POLICY FORUM: NEUTRON SCATTERING

The Case for Neutron Sources

B. Keimer, E. Sackmann, P. J. Withers

At Oak Ridge National Laboratory in Tennessee, construction is well under way for the world's most powerful source of neutrons (SNS), to be completed in 2006. Work is starting on a similar neutron source at the Japanese Atomic Energy Research Institute in Tokai, Japan (JNS). Both projects were greeted with enthusiasm by U.S. and Japanese researchers.

Enhanced online at www.sciencemag.org/cgi/content/full/298/5593/543

In contrast, the Wissenschaftsrat, Germany's national science council, recently questioned the scientific case for a next-generation neutron source, the European Spallation Source (ESS), proposed by a consortium of European research institutions. Citing doubts about its timeliness and uniqueness, the Wissenschaftsrat declined to endorse the project, thereby jeopardizing a European project with a €1.5 billion price tag.

The council reasoned that less expensive experimental techniques such as nuclear magnetic resonance (NMR) and synchrotron radiation could largely replace neutrons before the ESS would become operational. If this is the case, the United States and Japan have wasted billions of dollars of research funding on a technique that will soon become obsolete.

Neutrons are increasingly important for research by virtue of their unique properties, including charge neutrality, magnetic moment, large scattering cross sections for light elements such as hydrogen and oxygen, and strongly isotope-dependent scattering lengths (*1*). The scientific case for next-generation neutron sources consequently encompasses many fields of research (*2*), as illustrated by the following examples.

Solid state physics. Research on the electron-electron interactions underpinning such phenomena as high-temperature superconductivity and "colossal" magnetoresistance are at the cutting edge of solid state physics (*3*). Neutron-scattering experiments on the microscopic magnetic properties are much more incisive than studies of macroscopic properties, and the neutron flux anticipated at next-generation facilities will be two orders of magnitude higher. This will enable experiments on excitation continua of metallic systems, among others, that will yield a wealth of new information.

Could alternative methods provide similar insights? NMR techniques yield valuable local data on the magnetic susceptibility of solids, but interpretation of these data requires knowledge of the material-specific hyperfine interactions. The interaction parameters are difficult to calculate and to measure independently, especially for complex materials. Even if they could be calculated accurately, NMR would remain constrained to energies several orders of magnitude below those of electronic correlation effects.

Synchrotron radiation is another valuable characterization tool for solid state magnetism. However, the cross section for charge scattering is several orders of magnitude larger than that for magnetic scattering of photons. Thus, even magnetic structure determinations of simple single-crystalline solids by magnetic x-ray scattering are exceedingly difficult. A quantitative determination of the magnetic collective modes and excitation continua of complex electronic materials by inelastic x-ray scattering will not be feasible in the foreseeable future.

Biophysics. The life sciences are turning to more complex biological materials or systems that require new tools for structural research on mesoscopic scales. Furthermore, the combination of recombinant proteins with organic molecules enables the fabrication of complex biofunctional systems on solid devices, which may lead to smart biosensors or adaptive biocompatible materials (transplants) with long-term stability under physiological conditions (*4*).

Neutron scattering is an ideal tool to study such materials. Varying solvent contrast and labeling certain components or parts of them enables detailed structural analysis of complex structures. Correlations can readily be made between molecular dynamics and molecular architecture of soft materials or single proteins.

In contrast to x-rays, neutron scattering is not destructive, thus allowing studies of living systems such as whole cells. The combination of x-ray and neutron results can yield further insight into the components of complex, soft materials. Structural and dynamic studies with NMR are also complementary to scattering techniques but generally rely on a priori information, such as sequences of biomolecules. Where this is not available, or for more disordered and random local structures, scattering techniques will remain the decisive tool. Space-time information on large-scale molecular motions will also remain a domain of neutron scattering.

Present neutron sources require large sample sizes, which are often not available. Their limited intensity renders multidimensional contrast variation schemes impossible and constrains time resolution severely. Next-generation sources will enable the miniaturization of neutron-scattering techniques, facilitate multiparameter studies, and reduce the time gap between kinetic and dynamic experiments.

Engineering. Until recently, neutron-scattering instruments could only handle small idealized samples of little relevance to engineers. Lately, specialized engineering instruments at the world's major neutron facilities have led to a dramatic increase in engineering data. The excellent penetration of thermal neutrons enables information about the state of an engineering component (such as texture, stress, and structure) to be mapped nondestructively in three dimensions (3D). Full-scale or sub-scale prototype components can be studied in situ, subjected to realistic manufacturing processes, in-service stresses, and environments. This is leading to a better understanding of material and component behavior and, hence, safer design, especially in sectors such as aerospace and nuclear power generation.

The high penetration of synchrotron x-rays complements the information provided by neutrons, especially for events on subsecond time scales. But the low scattering angles inherent in using very high x-ray energies (60 to 300 keV) mean that 3D information (needed for stress mapping) cannot normally be obtained. The engineering instruments planned at the SNS, JNS, and ESS will allow imaging of defects that cannot even be detected at present and will provide 3D maps of stress fields in cases where only point measurements are now possible.

Conclusion. The scientific case for next-generation neutron sources has been made numerous times in many countries. There will continue to be fruitful overlap and complementarity between approaches, but a wholesale substitution for neutron studies with allegedly faster, better, and cheaper methods is inconceivable. This will become painfully obvious to Europeans if they carelessly allow their lead in neutron science to evaporate. When the Wissenschaftsrat meets again in November, they would do well to consider these issues.

B. Keimer is in the Max-Planck-Institute for Solid-State Research, 70569 Stuttgart, Germany. E-mail: b.keimer@fkf.mpg.de. E. Sackmann is in the Physics Department, Technical University of Munich, 85747 Garching, Germany. E-mail: sackmann@ph.tum.de. P. J. Withers is in the Manchester Materials Science Centre, University of Manchester, Manchester M1 7HS, UK. E-mail: philip.withers@man.ac.uk

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