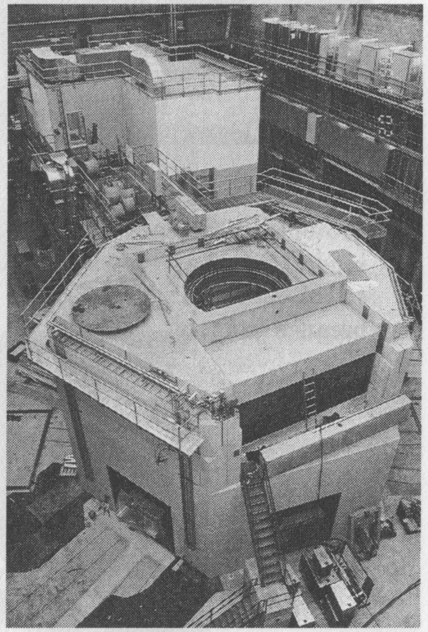
Impressionen von SINQ

P. Böni und P. Keller

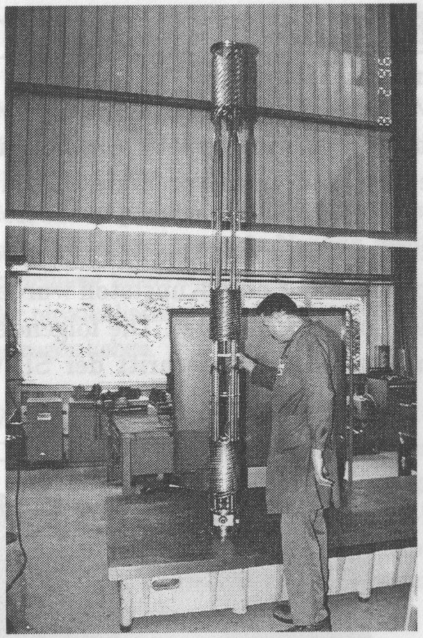
Am 4. Juli wird der D_2O Moderatortank ans PSI geliefert und installiert werden. Damit sollte der Weg frei sein, noch vor Ende 1996 die ersten Neutronen zu produzieren.
In der Zwischenzeit macht der Bau der Quelle und der Spektrometer grosse Fortschritte. Die Tanzböden aus Granit oder Kunststoff wurden verlegt und die kalte Quelle wurde erfolgreich getestet. Die folgenden Bilder sollen einen Eindruck vom jetzigen Baufortschritt der SINQ geben.



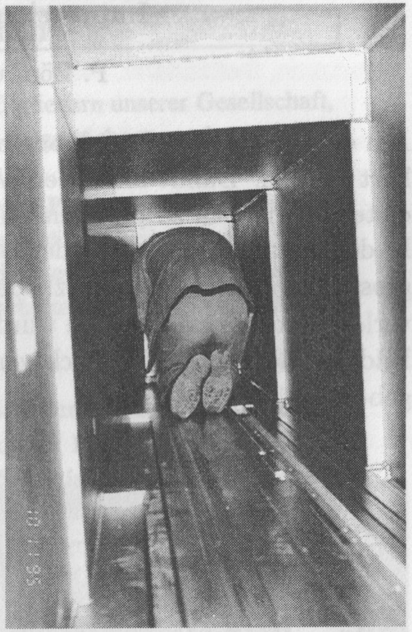
Blick in den Strahlgraben, wo die Protonen auf das Target gelenkt werden.



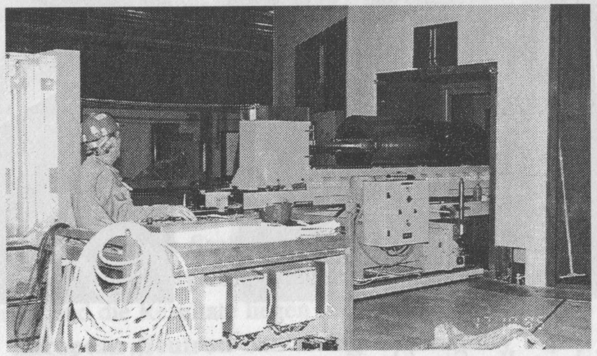
Targetstation von oben: Unten links die Granittanzböden für das Pulver- und das Einkristalldiffraktometer.



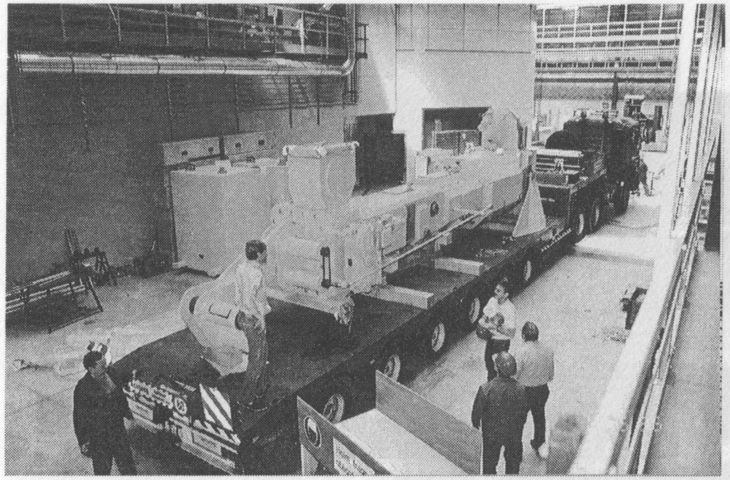
Protonenkollimator: Er verhindert, dass der Protonenstrahl ein Loch in das Target brennen kann.



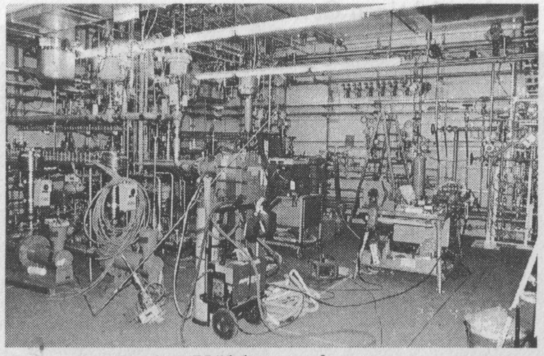
Strahlkanal an der Targetstation: Auf der Suche nach dem ersten Neutron.



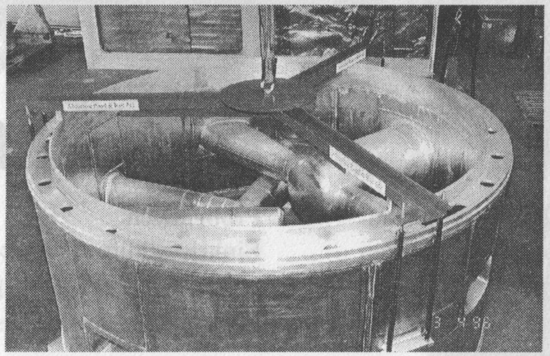
Mit der Lademaschine wird ein Einschub in das Einschubgehäuse der D_2-Quelle eingeschoben.



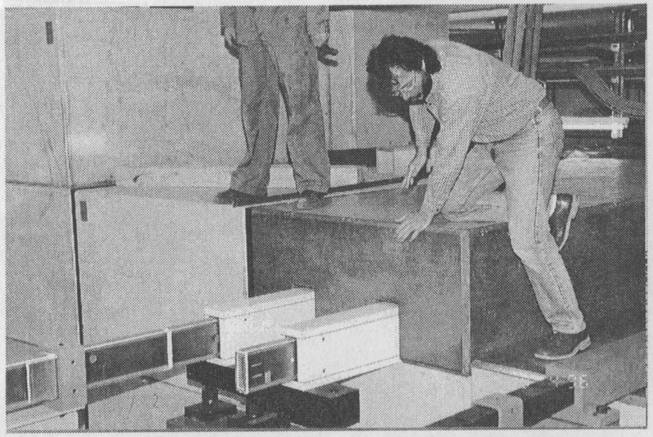
Anlieferung der Wechselflasche für das Neutronentarget.



Leitungsgewirr in der Kühlzentrale.

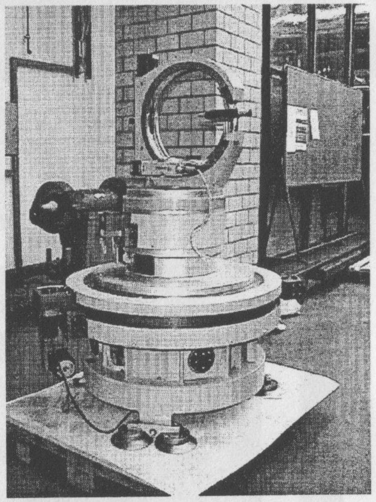


Der D_2O Moderatortank mit den eingeschweissten Strahlrohren.



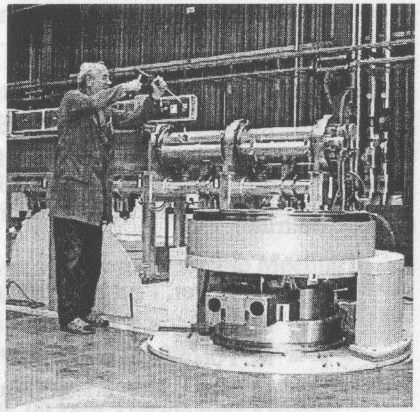
Jürgen Duppich schiebt einen der letzen Abschirmblocks zum Neutronenleiterbunker an den richtigen Ort.

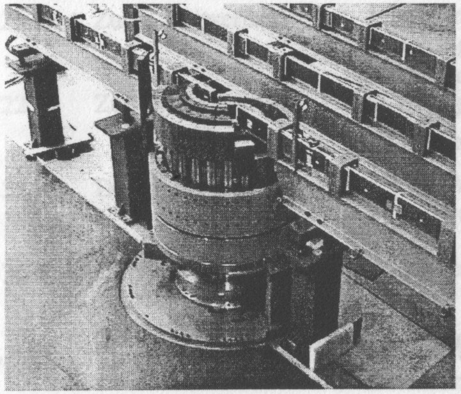
Leiterhalle: Die ersten Neutronenspektrometer werden an den Leitern installiert.



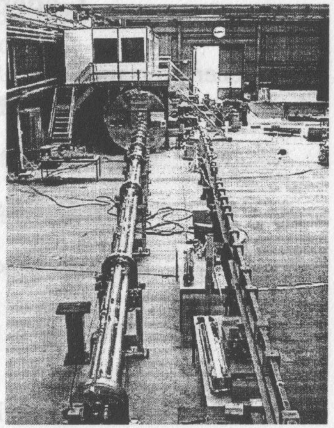
Probentisch für das Einkristalldiffraktometer.

Polarisiertes Dreiachsenspektrometer: Präzisionsjustierung am Neutronenleiter.





Dreiachsenspektrometer Drüchal: Die Monochromatorabschirmung kurz vor der Fertigstellung.



Kleinwinkelstreuanlage und Leiter für TASP.

Neue Mitglieder

P. Böni

Seit dem 1. Januar 1996 sind vier Mitglieder der SGN beigetreten. Leider sind auch drei Mitglieder aus der SGN ausgetreten. Damit hat sich der Mitgliederbestand der SGN auf 151 erhöht:

Beitritte:

- H. Weyer, Paul Scherrer Institut
- M. Jermann, Paul Scherrer Institut
- M. Forstner, ETH Zürich
- M. Bortz, Universität Genf

Austritte:

- R. Brogli, Paul Scherrer Institut
- S. Schulz, ETH Zürich
- B. Hellebrand, Universität Linz

Generalversammlung 1996

Die Generalversammlung 1996 wird während der ECNS'96 in Interlaken durchgeführt. Eine separate Einladung folgt.

Ort: Interlaken
Datum: Mittwoch, 9. Oktober 1996
Zeit: 12^{30} - 13^{00}

Konferenzen 1996/97

Datum	Ort	Thema
1996		
2.-6.8.	Karlsruhe, BRD	MOS'96 HTSc
4.-9.8.	Denver, USA	SPIE's Annual Meeting "Optical Science, Engineering, and Instrumentation"
5.-7.8.	Gaithersburg, USA	Neutron Scattering Satellite Meeting to XVII IUCr
8.-17.8.	Seattle, USA	17*th* Int. Congress on Crystallography
8.-14.8.	Prague, Czech Rep.	Conf. on Low Temperature Physics
18.-24.8.	Zuoz, Switzerland	4*th* Summer School on Neutron Scattering
19.-22.8.	Zürich, Switzerland	SCES'96 (strongly correlated electron systems)
19.-31.8.	Delphi, Greece	NATO-ASI: Materials Aspects of High-T_c Superconductivity
25.-30.8	Les Diablerets, Switz.	Properties and Applications of M-H Systems
1.-6.9.	Stockholm, Sweden	School "Understanding Protein Structure Determination"
2.-13.9.	Leipzig, BRD	Kurs "Diffusion in kond. Mat."
3.-6.9.	Bordeaux, France	7th Int. Conf. on Ferrites
9.-13.9.	Sevilla, Spain	EPS "Trends in Physics"
12.-15.9.	Heidelberg, BRD	Workshop Pulverdiffraktometrie
16.-27.9.	Halle, BRD	Kurs "Neue Aspekte kristallographischer Strukturen"
24.-27.9.	Osaka, Japan	Physics of Transition Metals
29.9.-2.10.	München, BRD	Workshop Strukturbestimmung (Pulver & Einkristalle)

Datum	Ort	Thema	Teilnehmer
30.9.-2.10.	Les Diablerets, Switz.	Swiss Workshop on Superconductivity & Novel Metals	
8.-11.10.	Interlaken, Switzerland	1*st* European Conference on Neutron Scattering (ECNS'96)	
9.10.	Interlaken, Switzerland	General Assembly of the Swiss Society for Neutron Scattering	
10.10.	Zürich, Switzerland	Annual Meeting of the Swiss Crystallographic Society	
14.-15.10.	Grenoble, France	Inelastic and Quasielastic Neutron Scattering in Biology	
4.-8.11.	Johannesburg, SA	Int. Symp. "Industrial Appl. of the Mössbauer Effect"	
12.-15.11.	Atlanta, USA	41st Annual Conference on Magnetism & Magnetic Materials	
9.-13.12.	Rome, Italy	Int. Conf. on "Stripes, Lattice Instabilities and High-T_c Superconductors"	
1997			
28.2.-4.3.	Beijing, China	M²S-HTSC-V	
22.-25.4.	Saint-Malo, France	12th Int. Conf. on "Solid Compounds of Transition Elements"	
25.-28.5.	Parma, Italy	5*th* European Powder Diffraction Conference	
13.-17.7.	Oxford, UK	5th Int. Conf. "Surface X-Ray and Neutron Scattering"	
17.-21.8.	Toronto, Canada	International Conference on Neutron Scattering (ICNS'97)	
25.-28.8.	Leuven, Belgium	16th General Conf. Condensed Matter Division EPS	
27.-31.8.	Alpe d'Huez, France	Conf. on Aperiodic Crystals	

Magnetic excitations of Nd in Nd_2CuO_4

W. Henggeler[1,2], T. Chattopadhyay[1], P. Thalmeier[3], B. Rössli[1], P. Vorderwisch[4], and A. Furrer[2]

[1]Institut Laue-Langevin, B.P.156, F-38042 Grenoble Cedex 9, France
[2]Lab. for Neutron Scattering, ETHZ & PSI, CH-5232 Villigen PSI, Switzerland.
[3]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany
[4]Hahn-Meitner-Institut, Glienecker Str. 100, D-14109 Berlin, Germany

Introduction

Ever since the discovery of superconductivity in the Ce doped $Nd_{2-x}Ce_xCuO_{4-\delta}$ cuprates [1] the parent compound Nd_2CuO_4 has been subject to intensive investigations. The interest in this compound was further enhanced by the results obtained in specific heat measurements. The doped compounds with Ce content x>0.1 show below 0.3 K a specific heat linear in temperature with a huge γ-coefficient, indicating heavy fermion like behavior [2]. There have been several theoretical attempts to explain this behavior [3-5]. The common feature of all the models is the assumption that the large specific heat coefficient arises from the interaction of the strongly correlated electrons in the copper oxide planes with the Nd spins. In these models the influence of the Nd-Nd exchange interaction on the excitation spectrum and specific heat is neglected.

It was the purpose of our inelastic neutron scattering experiments to investigate in detail the magnetic excitation spectrum of Nd in pure Nd_2CuO_4. If one neglects exchange interactions between the ions, this spectrum consists of dispersionless crystalline electric field (CEF) excitations between the five Kramers doublets lying at 0 meV, 14 meV, 21 meV, 27 meV and 93 meV [6-10]. The exchange interaction between the Nd ions leads to a dispersion of these crystal field excitations and - below the ordering temperature of the Nd-moments - to the formation of low energy spin waves modes. Neutron scattering on single crystals is the experimental technique of choice to investigate these dynamic spin correlations from which the magnetic exchange interactions can be quantitatively derived.

Dispersion of the Nd CEF excitations

The experiments were performed on the triple axis spectrometers IN8 and IN3 at the high flux reactor of the Institute Laue-Langevin (ILL) at Grenoble. The plate like Nd_2CuO_4 single crystal with a mosaic spread of less than 0.3° was mounted in an ORANGE He cryostat and kept at a temperature of 4 K. This temperature is well above the Nd ordering temperature of ~1.5 K. Only two of the four possible ground state CEF transitions were accessible in this experiment. The transition at 14 meV has a very small matrix element, whereas the transition at 93 meV is out of reach on a thermal triple-axis spectrometer. Fig. 1 shows the result of a measurement at two different positions in reciprocal space.

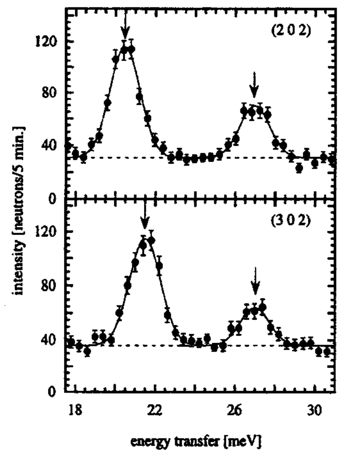


Fig. 1: Energy spectra of neutrons scattered from Nd_2CuO_4 at 4 K at two different $\vec{Q}$-positions.

The transition at 21 meV shows a pronounced $\vec{Q}$-dependence, while no dispersion was found for the excitation at 28 meV. In Fig. 2 we show the measured dispersion of the $\Gamma_6^{(1)}$ - $\Gamma_6^{(2)}$ CEF excitation at ~21 meV along the three main symmetry directions.

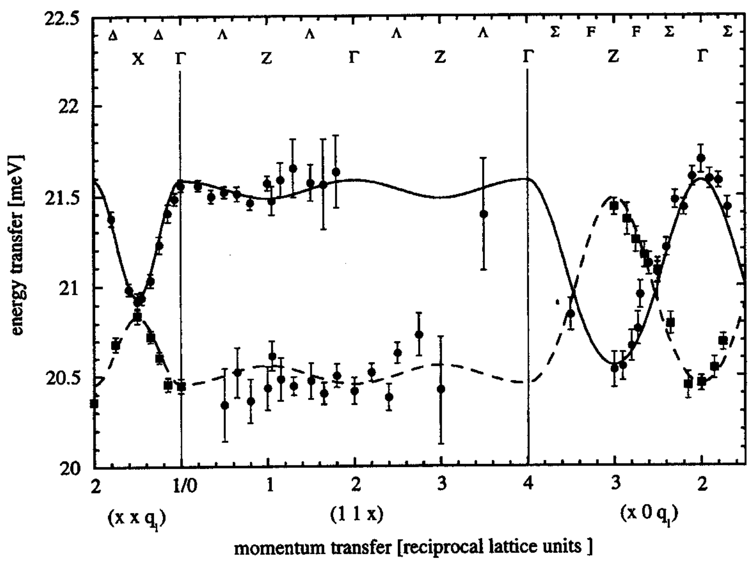


Fig. 2: Measured dispersion of the $\Gamma_6^{(1)}$ - $\Gamma_6^{(2)}$ - Nd crystal field excitation in Nd_2CuO_4 at 4 K (circles: q_l=0, squares: q_l=2). The lines correspond to the RPA model calculation (— : acoustic branch, --- : optical branch).

Because of the two ion basis of the Nd in Nd_2CuO_4 we observe two excitation branches, an optic and an acoustic one. These two branches continuously interchange their intensities along the [0 0 1] direction (Fig. 3).

To interpret the data we made use of the random phase approximation (RPA) model [11]. In the paramagnetic state, at low temperatures, the energy dispersion is given by

$$E(\vec{q}) = [\Delta^2 - 2M^2\Delta(J(\vec{q}) \pm \nu|J'(\vec{q})|)]^{1/2} \qquad (1)$$

where Δ is the crystal field splitting, M the transition matrix element, $J(\vec{q})$ and $J'(\vec{q})$ the Fourier transformed coupling constants between ions of the same and of different sublattices, respectively, and $\nu=\pm1$ denotes the sign of $J'(0)$. In Fig. 2 the drawn line corresponds to the model calculation. The exchange coupling constants included in our model calculations are indicated in Fig 4.

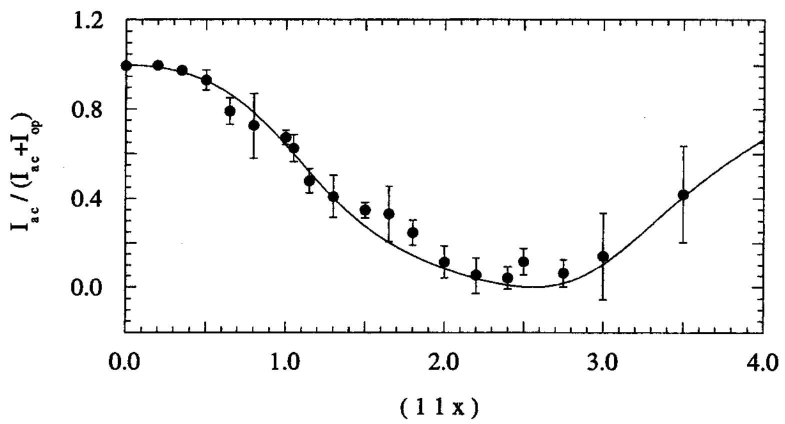


Fig. 3: Measured intensity of the acoustic branch at (11x) positions, normalized to the total magnetic scattering. The line corresponds to the RPA model calculation.

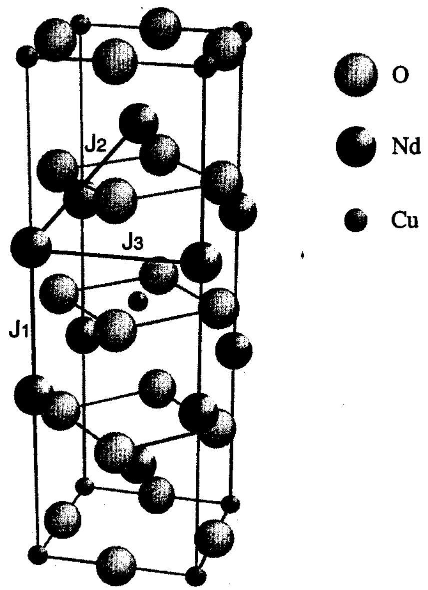


Fig.4: Crystal structure of Nd_2CuO_4 with the various Nd-Nd exchange constants indicated.

The scattering intensity of the two branches is proportional to:

$$I \propto M_\alpha^2 \Delta^2 \sum_\alpha (1 - Q_\alpha^2)[F(\bar{Q})]^2 (1 \pm \cos(\varphi)) / E(\bar{q}) \qquad (2)$$

where $F(\bar{Q})$ is the Nd^{3+} magnetic form factor, and the phase φ is defined through $J'(\bar{Q}) = J'(\bar{q})\exp(-i\bar{\tau}\cdot\bar{\rho}) = v|J'(\bar{q})|\exp(-i\varphi)$, with $\bar{\tau}$: reciprocal lattice vector and $\bar{\rho}$: vector connecting the two sublattices. The line drawn in Fig. 3 corresponds to this model calculation. The coupling constants that we derive from the calculations are the following:

J_1= -7±2μeV, J_2= -19±1μeV, J_3= -2.5±1μeV.

It is evident from formula (1) why no $\bar{Q}$-dependence has been observed for the transition at 28 meV within our resolution. The matrix element M for this excitation is less than half as big as for the $\Gamma_6^{(1)}$ - $\Gamma_6^{(2)}$ CEF transition at ~21 meV.

Spin wave excitations

The experiments were performed on the cold triple-axis spectrometer V2 of the Berlin Neutron Scattering Center (BENSC). The sample was placed into a He^3-He^4 dilution refrigerator insert. The temperature was kept fixed at 50 mK, well below the Nd ordering temperature of ~1.5 K.

Due to the noncollinear AF structure [12] with eight magnetic Nd-sublattices, (four per chemical sublattice) one expects eight spin wave modes, four acoustical (A) and four optical (O) branches. A model calculation was performed in the context of a mean field RPA approximation. We were able to obtain closed expressions for the spin wave frequencies in the whole Brillouin zone for arbitrary uniaxial anisotropy of the exchange constants whose explicit expressions are given elsewhere [13]. For the case with q_z=0 the polarization vectors of spin wave modes could easily be obtained which also allowed to compute their structure factors. To index the positions in reciprocal space we used the magnetic unit cell which is obtained by a $\sqrt{2}\times\sqrt{2}$ expansion and 45 degree rotation of the chemical unit cell basal plane.

Fig. 5 shows the results of the experiments at two different M-points. The model calculation reveals that independently of the number of included exchange constants there are two fourfold degenerate excitations present at this point, an acoustic and an optic one. For l=0, the optic excitation should nearly vanish. We saw indeed that both excitations are very well detectable at (0.5 0.5 1). Because the excitation at ~0.25 meV vanishes nearly for q_z=0, it could clearly be identified as the optic one.

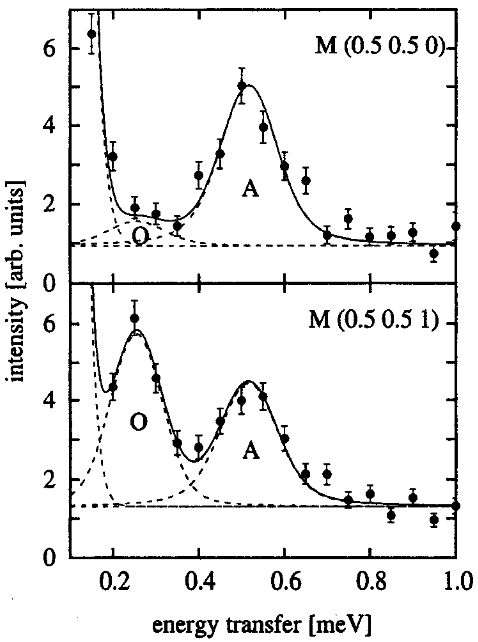


Fig. 5: Energy spectra of neutrons scattered from Nd_2CuO_4 at two different M-points. A stands for the acoustic, O for the optic excitation.

In Fig. 6 we show the measured and calculated dispersion relation. The resulting exchange constants J and the splitting h_{Cu} of the Nd ground state doublet due to the Nd-Cu exchange are as follows:

J_1=-32 ± 2 μeV, J_2=-4 ± 1 μeV, J_3=-5 ± 1 μeV, J_4=-3 ± 1 μeV

h_{Cu}=0.63 ± 0.03 meV

where the extra coupling J_4 used here corresponds to the in-plane diagonal Nd-pairs.

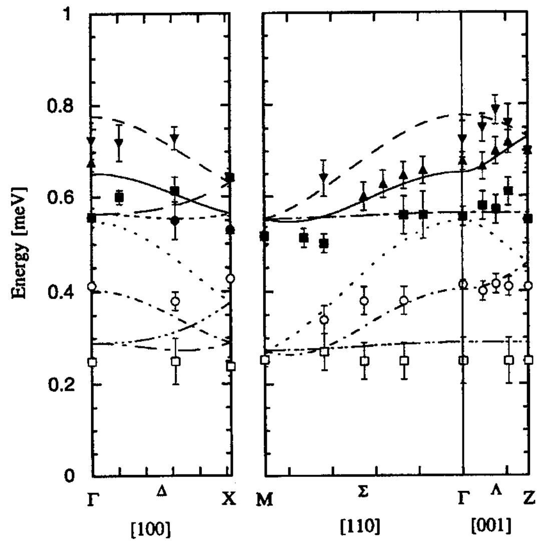


Fig. 6: Measured dispersion of the Nd spin waves in Nd_2CuO_4 .The lines correspond to the model calculation with the exchange constants given in the text.

Discussion

There are two striking points regarding the results. Firstly, we see that there is a remarkable difference of the exchange constants of the spin wave excitations to the ones obtained for the $\Gamma_6^{(1)}$ - $\Gamma_6^{(2)}$ CEF excitation. This shows that the exchange interaction is dependent on the initial and final state of an excitation. This has so far only been observed in the case of a dimer compound [14].

Secondly, the result shows that the mean field at the Nd site created by the Nd-spin interaction (-0.15 meV) is directed opposite to the field created by the Cu-Nd exchange (+0.63 meV). This implies that the observed magnetic order of the Nd spins in Nd_2CuO_4 is enforced by the Cu-Nd exchange. The Nd spins itself would prefer an antiferromagnetic arrangement along the c direction. This leads us to argue about the consequences for the Ce-doped samples. The main effect of doping is a reduction of magnetic moments on both the Cu and Nd-lattice.

Specifically the Cu-mean field h_{Cu} at the Nd-sites will be reduced with increasing x. The center of spin wave bands in Fig. 6 will be pushed to lower energies up on doping until a concentration x≅0.1 where the lowest optical mode in Fig.3 will have zero energy. This signifies the onset of a magnetic instability where Nd will tend to an AF order along the c-axis. It is likely that due to the increasing effect of disorder the spin wave spectrum will not recover a finite gap upon further doping as is indeed observed in the results on a polycrystalline sample [15]. We therefore conjecture that the large specific heat increase observed for x≅0.1 is triggered by a softening of Nd-spin wave modes connected with a magnetic instability of the forced Nd magnetic structure.

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Specifically the Cu-mean field h_{ex} in the Nd-sites will be reduced with increasing x. The center of spin wave bands in Fig. 6 will be pushed to lower energies up on doping until a concentration $x \cong 0.1$ where the lowest optical mode in Fig.3 will have zero energy. This signifies the onset of a magnetic instability where Nd will tend to an AF order along the c-axis. It is likely that due to the increasing effect of disorder the spin wave spectrum will not recover a finite gap upon further doping as is indeed observed in the results on a polycrystalline sample [15]. We therefore conjecture that the large specific heat increase observed for $x \cong 0.1$ is triggered by a softening of Nd-spin wave modes connected with a magnetic instability of the forced Nd magnetic structure.

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