X-ray Scattering Facilities

Portfolio Description

This activity supports the operation of five synchrotron radiation light sources. Four of the light sources are storage ring-based sources: the Advanced Light Source (ALS) at Lawrence Berkeley National Laboratory (LBNL); the Advanced Photon Source (APS) at Argonne National Laboratory (ANL); the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL); the Stanford Synchrotron Radiation Lightsource (SSRL) at the Stanford Linear Accelerator Center (SLAC). The fifth light source, the Linac Coherent Light Source (LCLS) at SLAC, is a free electron laser which provides laser-like radiation in the short x-ray region of the spectrum with 10 orders of magnitude greater peak power and brightness than that available from any existing synchrotron radiation x-ray light source. Under construction is the NSLS-II which will replace NSLS to enable the study of material properties and functions at the nanoscale level and to provide the world's finest x-ray imaging capabilities.

Unique Aspects

The synchrotron radiation light sources are the most advanced facilities of their kind in the world. Together, they serve over 11,000 users annually from academia, Department of Energy (DOE) national laboratories, and industry, a number that has nearly doubled in the past decade and that can double again in the next decade as current facilities and those under construction are fully instrumented. These light sources represent the largest collection of such facilities operated by a single organization in the world. Conception, design, construction, and operation of these facilities are among the core competencies of the BES program.

Relationship to Other Programs

- This activity has very strong interactions with all BES programmatic research that use synchrotron sources. This includes research in atomic physics, condensed matter and materials physics, chemical dynamics, catalysis, geosciences, high-pressure science, environmental sciences, engineering, biosciences, and much more.
- Interaction also exists with other parts of the Office of Science, notably the Office of Biological and Environmental Research, and the Office of Fusion Energy Sciences, and with other areas of DOE, notably the National Nuclear Security Administration, the Office of Energy Efficiency and Renewable Energy, and the Office of Environmental Management.
- There are frequent contacts with other federal agencies in order to better coordinate efforts in optimizing beamlines and instruments. This activity is establishing more frequent contacts with international user facilities such as ESRF, XFEL, SPring-8, and others. The objectives are to share experiences and to make optimal use of present facilities.

Significant Accomplishments

During the past three decades, BES has been the nation's major supporter of synchrotron x-ray light sources. BES support pioneered new storage ring lattices for improved beam stability and brightness; developed insertion devices that provide 10 to 12 orders of magnitude greater brightness than the best conventional x-ray sources; and discovered or developed such powerful experimental techniques as magnetic x-ray scattering, microbeam diffraction, x-ray microscopy, photoelectron spectroscopy and holography, x-ray nanoprobe, full-field and diffraction imaging, Rapid Acquisition Pair Distribution Function (RA-PDF), inelastic x-ray scattering using nuclear resonances, extended x-ray absorption fine structure (EXAFS), and near-edge absorption fine structure (NEXAFS). The newly constructed fourth generation light source, LCLS, the world's first "hard" x-ray free-electron laser, has exceeded its original designed performance specifications and all six experimental stations have successfully been commissioned and are available for users. Recent research at the light source facilities supported by BES, other agencies, industry, and private sponsors includes:

- Time-resolved soft x-ray transmission microscopy measurement revealing the strength and duration of trains of electric and magnetic pulses affect the circulation of a magnetic vortex that may lead to the possibility of magnetic memory bits with four states instead of two, improving storage capacity as well as energy efficiency
- *In situ* x-ray diffraction studies to investigate and map out the process-structure-property relationships in CuInGaSe materials, the active material in the solar shingles leading to the development of the first-of-its-kind commercial 'Solar Singles', Powerhouse™ Solar Shingles, by Dow Chemical
- Coherence diffraction imaging measurement using intense, coherent, and ultrashort x-ray pulses revealing vibration modes in gold nanoparticles at trillionths of seconds time scale with never-before-seen details; and
- Particularly significant was the award of the 2012 Nobel Prize in Chemistry for studies on G-protein–coupled receptors (GPCRs) which cells use to pick up signals from the outside world such as tastes, flavors and sights, and to communicate with mobile messengers from inside the body, such as hormones and neurotransmitters.

Mission Relevance

These facilities were born from the most fundamental of needs, i.e., the need to characterize materials at the atomic and molecular level. In order to understand, predict, and ultimately control materials properties, it is necessary to determine the atomic constituents of materials, the positions of the atoms in materials, and how the materials behave under the influence of external perturbations such as temperature, pressure, magnetic or electric field, and chemical change. A large number of experimental and theoretical tools are used to achieve these ends. In the last two decades, the experimental demands have motivated the development of large scale powerful facilities that are not possible to develop, construct and operate by individual institutions and/or companies. Such highly sophisticated and expensive tools are by their nature centralized and staffed with specialists that provide expertise to the user community to optimize the scientific use of the facility. The development, construction, and operation of these facilities are one of the most important missions and core competencies of BES. The scientific accomplishments of these facilities are reflected in the large number of publications appearing annually in the most important scientific journals.

Scientific Challenges

First, the facilities must be operated optimally, which means optimizing instrument-hours of operation, not just accelerator hours of operation, and making the instruments widely available to the general user community. Second, optimal utilization of the LCLS coherent short-wavelength x-ray source will require continued development of new capabilities and advanced optics, instruments, and detectors.

Projected Evolution
X-ray scattering will continue to play a central role in the growth of BES programmatic science. The facilities will need continuous growth and advancement in terms of upgrades, new instruments, and increase in availability of user time. The set of instruments associated with these facilities provides unique scientific and technical capabilities, rarely available in other parts of the world. These facilities need to be kept in an optimal operational condition in order to maintain and increase the tremendous scientific achievements they have facilitated.

The LCLS will have properties vastly exceeding those of current x-ray sources in three key areas: peak brightness, coherence, and ultrashort pulses. The peak brightness of the LCLS is 10 orders of magnitude greater than current synchrotrons; the light is coherent or "laser like" enabling many new types of experiments; and the pulses are short (50 femtoseconds in standard operation with planned improvements that will further reduce the pulse length to <5 femtoseconds), enabling studies of fast chemical and physical processes. These characteristics open new realms of scientific applications in the chemical, material, and biological sciences including fundamental studies of the interaction of intense x-ray pulses with simple atomic systems, structural studies on single nanoscale particles and biomolecules, ultrafast dynamics in chemistry and solid-state physics, studies of nanoscale structure and dynamics in condensed matter, and use of the LCLS to create plasmas.