Neutron Sources

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African School of Fundamental Physics and its Applications

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Outline

• 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
Measurements of the Vertical Coherence Length in Neutron Interferometry

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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.

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Small-Angle (SANS/SAXS)

- Polymers and colloids, e.g.
  - Micelles
  - Dendrimers
  - Liquid crystals
  - Gels
  - Reaction kinetics of mixtures
- Materials Science
  - Phase separation in alloys and glasses
  - Morphologies of superalloys
  - Micro-porosity in ceramics
  - Interfaces and surfaces
- Biological macromolecules
  - Size and shape of proteins, nucleic acids, and of macromolecular complexes
  - Bio-membranes
  - Drug vectors
- Magnetism
  - Magnetic correlations
  - Flux line lattices in superconductors

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

D22 at www.ill.eu
Quasielastic Neutron Scattering Study on the Dynamics of Poly(alkylene oxide)

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ABSTRACT: By means of quasielastic neutron scattering, the hydrogen dynamics in poly(ethylene oxide) with different side-chain lengths at temperatures above the glass-transition temperature have been investigated. The combination of different spectrometers (time-of-flight and the Inelastic Neutron Scattering instruments) has allowed for the observation of the side-group motions at low temperatures and (segmental) dynamics at high temperatures. Of the side groups, some (a) stretching of the (a) associated activation energies to the cooperative bond rotations of polyethylene, (b) increase with increasing temperature. The present study presents (i) the same spectral shape, (a) a detailed behavior. The present study presents (i) the same spectral shape, (a) a detailed behavior. For comparison, we also report on the same temperature range, that show evi process (ii) the same spectral shape, (a) a detailed behavior. For comparison, we also report on the same temperature range, that show evidence the simultaneous occurrence of the side-group motions at low temperatures and (segmental) dynamics at high temperatures. The side groups show (i) stretching of the (a) associated activation energies to the cooperative bond rotations of polyethylene, (b) increase with increasing temperature. The present study presents (i) the same spectral shape, (a) a detailed behavior. For comparison, we also report on the same temperature range, that show evidence the simultaneous occurrence of the side-group motions at low temperatures and (segmental) dynamics at high temperatures.

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

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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 \( R - C l / R u C l_2( P P h_3)_2 / t r i b u l y a m i n e ( n - B u t N ) \) initiating system, followed by the addition of ethylene glycol dimethacrylate (EGDMA) 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 (\( \sim 1 \) nm), and average arm numbers \( N \sim 17 \).
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

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ABSTRACT

Most materials exist as several phases, however, the use of nanoscale materials with high aspect ratios can significantly increase the effective properties of a composite material. The use of nanocomposites in food packaging can improve the properties of the final product in terms of shelf life extension, barrier properties, and the ability to inhibit or retard spoilage. However, the use of nanocomposites requires the development of new processes and materials with improved properties. This article provides an overview of the current state of research on nanocomposites for food packaging and highlights some of the challenges and opportunities for future developments.

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4. Oxygen scavenging films
4.1. Nano-based sensors
4.2. Detection of gases produced by food spoilage
4.3. CO2 indicators
5. Nanoscale enzyme immobilization systems
6. Final considerations
References

Specular reflection

θ_{in} = θ_{out}

Q_z = |\mathbf{k}_{\text{out}} - \mathbf{k}_{\text{in}}| = (2π/λ)(\sin \theta_{\text{in}} + \sin \theta_{\text{out}})

Precise density profile along the depth direction

Model fitting

精密密度图示沿深度方向
Neutron radiography characterization of an operating proton exchange membrane fuel cell with localized current distribution measurements

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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 x 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

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

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Figure 7. Initial D$_2$ adsorption sites within 1m. 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
- $x=0.07$, $T_c=93K$ most efficient
Superconductivity in the non-oxide perovskite MgCNi$_3$


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

Figure 1 The powder neutron diffraction pattern at ambient temperature for the sample of nominal composition MgC$_{1.25}$Ni$_{3}$ and the perovskite crystal structure for the superconducting compound MgCNi$_3$ ( 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$^{-1}$) 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 MgCNi$_{3}$ phase. The sample contains 2.6 wt% graphite (about 25 mol%) in agreement with the nominal composition. Positions of the graphite peaks are shown as vertical lines above those for MgCNi$_{3}$. The refinement agreement, weighted profile agreement, and $\chi^2$ values obtained were $R = 5.14\%$, $R_w = 6.39\%$ and $\chi^2 = 1.258$, indicating the high quality of the structural model.
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

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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 onto 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 ...’.
Applications:
- Detergents: Ion exchange capability
- Gas separation: Microporosity
- Dessicants: Adsorption
- Catalysis: acidity, porosity, high surface area
**Experimental vi**

**diffusion in Li$_x$FePO$_4$**

**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.
Research at Large Facilities

Laboratory work

Large Scale Facility
Science with Neutrons
Further Reading

- 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

Proton (p)
3 GeV, 50 GeV

Target Nucleus

Neutron (n)

Muon (µ)

Neutrino (ν)

Kaon (K)

Anti Proton (p̅)

Pion (π)

π → µν

Need to have high-power proton beams

→ MW-class proton accelerator (current frontier is about 0.1 MW)

Materials & Life Science from RCS
Nuclear & Particle Physics from MR
R&D toward Transmutation from LINAC