

Neutron Sources

Christine Darve

African School of Fundamental Physics and its Applications



August 20, 2014

- Neutrons properties and their interactions
- How to generate intense neutron beams using high power proton linear accelerator: The example of the ESS

for further reading

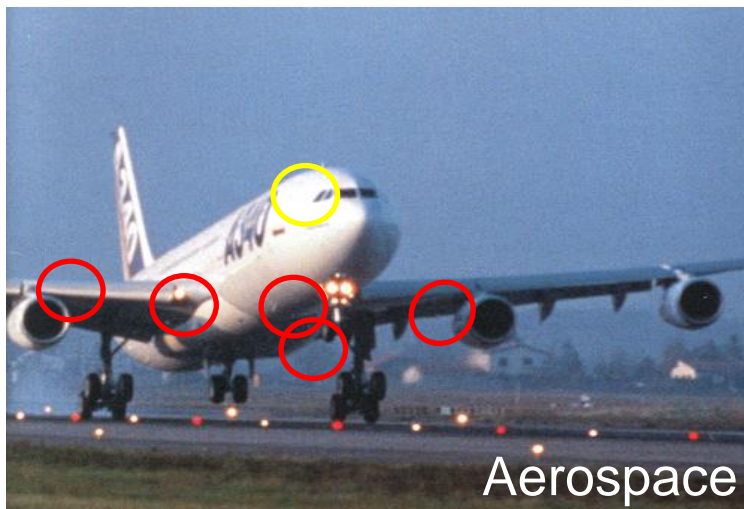
- Applications using Neutrons

General Applications

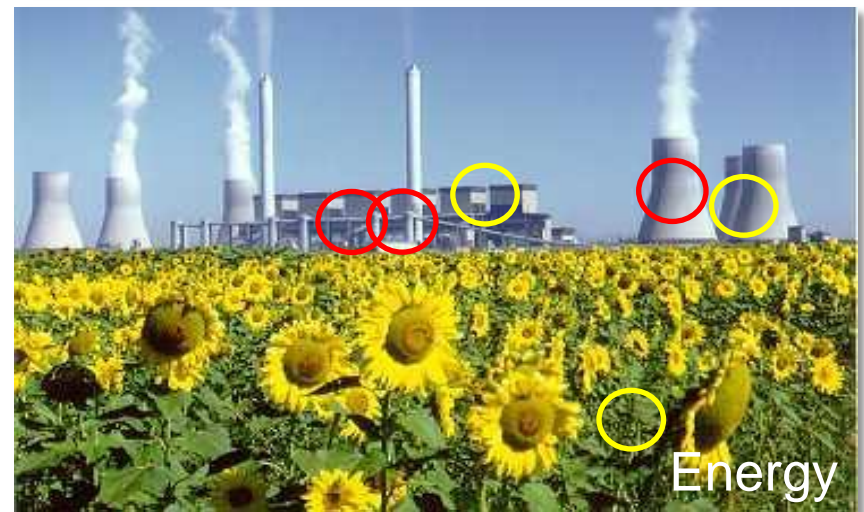
Consumer, Health, Life, IT



Automotive



Aerospace



Energy

PRL **100**, 250404 (2008)

PHYSICAL REVIEW LETTERS

week ending
27 JUNE 2008

Measurements of the Vertical Coherence Length in Neutron Interferometry

D. A. Pushin,^{1,*} M. Arif,² M. G. Huber,³ and D. G. Cory¹

¹*Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA*

²*National Institute of Standards and Technology, Gaithersburg, Maryland, USA*

³*Department of Physics, Tulane University, New Orleans, Louisiana, USA*

(Received 19 March 2008; published 26 June 2008)

The study and use of macroscopic quantum coherence requires long coherence lengths. Here we describe an approach to measuring the vertical coherence length in neutron interferometry, along with improvements to the NIST interferometer that led to a measured coherence length of 790 Å. The measurement is based on introducing a path separation and measuring the loss in contrast as this separation is increased. The measured coherence length is consistent with the momentum distribution of the neutron beam. Finally, we demonstrate that the loss in contrast with beam displacement in one leg of the interferometer can be recovered by introducing a corresponding displacement in the second leg.

DOI: [10.1103/PhysRevLett.100.250404](https://doi.org/10.1103/PhysRevLett.100.250404)

PACS numbers: 03.75.Dg, 03.65.-w, 42.50.-p

Small-Angle (SANS/SAXS)

Velocity selector | Collimation

- Polymers and colloids, e.g.
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 - ~ Dendrimers
 - ~ Liquid crystals
 - ~ Gels
 - ~ Reaction kinetics of m
- Materials Science
 - ~ Phase separation in all
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 - ~ Micro-porosity in c
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 - ~ Flux line lattices in

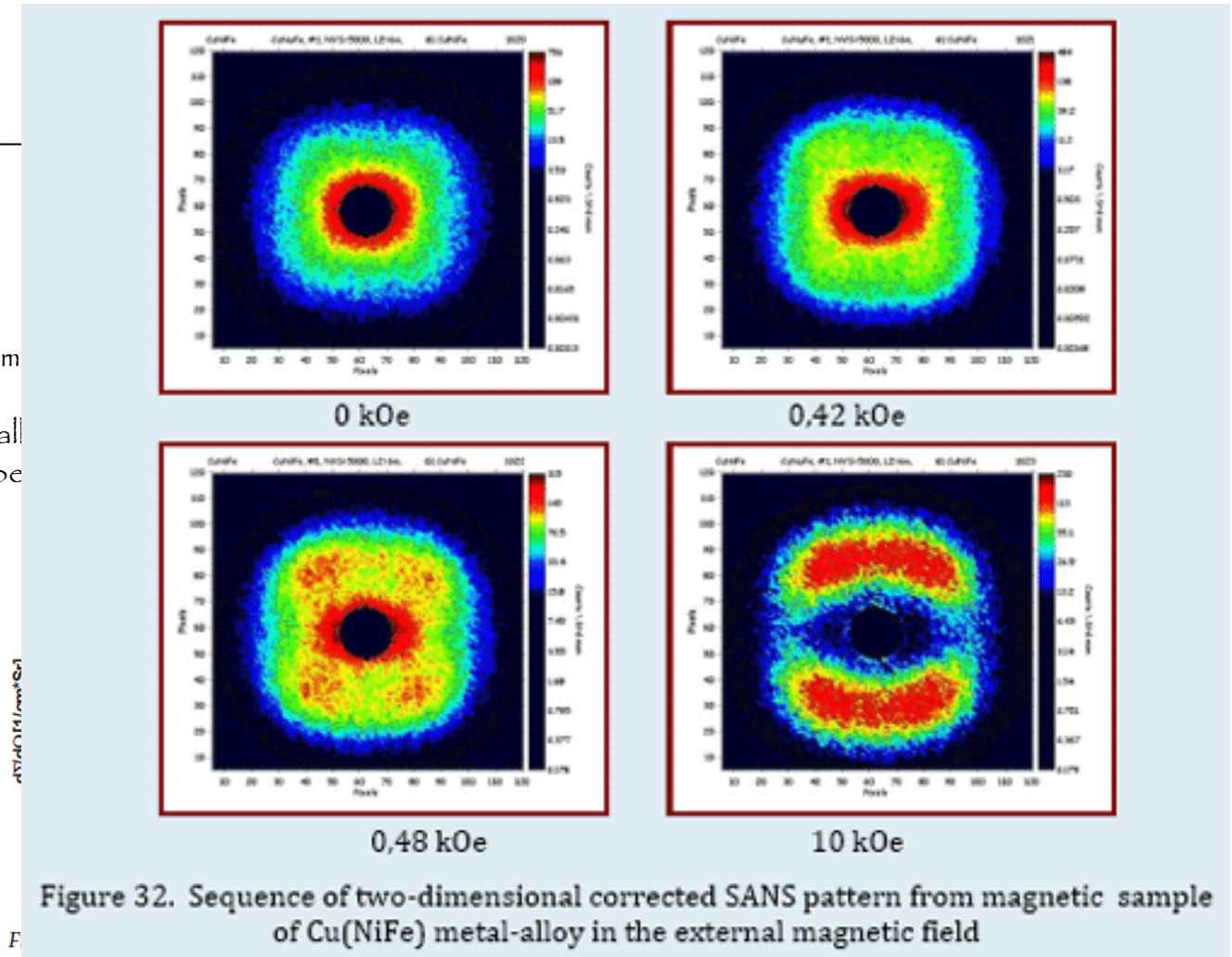


Figure 32. Sequence of two-dimensional corrected SANS pattern from magnetic sample of Cu(NiFe) metal-alloy in the external magnetic field

Figure 32. a) Measured scattering curve corresponds to the scattering from four independent Gaussian particles as indicated by D1-D4. b) Fit results to the measured scattering curve shown in a). Fitting was performed using 4 independent Gaussian distributions (D1-D4). The corresponding errors are indicated by thin lines. c)

Quasielastic Neutron Scattering Study on the Dynamics of Poly(alkylene oxide)s

C. Gerstl,^{†,‡} G. J. Schneider,^{*,‡} A. Furukawa,[†] J. Allgaier,[†] D. Richter,^{†,‡} J. Colmenero,[†] and M. Bechler,[†]

[†]Jülich Centre for Neutron Science (JCNS 1), D-52425 Jülich, Germany

[‡]Jülich Centre for Neutron Science (JCNS 1), Institut Laue–Langevin, BP 156, 38042 Grenoble, France

[§]Laboratoire Charles Coulomb, UMR 5221, CNRS, Montpellier, France

[¶]Centro de Física de Materiales (CSIC, UPV/E-20018 San Sebastián, Spain

^{||}Departamento de Física de Materiales (UPV/EHU), Leioa, Spain

[⊙]Donostia International Physics Center, Paseo de Miramón, 40, 48940 Leizor, Spain

[⊙]Donostia International Physics Center, Paseo de Miramón, 40, 48940 Leizor, Spain

[⊙]Donostia International Physics Center, Paseo de Miramón, 40, 48940 Leizor, Spain

ABSTRACT: By means of quasielastic neutron scattering, we investigated the hydrogen dynamics in poly(alkylene oxide)s with different side-chain lengths at temperatures above the glass-transition. The combination of different spectrometers (a time-of-flight spectrometer and a neutron spin-echo spectrometer) has allowed covering almost 4 orders of magnitude in time—from the ps to ns range—with spatial resolutions down to the Å scale. The experimental evidence shows the simultaneous occurrence of (i) side-group motions at low temperatures and (ii) segmental dynamics at high temperatures. The dynamics of the side groups show (i) stretching of the side chains and (ii) associated activation energies similar to the cooperative bond rotations of polyethylene, that increase with increasing temperature. We present (i) the same spectral shape, (ii) slow dynamics, and (iii) the same temperature behavior. For comparison, we also report on the dynamics of the side groups in poly(alkylene oxide)s with the same temperature range, that show evidence with intrinsic dynamic heterogeneities between confinement effects.

Introduction

AS

sites

8218 Macromolecules 2010, 43, 8218–8232

DOI: 10.1021/ma101235j

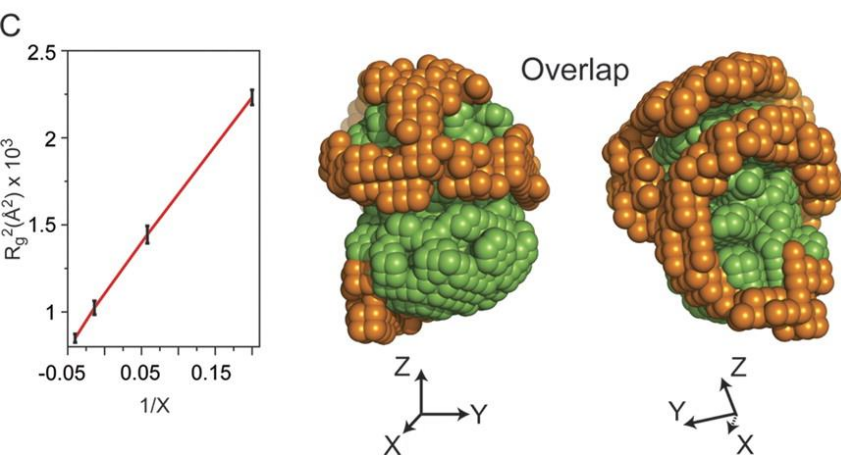
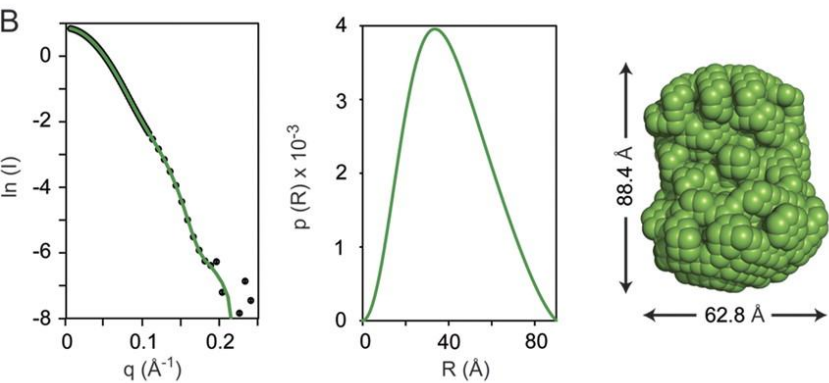
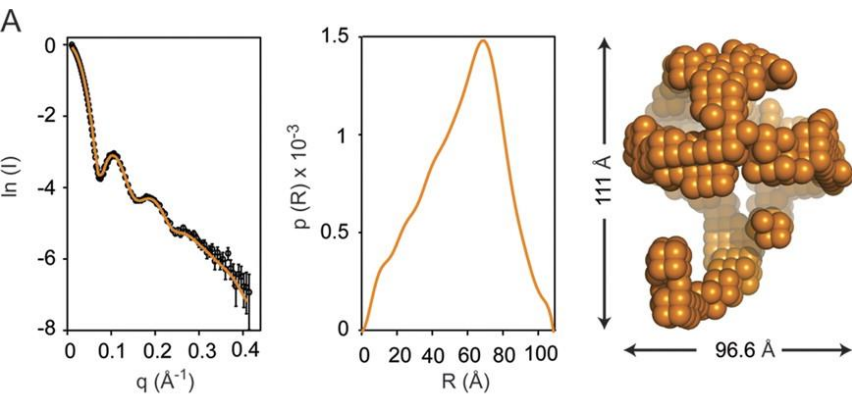
In Situ and Time-Resolved Small-Angle Neutron Scattering Observation of Star Polymer Formation via Arm-Linking Reaction in Ruthenium-Catalyzed Living Radical Polymerization¹

Takaya Terashima,^{*,†} Ryuhei Motokawa,^{*,‡} Satoshi Koizumi,^{*,‡} Mitsuo Sawamoto,^{*,†} Masami Kamigaito,[§] Tsuyoshi Ando,^{†,||} and Takeji Hashimoto[‡]

[†]Department of Polymer Chemistry, Graduate School of Engineering, Kyoto University, Katsura, Nishikyo-ku, Kyoto 615-8510, Japan, [‡]Research Group for Soft Matter & Neutron Scattering, Advanced Science Research Center, JAEA, Ibaraki 319-1195, Japan, and [§]Department of Applied Chemistry, Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan. ^{||}Present address: Graduate School of Material Science, Nara Institute of Science and Technology, 8916-5 Takayama-cho, Ikoma, Nara 630-0192, Japan

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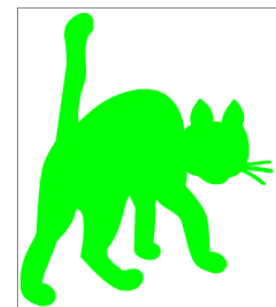
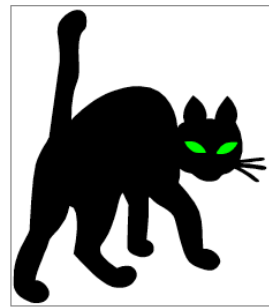
ABSTRACT: *In situ* and time-resolved small-angle neutron scattering (SANS) was employed for the elucidation of star polymer formation mechanism via linking reaction of living linear polymers in ruthenium-catalyzed living radical polymerization. Here, methyl methacrylate (MMA) was first polymerized with R–Cl/RuCl₂(PPh₃)₃/tributylamine (*n*-Bu₃N) initiating system, followed by the addition of ethylene glycol dimethacrylate (EGDMA: **3**) as a linking agent. After the *in situ* addition of a small amount of **3** to living linear PMMA, the SANS analysis revealed the following three steps: (process II-1) formation of block copolymers (**4**) and competitive formation of the small star polymers via the linking reaction of **4** and **4**; (process II-2) star–star linking of the small star polymers into star polymers and putting **4** into the core of the star polymers, leading to formation of the microgel-core star polymers; (process II-3) growth of the microgel-core star polymers (**5**) via placement of **4** into the microgel-core star polymers. Furthermore, the SANS profiles, obtained as a function of polymerization time, were quantitatively analyzed with a core–shell spherical model in order to determine the microstructures of the star polymers: The final reaction product had an average radius of microgel-core (~1 nm), and average arm numbers *N* ~ 17.



Contrast Variation

Spherical high density lipoprotein (sHDL), a key player in reverse cholesterol transport and the most abundant form of HDL, is associated with cardiovascular diseases.

Small angle neutron scattering with contrast variation was used to determine the solution structure of protein and lipid components of reconstituted sHDL. Apolipoprotein A1, the major protein of sHDL, forms a hollow structure that cradles a central compact lipid core. Three apoA1 chains are arranged within the low resolution structure of the protein component as one of three possible global architectures: (i) a helical dimer with a hairpin (HdHp), (ii) three hairpins (3Hp), or (iii) an integrated trimer (iT) in which the three apoA1 monomers mutually associate over a portion of the sHDL surface. Cross-linking and mass spectrometry analyses help to discriminate among the three molecular models and are most consistent with the HdHp overall architecture of apoA1 within sHDL.



Review

Nanocomposites for food packaging applications

Henriette M.C. de Azeredo*

Embrapa Tropical Agroindustry, R. Dra. Sara Mesquita, 2270, Fortaleza, CE, CEP 65131-110, Brazil

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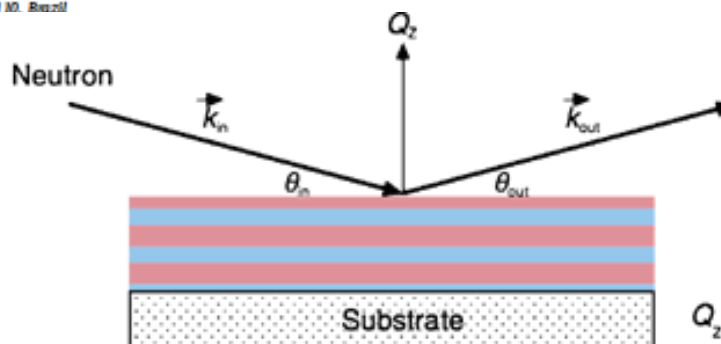
Keywords:
Nanotechnology
Biodegradable polymers
Whiskers
Nanofillers

ABSTRACT

Most materials... Several... However, the... properties, whi... reinforced mate... dimensions. Th... posites. Nanopa... favors the filler... reinforcements, na... activity, enzym... used for use in fi

Contents

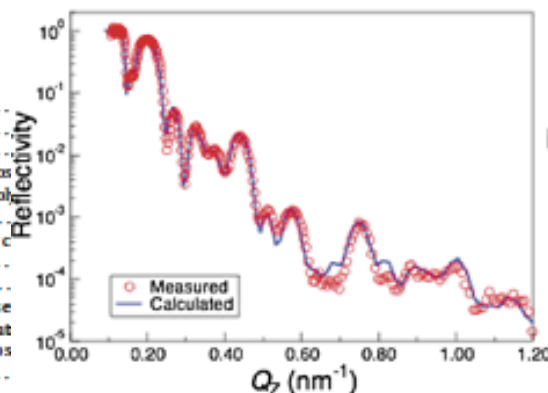
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Specular reflection

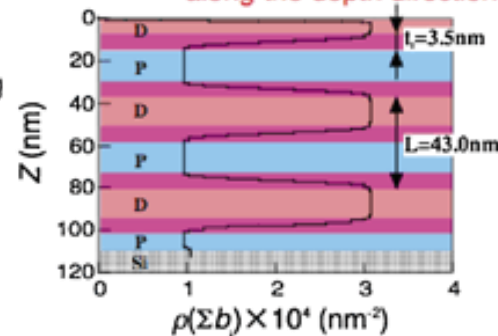
$$\theta_{in} = \theta_{out}$$

$$Q_z = |\vec{k}_{out} - \vec{k}_{in}| = (2\pi/\lambda)(\sin\theta_{in} + \sin\theta_{out})$$



Model fitting

Precise density profile along the depth direction





Contents lists available at [ScienceDirect](http://www.sciencedirect.com)

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima



Neutron radiography characterization of an operating proton exchange membrane fuel cell with localized current distribution measurements

J.J. Gagliardo*, J.P. Owejan, T.A. Trabold, T.W. Tighe

General Motors Corporation, Fuel Cell Research Laboratory, Honeoye Falls, NY 14472-0603, USA

ARTICLE INFO

Available online 5 February 2009

Keywords:

Neutron radiography

Fuel cell

Proton exchange membrane

Water management

Current distribution

ABSTRACT

Neutron radiography has proven to be a powerful tool to study and understand the effects of liquid water in an operating fuel cell. In the present work, this experimental method is coupled with locally resolved current and ohmic resistance measurements, giving additional insight into water management and fuel cell performance under a variety of conditions. The effects of varying the inlet humidification level and the current density of the 50 cm² cell are studied by simultaneously monitoring electrochemical performance with a 10 × 10 matrix of current sensors, and liquid water volumes are measured using the National Institute of Standards and Technology (NIST) neutron imaging facility. A counter flow, straight channel proton exchange membrane (PEM) fuel cell is used to demonstrate localized performance loss corresponds to water-filled channels that impede gas transport to the catalyst layer, thereby creating an area that has low current density. Furthermore, certain operating conditions causing excess water accumulation in the channels can result in localized proton resistance increase, a result that can only be accurately observed with combined radiography and distributed electrochemical measurements.

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Phase-sensitive neutron reflectometry measurements applied in the study of photovoltaic films

J. W. Kiel,^{1,2} M. E. Mackay,^{2,a)} B. J. Kirby,³ B. B. Maranville,³ and C. F. Majkrzak^{3,a)}

¹*Department of Chemical Engineering and Materials Science, Michigan State University, East Lansing, Michigan 48824, USA*

²*Department of Materials Science and Engineering, The University of Delaware, Newark, Delaware 19716, USA*

³*National Institute of Standards and Technology Center for Neutron Scattering, Gaithersburg, Maryland 20899, USA*

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Due to low charge carrier mobilities in polymer-based solar cells, device performance is dictated by the nanoscale morphology of the active layer components. However, their morphological details are notoriously difficult to distinguish due to the low electron contrast difference between the components. Phase-sensitive neutron reflectivity (PSNR) is uniquely suited to characterize these systems due to the large, natural scattering length density difference between two common device materials, poly(3-hexylthiophene) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM). Using PSNR we find a high concentration of PCBM at the substrate and near but not at the air interface. Herein we discuss the method of applying PSNR to polymer-based solar cells, the results obtained, and an evaluation of its effectiveness. © 2010 American Institute of Physics.



Courtesy: STFC, UK



Hydrogen Storage

Hydrogen Storage in a Microporous Metal–Organic Framework with Exposed Mn^{2+} Coordination Sites

Mircea Dincă,[†] Anne Dailly,^{‡,⊥} Yun Liu,^{§,||} Craig M. Brown,^{§,#} Dan. A. Neumann,[§]
and Jeffrey R. Long^{*,†}

Contribution from the Department of Chemistry, University of California, Berkeley, California 94720, Chemical and Environmental Sciences Laboratory, General Motors Corporation, Warren, Michigan 48090, College of Engineering, Purdue University, West Lafayette, Indiana 47907, Center for Neutron Research, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, Department of Materials Science and Engineering, University of Maryland, College Park, Maryland 20742, and Indiana University, Bloomington, Indiana 47408

Received August 5, 2006; E-mail: jrlong@berkeley.edu

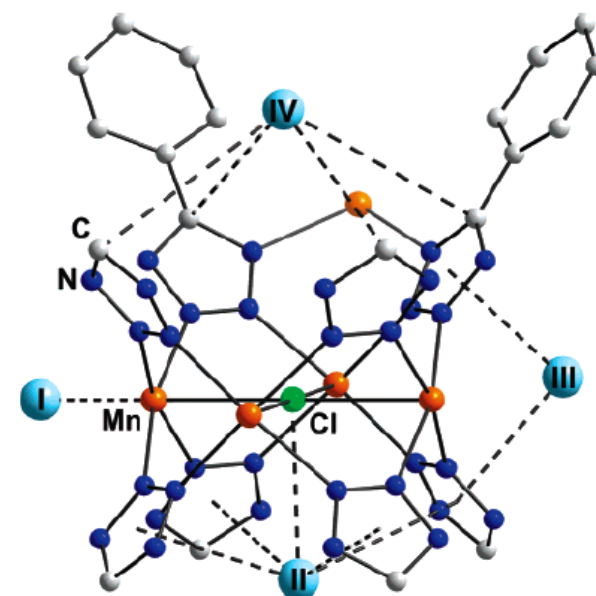
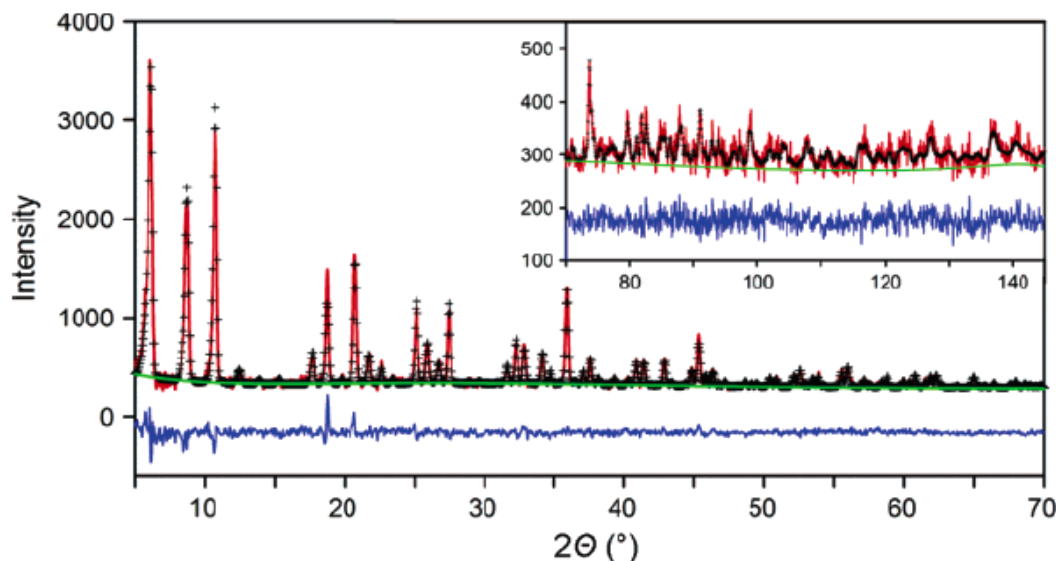
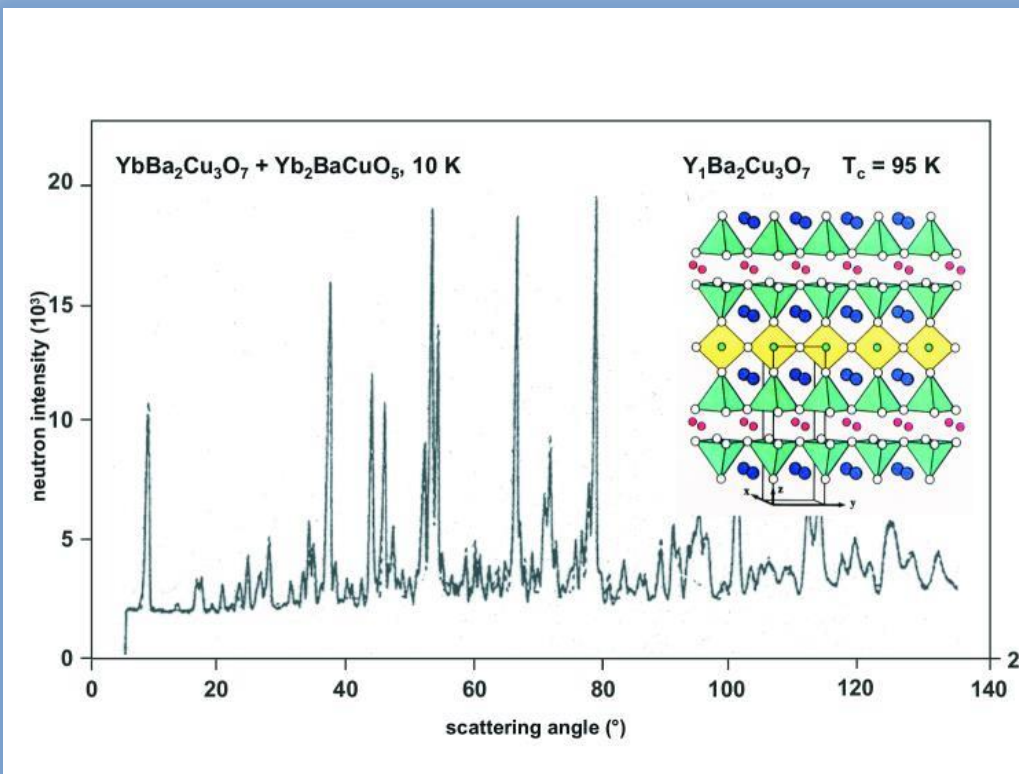


Figure 7. Initial D_2 adsorption sites within Im' . Light blue spheres represent D_2 centroids, while the transparent orange sphere shows the position of a partially occupied, extraframework Mn^{2+} ion site. Hydrogen atoms and methanol molecules are omitted for clarity.

YBCO

- $\text{YBa}_2\text{Cu}_3\text{O}_7$, $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$
- High- T_c superconductor
- $x=0.07$, $T_c=93\text{K}$ most efficient

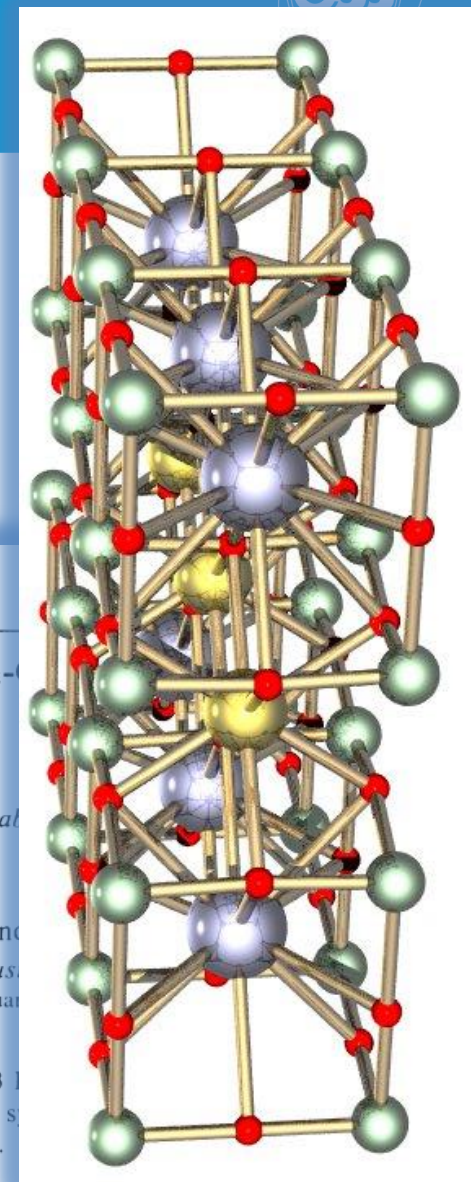


LETTERS

Phase Y-Ba-Cu-
structure

and C. J. Torng
a, Huntsville, Ala

Y. Q. Wang, and
University of Hous
received 18 Februar



between 80 and 93 K
Cu-O compound s

An estimated upper critical field $H_{c2}(0)$ between 80 and 180 T was obtained.

PACS numbers: 74.70.Ya

letters to nature

15. Roggan, H. L. & Anderson, P. W. Definition and measurement of the electrical and thermal resistance. *Phys. Rev. B* **24**, 1151–1154 (1981).
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Superconductivity in the non-oxide perovskite MgCNi₃

T. He^{*}, Q. Huang[†], A. P. Ramirez[‡], Y. Wang[§], K. A. Regan^{*}, N. Rogado^{*}, M. A. Hayward^{*}, M. K. Haas^{*}, J. S. Slusky^{*}, K. Inumara^{*}, H. W. Zandbergen^{*}, N. P. Ong[§] & R. J. Cava^{*}

^{*} Department of Chemistry and Princeton Materials Institute; [§] Department of Physics, Princeton University, Princeton, New Jersey, USA

[†] Department of Materials and Nuclear Engineering, University of Maryland, College Park, Maryland; and NIST Center for Neutron Research, Gaithersburg, Maryland, USA

[‡] Condensed Matter and Thermal Physics Group, Los Alamos National Laboratory, Los Alamos, New Mexico, USA

where they appear to be essential contributors to the exotic electronic states of these materials¹. Here we report that the perovskite-structured compound MgCNi₃ is superconducting with a critical temperature of 8 K. This material is the three-dimensional analogue of the LnNi₂B₂C family of superconductors, which have critical temperatures up to 16 K (ref. 2). The itinerant electrons in both families of materials arise from the partial filling of the nickel *d*-states, which generally leads to ferromagnetism as is the case in metallic Ni. The high relative proportion of Ni in MgCNi₃ suggests that magnetic interactions are important, and the lower *T_c* of this three-dimensional compound—when compared to the LnNi₂B₂C family—contrasts with conventional ideas regarding the origins of superconductivity.

The variable stoichiometry compound MgC_{*x*}Ni₃ (where 0.5 > *x* > 1.25) has been previously reported; it was supposed to have a perovskite structure by analogy^{3,4}. Neither its crystal structure nor its physical properties had been determined previously. In this study, samples with nominal formula MgC_{*x*}Ni₃ for *x* = 1.5, 1.25, 1.1, 1.0 and 0.9 were prepared. The starting materials were bright Mg flakes (Aldrich Chemical), fine Ni powder (99.9% Johnson Matthey), and glassy carbon spherical powder (Alfa AESAR). The starting materials were mixed in 0.5-g batches, and pressed into pellets. The pellets were placed on Ta foil, which was, in turn, placed on an Al₂O₃ boat, and fired in a quartz tube furnace under a mixed gas of 95% Ar and 5% H₂. The samples were heated for half an hour at 600 °C, followed by one hour at 900 °C. After cooling, they were

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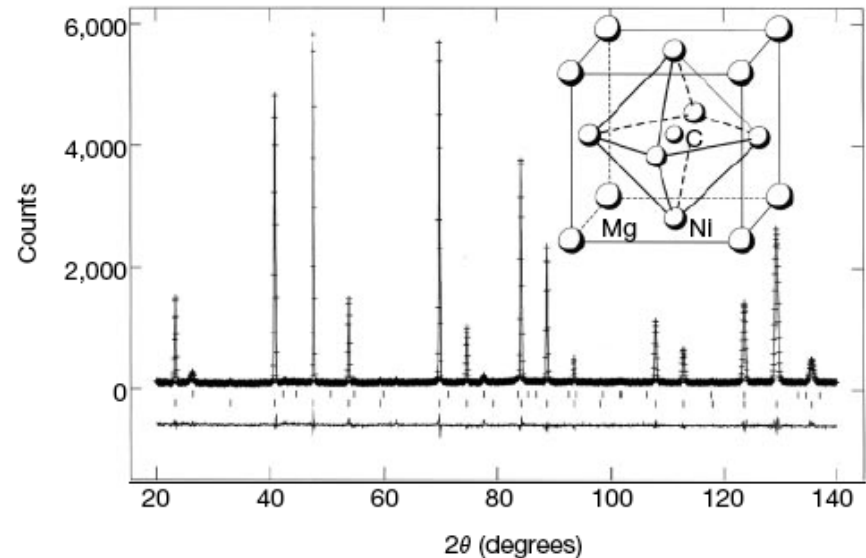


Figure 1 The powder neutron diffraction pattern at ambient temperature for the sample of nominal composition MgC_{1.25}Ni₃ and the perovskite crystal structure for the superconducting compound MgCNi₃ (inset). Neutrons of wavelength 1.5402 Å were employed (Cu 311 monochromator), with collimators of 15', 20' and 7' of arc before and after the monochromator, and after the sample, respectively. The neutron scattering lengths employed in the structure refinement were 0.538, 0.665 and 1.030 (cm⁻¹²) for Mg, C and Ni, respectively. Data are shown as crosses, and the difference plot between model and data shown directly below. The vertical lines (bottom) show the Bragg peak positions for the MgCNi₃ phase. The sample contains 2 wt% graphite (about 25 mol.%) in agreement with the nominal composition. Positions of the graphite peaks are shown as vertical lines above those for MgCNi₃. The refinement agreement, weighted profile agreement, and χ^2 values obtained were $R = 5.14\%$, $R_w = 6.39\%$ and $\chi^2 = 1.258$, indicating the high quality of the structural model.

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above those for MgCNi₃. The refinement agreement, weighted profile agreement, and χ^2 values obtained were $R = 5.14\%$, $R_w = 6.39\%$ and $\chi^2 = 1.258$, indicating the high quality of the structural model.

Buckminster Fullerenes

High resolution neutron powder diffraction: a case study of the structure of C_{60}

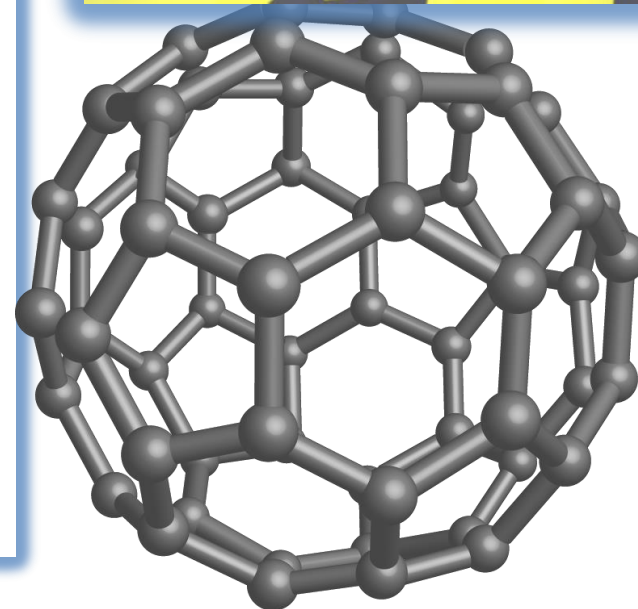
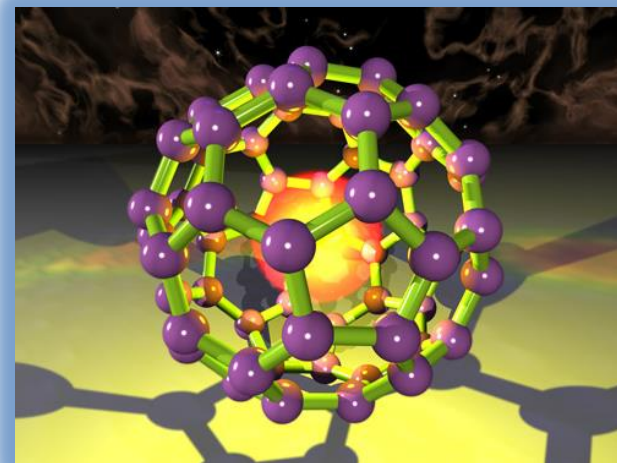
BY W. I. F. DAVID¹, R. M. IBBERSON¹ AND T. MATSUO²

¹*ISIS Science Division, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, U.K.*

²*Department of Chemistry and Microcalorimetry Research Centre, Faculty of Science, Osaka University, Toyonaka 560, Japan*

High resolution time-of-flight neutron powder diffraction has been used to determine the detailed structure of C_{60} as a function of temperature. Rapid data collection coupled with high resolution has enabled subtle aspects of the 86 K orientational glass transition and precursor effects of the 260 K order-disorder transition to be observed. This surveying capability complements traditional single crystal methods. The power of the Rietveld method of profile refinement is demonstrated in the elucidation of the detailed crystal structure of the orientationally-ordered low temperature phase and in the evaluation of the departure from isotropic scattering of the C_{60} molecule in the disordered high temperature phase. The counter-intuitive success in obtaining high-order cubic-harmonic coefficients, albeit to poorer precision than single crystal X-ray measurements, confirms the efficacy of the Rietveld profile refinement method. The collapse of three dimensions of diffraction information on to the one dimension of a high resolution powder diffraction pattern can still lead to an impressive amount of structural information that substantiates the assertion made by W. H. Bragg

'the second method [powder diffraction], first used independently by Debye and Hull, can be used when the crystal is in powder, and can, therefore be employed when no single crystal can be obtained of sufficient size. All the spectra of the different planes are thrown together on the same diagram or photograph, and must be disentangled. This is not as difficult as it may seem ...'.



Diffraction: Zeolites

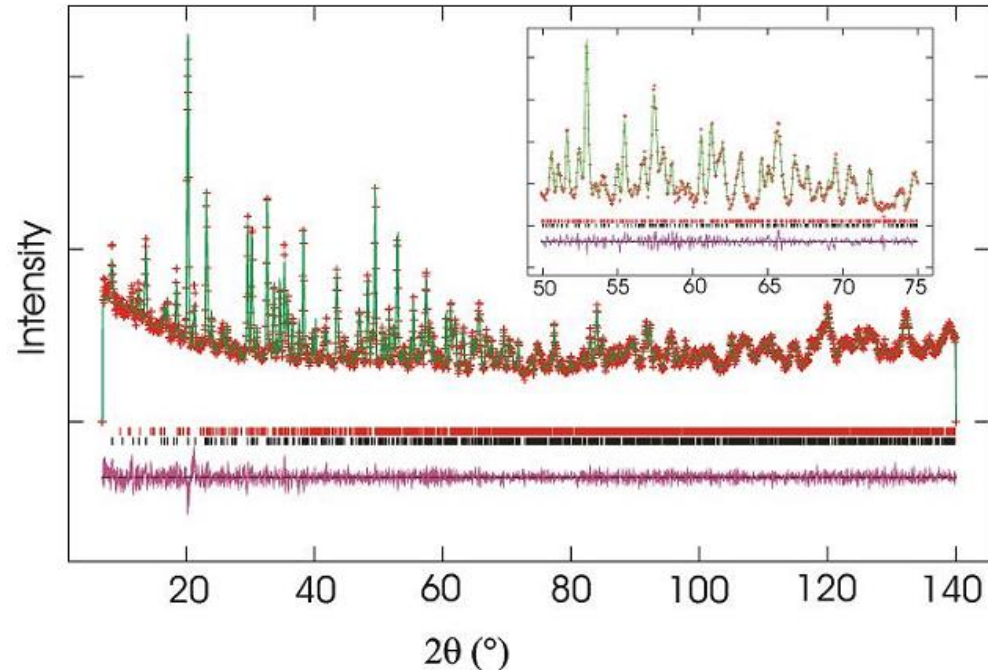
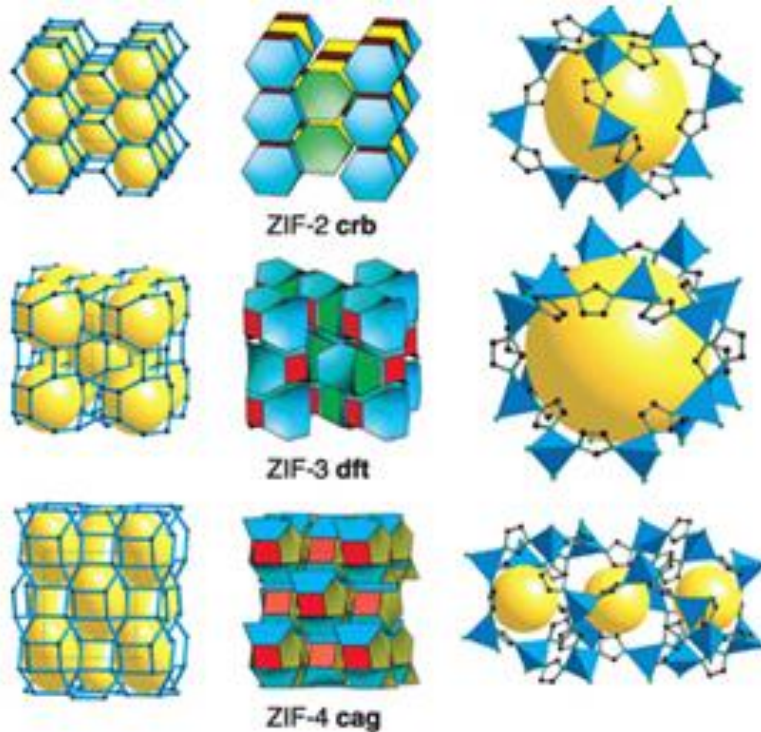


Fig. 1. Observed neutron diffraction intensities (crosses) for deuterium-exchanged RUB-29 superimposed on those computed from the crystallographic model (upper line). The upper and lower sets of short vertical lines indicate reflections of the impurity compound RUB-23 and RUB-29, respectively. The lower curve shows the difference between the observed and calculated data. The plot is enlarged in the high angle range between $50^\circ < 2\theta < 75^\circ$ to emphasize agreement between the data and the model.

Applications:

Detergents: Ion exchange capability

Gas separation: Microporosity

Dessicants: Adsorption

Catalysis: acidity, porosity, high surface area

Large Unit Cell!

Source: B Toby NIST

Batteries

Experimental vibrational dynamics and lithium diffusion in Li_xFePO_4

SHIN-ICHI NISHIMURA¹, GENKI KOBA²
AND ATSUO YAMADA³

¹Department of Electronic Chemistry, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan
²Institute for Materials and Chemical Process, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan
³Department of Materials Science, National Institute of Advanced Industrial Science and Technology, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8565, Japan
*e-mail: yamada@chem.naai.ac.jp

Nature

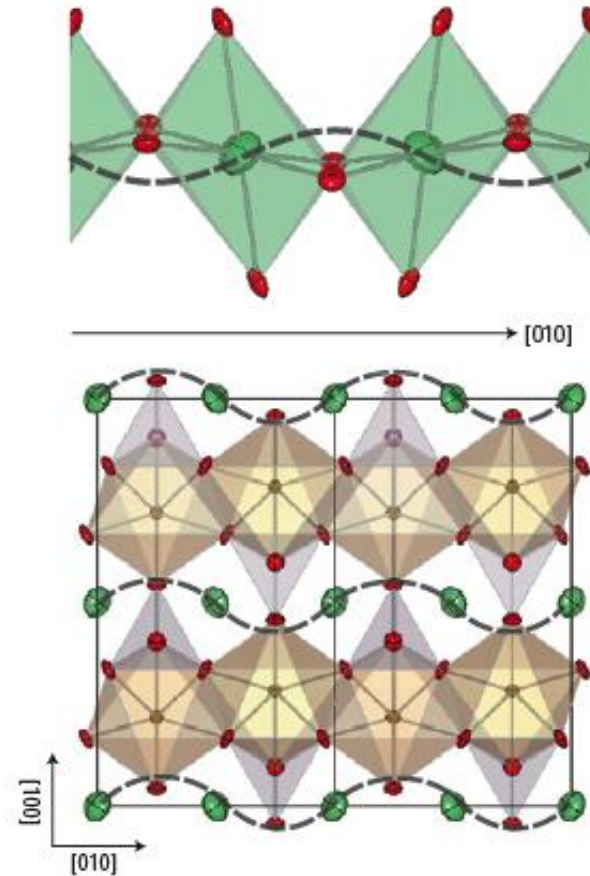
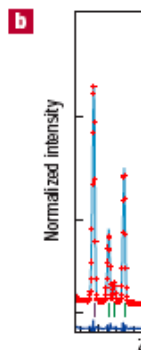
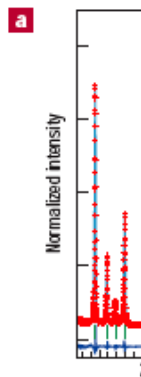
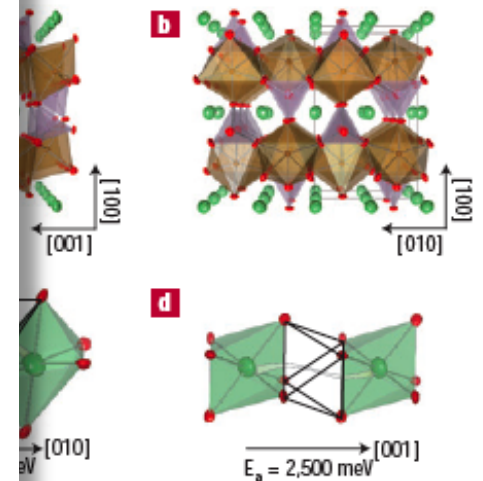


Figure 3 Anisotropic harmonic lithium vibration in LiFePO_4 , shown as green thermal ellipsoids and the expected diffusion path. The ellipsoids were refined with 95% probability by Rietveld analysis for room-temperature neutron diffraction data. Expected curved one-dimensional continuous chains of lithium motion are drawn as dashed lines to show how the motions of Li atoms evolve from vibrations to diffusion.



of LiFePO_4 and possible lithium pathways. a,b, The structure is projected along the [010] (a) and [001] (b) directions. The migration pathways are parallel to these directions. The structure parameters were determined from the experimental data and are listed in Supplementary Information, Table S1. The structure can be described as an agonal close-packed oxygen sub-array, in which Li, Fe and P sites form (1) corner-sharing FeO_6 octahedra that form a distorted two-dimensional square lattice perpendicular to the [010] direction, and (2) LiO_4 tetrahedra aligned in parallel chains along the [010] direction. The green ellipsoids indicate Li, Fe, P and O atoms, respectively. The dashed lines indicate the lithium migration paths: c, along the [010] direction through tetrahedral sites; and d, along the [001] direction through octahedral sites. One-dimensional diffusion along the [010] direction was studied by the computational method^{15,16}.

Laboratory work



Large Scale Facility

Science with Neutrons



NEUTRONS & HEALTH

“The role of future neutron facilities in meeting today's challenges in medicine, nutrition and the environment”

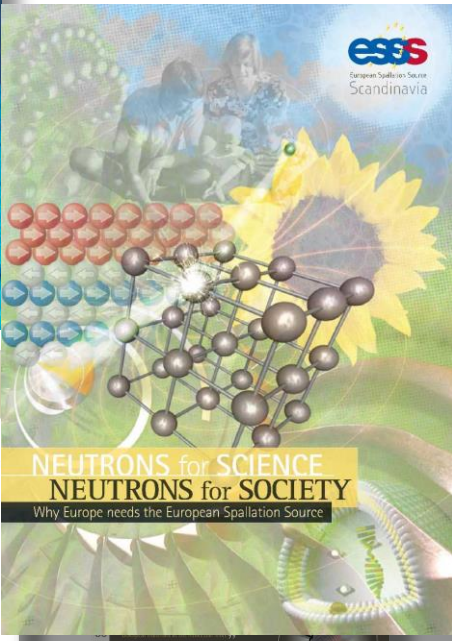


22 **SMOOTHER CREAM CHEESE**
 A new neutron technique helps keep cream from separating. The European Spallation Source (ESS) is helping researchers understand the structure of cream cheese to improve its texture and shelf life. Neutron scattering is used to study the structure of cream cheese, which is a complex material with a network of fat and protein. The researchers are looking for ways to improve the texture and shelf life of cream cheese, which is a major product in the food industry.

24 **NEUTRONS FOR SOCIETY**
 Why Europe needs the European Spallation Source. Neutron scattering is a powerful tool for understanding the structure of materials at the atomic level. It is used in a wide range of fields, from materials science to biology. The European Spallation Source (ESS) is a major facility for neutron scattering, and it is essential for Europe's scientific and industrial progress. The ESS will provide access to a wide range of neutron scattering techniques, including neutron diffraction, neutron scattering, and neutron spectroscopy. This will enable researchers to study the structure of materials in a way that is not possible with other techniques.

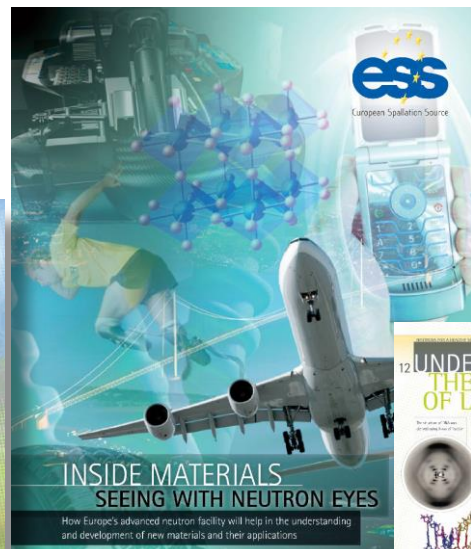
26 **UNDERSTANDING LIVING PROCESSES**
 The structure of proteins is essential for understanding living processes. Neutron scattering is used to study the structure of proteins, which are the building blocks of life. The European Spallation Source (ESS) is helping researchers understand the structure of proteins, which is essential for understanding living processes. The ESS will provide access to a wide range of neutron scattering techniques, including neutron diffraction, neutron scattering, and neutron spectroscopy. This will enable researchers to study the structure of proteins in a way that is not possible with other techniques.

28 **MATERIALS FOR TOMORROW**
 Research using neutrons is producing the next generation of advanced materials with new properties. Neutron scattering is used to study the structure of materials, which is essential for understanding their properties. The European Spallation Source (ESS) is helping researchers understand the structure of materials, which is essential for understanding their properties. The ESS will provide access to a wide range of neutron scattering techniques, including neutron diffraction, neutron scattering, and neutron spectroscopy. This will enable researchers to study the structure of materials in a way that is not possible with other techniques.



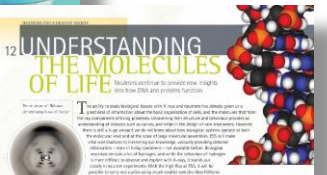
NEUTRONS for SCIENCE NEUTRONS for SOCIETY

Why Europe needs the European Spallation Source



INSIDE MATERIALS SEEING WITH NEUTRON EYES

How Europe's advanced neutron facility will help in the understanding and development of new materials and their applications



12 UNDERSTANDING THE MOLECULES OF LIFE

How Europe's advanced neutron facility will help in the understanding and development of new materials and their applications



16 NEUTRON SCATTERING AND BIOLOGICAL MOLECULES

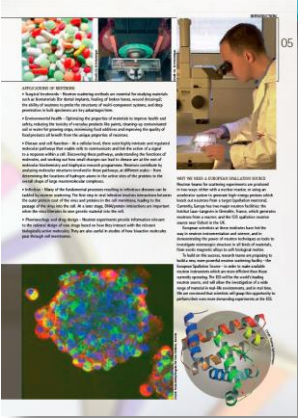
How Europe's advanced neutron facility will help in the understanding and development of new materials and their applications



16 MATERIALS FOR TOMORROW

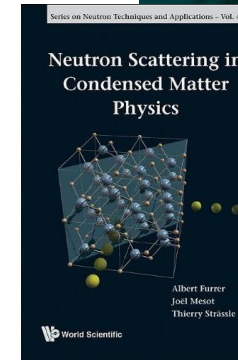
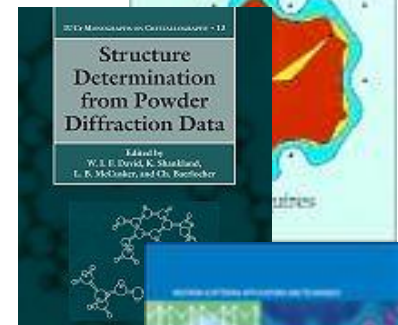
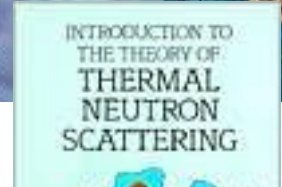
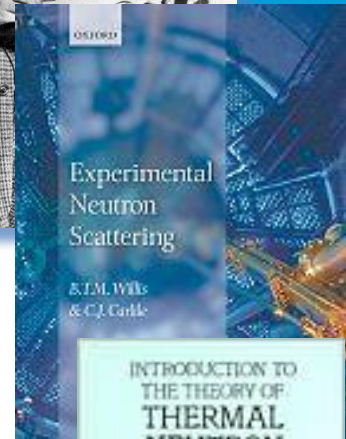
Research using neutrons is producing the next generation of advanced materials with new properties

CARBON NANOTUBES
 Carbon nanotubes are a new class of material with unique properties. Neutron scattering is used to study the structure of carbon nanotubes, which is essential for understanding their properties. The European Spallation Source (ESS) is helping researchers understand the structure of carbon nanotubes, which is essential for understanding their properties. The ESS will provide access to a wide range of neutron scattering techniques, including neutron diffraction, neutron scattering, and neutron spectroscopy. This will enable researchers to study the structure of carbon nanotubes in a way that is not possible with other techniques.



Further Reading

- B.T.M. Willis & C.J. Carlile 'Experimental Neutron Scattering', Oxford University Press
- G.L. Squires 'Introduction to the Theory of Thermal Neutron Scattering', Cambridge University Press / Dover
- W.I.F. David, K. Shankland, L.B. McCusker, and C. Bärlocher (Eds.) 'Structure Determination from Powder Diffraction Data' IUCr Monographs 13
- Liyuan Liang, Romano Rinaldi, and Helmut Schober, eds, 'Neutron Applications in Earth, Energy and Environmental Sciences', ISBN 978-0-387-09415-1, Springer 2009
- A Furrer, J Mesot, T Strässle, 'Neutron Scattering in Condensed Matter Physics', World Scientific,
- Google, ISI Web of Science, ScienceDirect..



EXTRA SLIDES

Secondary particle produced at J-PARC

