User Facilities around the World

View of the Swiss Light Source. PHOTO COURTESY SWISS LIGHT SOURCE/PSI

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National and international communities of scientists from a variety of disciplines have been successful in convincing a growing number of countries to construct major user facilities that collectively serve these communities. These user facilities make possible experimental studies that cannot be done in individual investigator laboratories. In addition, they have created a new style of research, in which scientists working in shared facilities conduct studies that benefit from a merging of ideas and techniques from different disciplines. Earth science users of these facilities are growing in number and are benefiting greatly from the multidisciplinary interactions such facilities stimulate and from the unique experimental capabilities they provide.

KEYWORDS: synchrotron X-rays, neutron scattering, electron beam microcharacterization, nanoscience research

INTRODUCTION

During the past 20 to 30 years, a large number of national scientific user facilities have been developed in North America, Europe, and elsewhere. These user facilities differ in scale, complexity, construction cost, operations cost, and size of user base relative to the typical analytical facilities that most Earth scientists use in university and government laboratories. Included among these facilities are synchrotron light sources, pulsed beam (spallation) and continuous (nuclear reactor) neutron sources, accelerator-based mass spectrometers, electron beam microcharacterization facilities, and nanoscience centers. In this article, we provide a brief overview of the facilities that are available, focusing on those in North America and Europe.

MAJOR SCIENTIFIC USER FACILITIES AROUND THE WORLD

Most of the national scientific user facilities in the US are supported by the Office of Science of the Department of Energy (DOE), and descriptions of them can be found at www.science.doe.gov/bes/BESfacilities.htm. The locations of many of these facilities are shown in FIGURE 1. In addition, a booklet entitled *Scientific Research Facilities* prepared by the DOE Office of Science can be downloaded at www.science.doe.gov/bes/srf.pdf. A number of widely distributed national user facilities also exist in Europe (FIG. 2). TABLE 1 summarizes these facilities, as well as the two major synchrotron facilities in Japan. It also lists a number of the US and European supercomputer centers where computer time is potentially available to Earth scientists on a peer-reviewed proposal basis.

At present, there are 58 synchrotron light sources in 29 countries, including seven in the US and twelve in Japan (the following URLs list these synchrotron light sources and their characteristics: www.chess.cornell.edu/chess/syncfclt.htm; www.lightsources.org). US light sources and the European Synchrotron Radiation Facility (ESRF) served about 8000 users and 5000 users, respectively, in 2004.

Facilities in Asia have been at the forefront of instrumentation development. For example, the Photon Factory (KEK) in Tsukuba, Japan, a second-generation synchrotron light

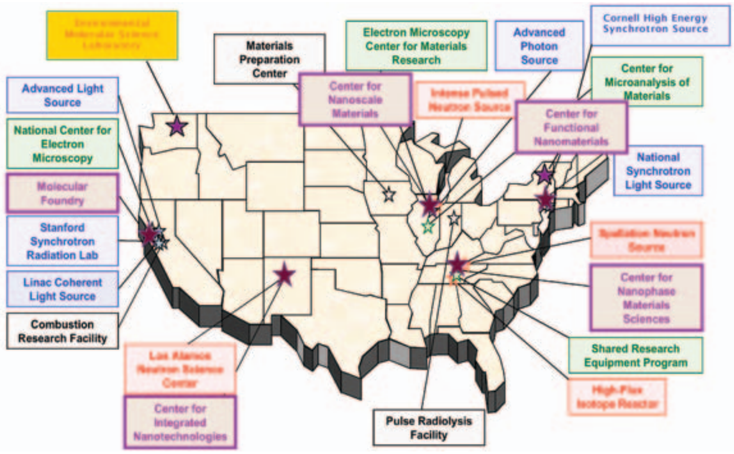

FIGURE 1 Locations of US scientific user facilities supported by DOE, Office of Basic Energy Sciences. The different color codes used in the labels represent different classes of user facilities (e.g. blue represents synchrotron radiation sources), and the facility labels that are hachured (e.g. Linac Coherent Light Source) represent user facilities that are currently under construction. Figure courtesy of Dr. Patricia Dehmer, Office of Basic Energy Sciences, DOE. Also shown are several other national user facilities supported by other US agencies, including CHESS (NSF) and EMSL (DOE-OBER). A more complete listing of US national user facilities, including mass spectrometry facilities and supercomputer centers, can be found in Table 1.

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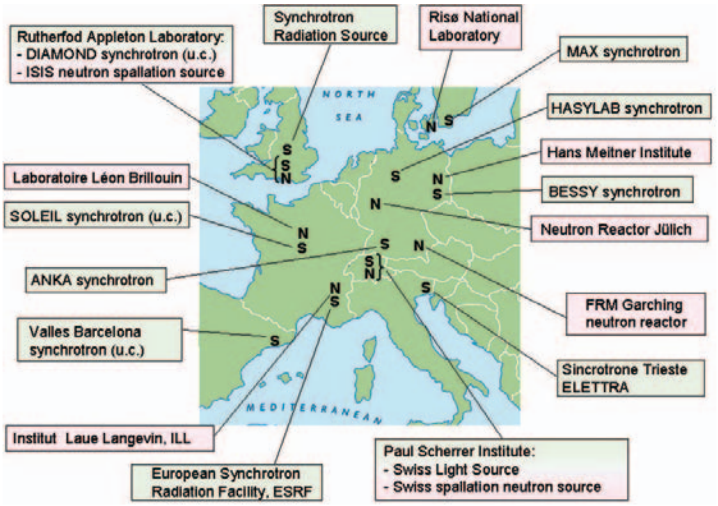

FIGURE 2 Locations of major synchrotron radiation (S) and neutron (N) user facilities in Europe. Under construction (u.c.)

source, has been a productive user facility since 1982. The world's largest third-generation synchrotron source is Spring-8 in Japan, a facility that has been in operation since 1997. The Beijing (China) Synchrotron Radiation Facility has been supporting users since 1991.

In addition, many new synchrotron facilities are under construction or just beginning operations around the world. These include the Canadian Light Source (Saskatchewan), the Australian Synchrotron (Melbourne), Diamond (Didcot, Oxfordshire, UK), and SOLEIL (Gif-sur-Yvette, France).

In most countries, Earth science users are not charged for access to most major research facilities. Access is typically granted on the basis of peer-reviewed proposals (see Reeder and Lanzirotti 2006). Support of research facilities is variable around the world. In the US, the DOE (www.doe.gov) is the steward for X-ray and neutron facilities used by Earth scientists (Astheimer et al. 2000) and by scientists from other disciplines. Substantial support for US Earth science research facilities is also provided by the NSF (www.nsf.gov), primarily through its Instrumentation and Facilities Program (www.nsf.gov/geo/ear/if/facil.jsp). In Europe, research facilities are largely supported by governing bodies in the country of the home institution, but collaborative funding is becoming more widespread, as exemplified by the ESRF (www.esrf.fr). Support for one of Canada's newest user facilities, the Canadian Light Source (www.lightsource.ca), also derives from a partnership approach, in which funding comes from federal, provincial, municipal, industrial, and academic sources.

CLASSES OF USER FACILITIES

User facilities range from large, multi-instrument laboratories (only parts of which are needed by any user) operated by large management and research teams, to facilities with multiple instruments operated by several investigators, and single instruments managed by individual researchers. An example of a *large, multi-instrument laboratory* is the Environmental Molecular Science Laboratory (EMSL) at Pacific Northwest National Laboratory (PNNL) (www.emsl.pnl.gov).EMSL is composed of six specialized facilities containing advanced and one-of-a-kind experimental and computational resources for scientists engaged in fundamental research at the interface of physical, chemical, and biological processes.

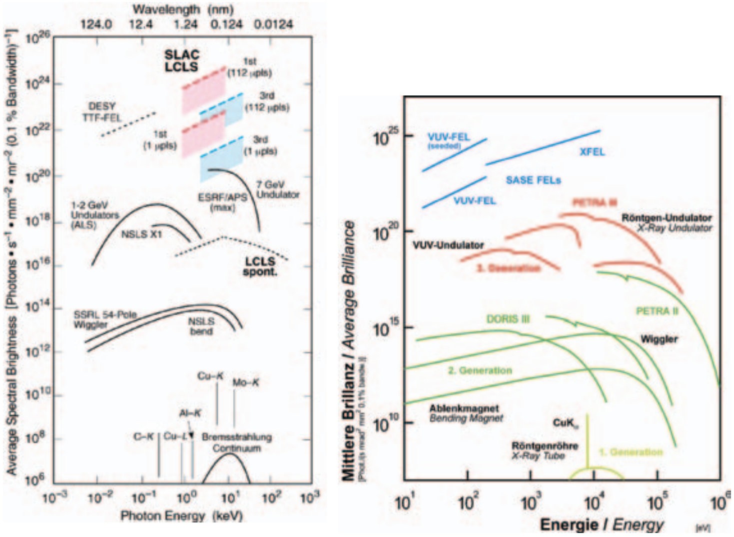

FIGURE 3 Average spectral brightness/brilliance versus photon energy for selected synchrotron light sources in the US (left) and Germany (right) compared with conventional sealed-tube and rotating anode laboratory X-ray sources. Left figure courtesy of Prof. Herman Winick, SSRL; Right figure is from the following URL: http://tesla-new.desy.de/content/relatedprojects/index_eng.html

At a somewhat smaller scale, *beamlines* are available at government-operated synchrotron radiation facilities and neutron sources. In some cases, these beamlines are dedicated to Earth sciences research (e.g. GeoSoilEnviroCARS Sector 13 at the Advanced Photon Source (APS) – www.gsecars.org); however, more typically a fraction of a beamline's scientific program is devoted to this mission. These beamlines often have multiple instruments sharing the experimental time.

Research centers are typically sited at academic institutions and normally house a variety of instruments organized around a particular type of technique or scientific theme. Examples include centers focused on accelerator mass spectrometry, on electron beam characterization, and on secondary ion mass spectrometry.

Finally, *individual instruments* are typically sited at universities; some fraction of their experimental time is made available to outside users. These instruments include electron microprobes/microscopes, X-ray diffractometers, X-ray photoelectron spectrometers, secondary ion mass spectrometers (SIMS), nano-SIMS, tomography equipment, magnetometers, and computational facilities.

WHAT IS A SYNCHROTRON LIGHT SOURCE?

Synchrotron light sources are the most widely used user facilities, and thus it is useful here to briefly describe their characteristics. A synchrotron light source consists of an electron or positron source coupled to a particle accelerator. Charged particles are accelerated and then injected into storage rings where they are further accelerated up to relativistic speeds and to energies ranging from 500 MeV to 8 GeV, depending on ring size. As bend magnets steer the charged particles around the storage ring, energy is lost in the form of synchrotron radiation. The energy of this radiation spans the range from far infrared (0.001 keV or 1240 nm) to hard X-rays (100 keV or 0.0124 nm) and is extremely intense, highly focused, and highly polarized relative to the X-rays produced by a sealed-tube or rotating anode X-ray generator (Winick 1987). As shown in Figure 3, the average brightness of synchrotron light produced by bend magnets, or by special multipole magnetic devices called wigglers or undulators, is six to twelve orders of magnitude greater than that from conventional laboratory X-ray sources. Beamlines are built tangential to the electron or positron orbit of the storage ring and capture the radiation emitted from a bend magnet, wiggler or undulator (Fig. 4). Experimental stations (beamstations) at the end of these beamlines can be configured in many ways to conduct scattering, spectroscopy, or imaging experiments using this extremely bright light. Such light sources make new classes of experiments possible for the first time. Also they greatly enhance the sensitivity of conventional types of studies using IR, UV-visible, and X-ray radiation, and they increase experimental throughput enormously. A number of examples of synchrotron radiation research on Earth and environmental materials are given in Brown et al. (2006).

The cost of a synchrotron light source ranges from less than 100 million to greater than one billion US dollars, depending on its size and complexity. For example, the Advanced Photon Source located at Argonne National Laboratory is a 7 GeV storage ring that produces extremely bright hard X-rays. This source, commissioned in 1996, cost about 1 billion US dollars including the cost of most experimental stations and beamlines (see Fig. 4).

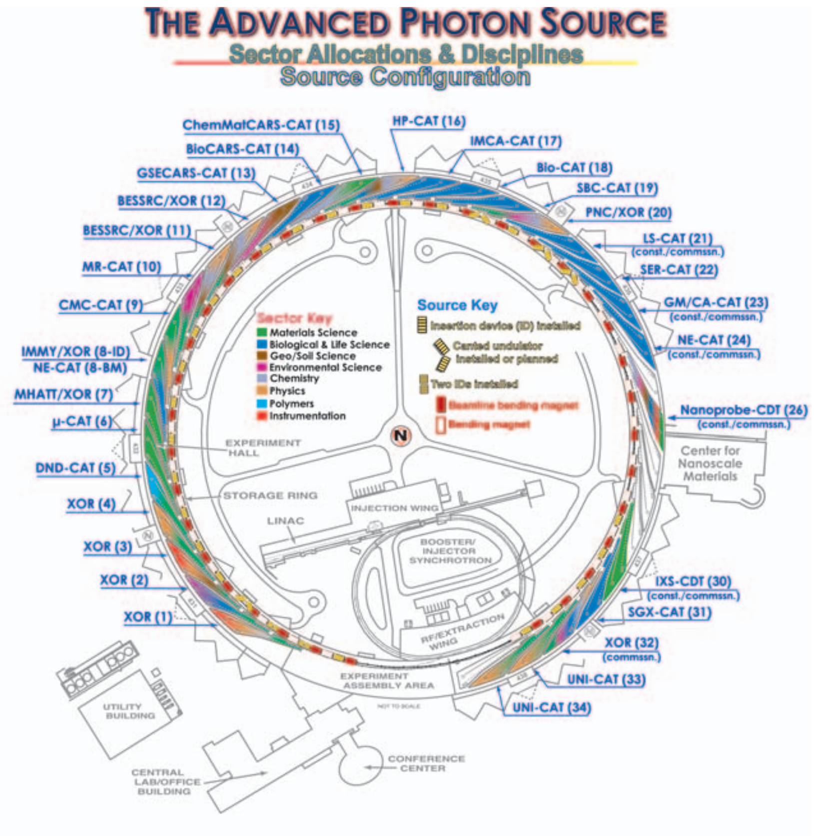

Figure 4 Distribution of beamlines at the Advanced Photon Source, Argonne National Laboratory, Argonne, Illinois, US. The various Collaborative Access Team (CAT) designations are shown for each sector. Figure from www.aps.anl.gov/About/Research_Teams/beamline_websites.htm

The seven US synchrotron light sources currently have approximately 215 beamstations ranging in energy from hard X-ray to soft X-ray/vacuum ultraviolet and far infrared. Among these beamstations, approximately 80 are currently being used by Earth and environmental scientists to various extents, and about 10% of the total beam time at these facilities is used by these two communities (Brown et al. 2004). In Europe, about 275 synchrotron radiation beamstations are available, and a similar proportion of beamstations are used by Earth and environmental science users.

NEUTRON SCATTERING FACILITIES

Neutron scattering centers represent another major type of national user facility that has had a significant impact on Earth sciences research. As shown in Table 1, there are four major neutron scattering facilities in the US and Canada and six in Europe. As pointed out by Sutton et al. (2006), neutron scattering is much more sensitive to light elements, including hydrogen, than X-ray scattering, and it is also sensitive to different isotopes of the same element. The latter characteristic allows neutron scattering experiments on isotopically substituted materials that focus on the structural role of a particular element where a relatively low-abundance isotope scatters more strongly than the naturally abundant isotope of that element. Examples of the types of research carried out at these facilities include neutron scattering on isotopically substituted silicate glasses (Cormier et al. 2001), magnetic ordering in wüstite at high pressure (Ding et al. 2005), and neutron scattering studies of hydrogen in novel clathrate hydrates (Lokshin et al. 2004).

A major disadvantage of neutron scattering relative to X-ray scattering is that large samples are required in neutron scattering because of the relatively low neutron scattering power of nuclei and the low neutron fluxes of existing neutron sources. This situation will change dramatically with the completion of the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in the United States, which will provide neutron fluxes that are 100 to 1000 times more intense than the highest flux neutron source currently existing (the ISIS pulsed neutron source at Rutherford Appleton Laboratory in the United Kingdom). This improvement will permit the use of much smaller samples, which will reduce difficulties in dealing with samples that are compositionally inhomogeneous on the millimeter scale. It will also reduce data collection times and sample throughput substantially. In addition, significant developments in high-pressure neutron diffraction have taken place recently. New opportunities are arising from the construction of the SNS, where a beamline dedicated to high-pressure neutron scattering will be built (see Parise and Brown 2006).

MASS SPECTROMETRY FACILITIES

Mass spectrometry laboratories are available as user facilities, and these include primarily ion microprobe and accelerator mass spectrometry (AMS) instruments. These facilities make it possible for members of the Earth science community to obtain isotopic measurements for studies of the geochronology of the early Earth, cosmochemistry, erosion rates, mantle dynamics, meteorite chronology, and radiocarbon dating, for example. Ion microprobes at least partially supported by the US National Science Foundation Instrumentation and Facilities Program (NSF-IF; www.nsf.gov/geo/ear/if/facil.jsp) include the Northeast National Ion Microprobe Facility at Woods Hole Oceanographic Institution (Massachusetts) and the National Ion Microprobe Facility at the University of California–Los Angeles. In Europe, examples of national ion microprobe facilities include (1) the UK Ion Microprobe Facility, which is located in the Department of Geology and Geophysics, University of Edinburgh, Scotland; (2) the Nordic Ion Microprobe Facility, located at the Swedish Museum of Natural History, Stockholm, Sweden; and (3) the National Ion Microprobe Facility, located at the Centre de Recherches Pétrographiques et Géochimiques, Nancy, France. AMS facilities partially supported by NSF-IF include the Purdue Rare Isotope Measurement Laboratory at Purdue University (Indiana) and the Arizona AMS Laboratory at the University of Arizona. In Europe, more than 15 AMS facilities are currently integrated in a network sponsored by the European Science Foundation (www.stats.gla.ac.uk/iaams/).

SUPERCOMPUTER CENTERS

Over the past 25 years, a number of supercomputer centers have been established at US multipurpose national laboratories by the US Department of Energy (see Table 1). Major Earth, atmospheric, and ocean science problems are being addressed using these supercomputers, including climate modeling, atmospheric chemistry simulations, ocean circulation models, simulation of the early universe, inversion of seismic data to generate 3-D tomographic images of Earth's interior, reactive transport modeling of contaminants in groundwater aquifers, and molecular environmental science problems, including molecular-scale simulations of mineral–water interfaces. A recent National Academy of Sciences report (Graham et al. 2005) presenting a comprehensive overview of supercomputing in the US and abroad can be obtained at http://books.nap.edu/html/up_to_speed/ notice.html. A similar overview describing supercomputing facilities in European countries has been produced by the Academic Research Computing Advanced Facilities Discussion Group Europe (ARCADE: www.arcade-eu.info/index.html). Several of the more recent US supercomputers have blazing speed and enormous storage capacities. For example, the 3328-processor IBM BlueGene/L - eServer Blue Gene Solution 65536 supercomputer at the National Energy Research Scientific Computing Center (NERSC), located at Lawrence Livermore National Laboratory, is currently the most powerful computer on Earth, according to the TOP500 List of Supercomputers (www.top500.org/lists/ 2005/06/); it operates at a maximum speed of 136.8 Teraflops. In addition, Yokohama, Japan, is the site of the Earth Simulator Center, which is built around a NEC Vector SX6 supercomputer that runs at 35.8 Teraflops (currently the fourth-fastest computer on Earth). The purpose of this center is to make quantitative predictions and assessments of variations in the atmosphere, oceans, and solid Earth; to forecast natural disasters and environmental problems; and to conduct simulations relevant to industry, bioscience, and energy. Access to US supercomputers, such as the HP Cluster Platform 6000 rx2600 Itanium2 at PNNL, which runs at a speed of 8.6 Teraflops (currently the 30th-fastest computer on Earth), is available to the scientific community on a peer-reviewed proposal basis. Once approved, investigators can access this supercomputer remotely.

CONCLUDING REMARKS

The impact of user facilities, both experimental and computational, around the world is growing, and these facilities are causing a revolution in the way science is conducted. As an example of the changes such facilities have created over the past 30 years, a modern third-generation synchrotron light source and fast-readout CCD detector make it possible to collect a complete set of X-ray intensity data from a typical large unit cell protein crystal in several minutes. In contrast, one of us (GEB) spent at least five weeks collecting diffraction data on five olivine single crystals with small unit cells in the late 1960s as part of his PhD work. This enormous change in experimental capability is now being felt in many different fields of science, including the Earth sciences.

ACKNOWLEDGMENTS

We are grateful to the governments of the countries that have funded the construction of user facilities and that continue to fund their operation costs. Such facilities are funded in large part by the Office of Science, Department of Energy in the US, by the Ministry of Research in France, and by national scientific funding agencies in other countries (see Table 1 footnotes).

TABLE 1 NORTH AMERICAN, EUROPEAN, AND JAPANESE NATIONAL SCIENTIFIC USER FACILITIES

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
US and Canadian Synchrotron Light Sources				
National Synchrotron Light Source I (X-Ray) (2.8 GeV – 2nd generation)	Brookhaven National Lab (BNL), Upton, NY	DOE-BES (1)	Spectroscopy, scattering, microscopy, tomography	1982
National Synchrotron Light Source II (VUV) (0.8 GeV – 2nd generation)	BNL	DOE-BES	Spectroscopy, scattering, microscopy, tomography, IR, photoemission	1982
Stanford Synchrotron Radiation Laboratory (SSRL) (3 GeV – 3rd generation)	Stanford Linear Accelerator Center (SLAC), Stanford, CA	DOE-BES	Spectroscopy, scattering, tomography, photoemission	1974 (SPEAR2) 2004 (SPEAR3)
Advanced Light Source (ALS) (1.5–1.9 GeV – 3rd generation)	Lawrence Berkeley National Lab (LBNL), Berkeley, CA	DOE-BES	Spectroscopy, scattering, microscopy, tomography, IR, photoemission	1993
Advanced Photon Source (APS) (7 GeV – 3rd generation)	Argonne National Lab (ANL), Argonne, IL	DOE-BES	Spectroscopy, scattering, microscopy, tomography	1996
Cornell High Energy Synchrotron Source (CHESS) (5.5 GeV – 2nd generation)	Ithaca, NY	NSF (2)	Spectroscopy, scattering	1979
Synchrotron Radiation Center (SRC) (0.8–1 GeV – 2nd generation)	Stoughton, WI	NSF	Spectroscopy, scattering, microscopy, photoemission, lithography	1987
Center for Advanced Microstructures and Devices (CAMD) (1.5 GeV – 2nd generation)	Baton Rouge, LA	State of LA	Lithography, spectroscopy, microscopy	1990
Canadian Light Source (CLS) (2.9 GeV – 3rd generation)	University of Saskatchewan, Canada	Canadian Consortium (3)	Spectroscopy, scattering, microscopy, IR scattering	2004
European and Japanese Synchrotron Light Sources				
European Synchrotron Radiation Facility (ESRF) (6.0 GeV – 3rd generation)	Grenoble, France	European Consortium (4)	Spectroscopy, scattering, microscopy, tomography	1994
Synchrotron Radiation Source (SRS) (2 GeV – 2nd generation)	Daresbury Laboratory, Warrington, UK	CCLRC (5)	Spectroscopy, scattering	1980

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
European and Japanese Synchrotron Light Sources (cont'd)				
Hamburger Synchrotronstrahlungslabor HASYLAB (4.5 &12 GeV – 2nd generation)	Deutsche Elektronen-Synchrotron (DESY), Hamburg, Germany	BMBF (6)	Spectroscopy, scattering, microscopy	1993 (DORIS III) (PETRA II)
Berliner Elektronenspeicherring-Gesellschaft für Synchrotron Strahlung (BESSY) (1.7–1.9 GeV – 3rd generation)	BESSY, Berlin-Adlershof, Germany	BMBF	Spectroscopy, scattering, microscopy	1979 (BESSY I) 1998 (BESSY II)
Swiss Light Source (SLS) (2.4 GeV – 3rd generation)	Paul Scherrer Institut, Villigen, Switzerland	Swiss Government (7)	Spectroscopy, scattering	2001
Sincrotrone Trieste (ELETTRA) (2.2–2.4 GeV – 3rd generation)	Trieste, Italy	Italian Consortium (8)	Spectroscopy, scattering	1978
Angströmquelle Karlsruhe (ANKA) (2.5 GeV – 3rd generation)	Forschungszentrum Karlsruhe, Germany	German Consortium (9)	Spectroscopy, scattering, microscopy	2000
MAX II (1.5 GeV – 3rd generation)	Lund University, Sweden	Vk (10), Lund University	Spectroscopy, scattering	1996
Source Optimisée de Lumière d'Energie Intermédiaire du LURE (SOLEIL) (2.75 GeV – 3rd generation)	Saint-Aubin, Gif-sur-Yvette, France	French Consortium (11)	Spectroscopy, scattering, microscopy	To be commissioned in 2006
DIAMOND (3 GeV – 3rd generation)	Rutherford Appleton Laboratory, Didcot, UK	CCLRC (12) and Wellcome Trust	Spectroscopy, scattering, microscopy	To be commissioned in 2007
Photon Factory (KEK) (2.5 GeV – 2nd generation)	Tsukuba, Japan	Japanese Government	Spectroscopy, scattering, microscopy	1982
Spring-8 (JASRI) (8 GeV – 3rd generation)	Nishi Harima, Japan	Japanese Government	Spectroscopy, scattering	1997
US and Canadian High-Flux Neutron Sources				
High-Flux Isotope Reactor (HFIR)	Oak Ridge National Lab (ORNL), Oak Ridge, TN	DOE-BES	Neutron scattering	1966
Intense Pulsed Neutron Source (IPNS)	ANL	DOE-BES	Neutron scattering	1981
Manual Lujan Jr Neutron Scattering Center (Lujan Center)	Los Alamos National Lab (LANL), Los Alamos, NM	DOE-BES	Neutron scattering	1985
Spallation Neutron Source (SNS)	ORNL	DOE-BES	Neutron scattering	Under construction
Canadian Neutron Beam Centre (CNBC)	Chalk River, Ontario, Canada	NRC (13)	Neutron scattering	1950
European High-Flux Neutron Sources				
Institut Laue Langevin (ILL) High Flux Reactor	Grenoble, France	European Consortium (14)	Neutron scattering	1967
ISIS Pulsed Neutron Source	Rutherford Appleton Laboratory, Didcot, UK	CCLRC	Neutron scattering	1985
Laboratoire Léon Brillouin (LLB) Neutron Reactor	Centre d'études nucléaires, Saclay, France	CEA, CNRS	Neutron scattering	1981
Swiss Spallation Neutron Source (SINQ)	Paul Scherrer Institut, Villigen, Switzerland	ETH (7)	Neutron scattering	Under construction
FRM Garching Neutron Reactor	TU Munich in Garching, Germany	BMBF	Neutron scattering	2004 (FRM II)
FRJ-2 Research Reactor	FZJ, Jülich, Germany	BMBF	Neutron scattering	1962
Berlin Neutron Scattering Center (BENSC)	Hans Meitner Institute, Wannsee, Germany	BMBF and Land Berlin	Neutron scattering	1993
US Electron Beam Microcharacterization Centers				
Center for Microanalysis of Materials	University of Illinois, Urbana-Champaign, Urbana-Champaign, IL	DOE-BES	Electron microscopy, surface microanalysis, diffraction, backscattering	NA
Electron Microscopy Center for Materials Research (EMCMR)	ANL	DOE-BES	High-resolution TEM	1981
National Center for Electron Microscopy (NCEM)	LBNL	DOE-BES	High-resolution electron-optical microcharacterization	1983
Shared Research Equipment (SHaRE) Program	ORNL	DOE-BES	Electron beam microcharacterization	NA
Examples of US and European Mass Spectrometry Facilities				
Arizona AMS Laboratory	University of Arizona, Tucson, AZ	NSF	Radiocarbon dating and studies involving other cosmogenic isotopes	1981
Purdue Rare Isotope Measurement Laboratory (PRIME)	Purdue University, West Lafayette, IN	NSF	Radiocarbon dating, exposure dating, erosion rates, meteorite chronology	1989
Northeast National Ion Microprobe Facility (NENIMF)	Woods Hole Oceanographic Institution, Woods Hole, MA	NSF	Solar/presolar processes, early Earth evolution, mantle dynamics	1996
National Ion Microprobe Facility	University of California – Los Angeles, CA	NSF	Geochronology, cosmochemistry	1996
Ion Microprobe Facility	University of Edinburgh, Scotland	NERC	Geochronology, climatology, early Earth evolution, volcanology	1987
National Ion Microprobe Facility	Centre de Recherches Pétrographiques et Géochimiques, Nancy, France	CNRS	Geochronology, cosmochemistry, erosion rates	2001
Nordic Geological Ion Microprobe Facility (NORDSIM)	Swedish Museum of Natural History, Stockholm, Sweden	European Consortium (15)	Geochronology, petrology	2001
US Nanoscale Science Research Centers				
Molecular Foundry	LBNL	DOE-BES	STM, AFM, TEM, mass spectrometers, NMR, e-beam lithography	Under construction
Center for Nanophase Materials Science (CNMS)	ORNL	DOE-BES	Synthesis, characterization, theory, modeling, simulation design	Under construction
Center for Integrated Nanotechnologies (CINT)	LANL and Sandia National Lab (SNL)	DOE-BES	Nanophotonics, nano-electronics, nanomechanics	Under construction

User Facility	Location	Main Sponsor	Currently Available Techniques and/or Research Topics	Year of First Operation
US Nanoscale Science Research Centers (cont'd)				
Center for Functional Nanomaterials (CFN)	BNL	DOE-BES	Fabrication and study of nanoscale materials	Under construction
Center for Nanoscale Materials (CNM)	ANL	DOE-BES	Bio-inorganic interfaces, complex oxides, nanocarbon, nanomagnetism, nanophotonics, nanopatterning, X-ray nanoprobe	Under construction
Other Examples of US and European User Facilities				
William R. Wiley Environmental Molecular Science Laboratory (EMSL)	Pacific Northwest National Laboratory (PNNL)	DOE-BER (16)	Environmental chemistry, surface and interface science, genomic research	1997
Bayerisches Geoinstitut	Universität Bayreuth, Germany	European Union	High-pressure syntheses and experiments, analytical equipment; characterization of material properties	1986
Williamson Research Centre for Molecular Environmental Science	University of Manchester, United Kingdom	NERC (17)	Molecular environmental science	2001
Examples of US, European, and Japanese Supercomputer Centers				
National Energy Research Scientific Computing Center (NERSC)	LLNL	DOE-OS (18)	Climate modeling, materials research, early universe simulations, protein structures	1978
San Diego Supercomputer Center	University of California, San Diego	NSF	Multidisciplinary	1985
Scalable Computing Laboratory	Ames Laboratory, University of Iowa	DOE-ASCR (19)	Multidisciplinary	1989
National Center for Computational Science (NCCS)	ORNL	DOE-OS	Multidisciplinary	1992
Brookhaven Computing Facility (BCF) – Riken BNL Research Center	BNL	RIKEN (20) & DOE	Multidisciplinary	1997
Molecular Science Computing Facility (MSCF)	PNNL (EMSL)	DOE	Molecular environmental science, atmospheric chemistry, systems biology, catalysis, materials science	2003
NASA/Ames Research Center	NASA/Ames Mountain View, CA	NASA	Multidisciplinary	2005
National Leadership Computing Facility (NLCF)	ANL	DOE	Multidisciplinary	2007
Earth Simulator Center	Yokohama, Japan	Japan Agency for Marine-Earth Science and Technology	Atmosphere and ocean sciences, solid Earth	2002
Barcelona Supercomputing Center (BSC)	Universitat Politécnica de Catalunya, Spain	Ministerio de Educación y Ciencia	Earth sciences, biology	2005
Ecole Polytechnique Fédérale de Lausanne	Lausanne, Switzerland	Swiss National Science Foundation	Multidisciplinary	2005

NA Not available

(1) US Department of Energy – Basic Energy Sciences (BES)

(2) US National Science Foundation (NSF)

(3) Alberta Heritage Foundation for Medical Research, Alberta Innovation & Science, Boehringer Ingelheim, Canada Foundation for Innovation, City of Saskatoon, Western Economic Diversification, Ontario Innovation Trust, Saskatchewan Industry and Resources, National Research Council, Natural Resources Canada, SaskPower, University of Alberta, University of Saskatchewan, University of Western Ontario

(4) France, Germany, Italy, United Kingdom, Spain, Switzerland, Belgium, Netherlands, Denmark, Finland, Norway, Sweden

(5) Council for the Central Laboratory of the Research Councils (CCLRC), United Kingdom

(6) Bundesministerium für Bildung und Forschung (Federal Ministry for Education and Research)

(7) Eidgenössische Technische Hochschule (ETH), Zurich

(8) AREA Science Park, Regione Friuli Venezia Giulia, National Institute for the Physics of Matter (INFM), Sviluppo Italia, Consiglio Nazionale delle Ricerche (CNR)

(9) Angströmquelle Karlsruhe, Land Baden-Württemberg

(10) Vetenskapsrådet (Swedish Research Council)

(11) Centre National de la Recherche Scientifique (CNRS), Commissariat à l'Energie Atomique (CEA), France

(12) Council for the Central Laboratory of the Research Councils (CCLRC), United Kingdom

(13) National Research Council (NRC), Canada

(14) France: CEA and CNRS; Germany: Forschungszentrum Jülich (FZJ); United Kingdom: CCLRC

(15) Nordic facility funded jointly by Sweden, Norway, Finland, and Denmark

(16) US DOE, Office of Biological and Environmental Research (BER)

(17) Natural Environment Research Council (NERC), United Kingdom

(18) US DOE, Office of Science (OS)

(19) US DOE, Office of Advanced Scientific Computing Research (ASCR)

(20) Rikagaku Kenkyusho (RIKEN, The Institute of Physical and Chemical Research) of Japan

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