**Advanced
Light
Source**

Advanced Light Source

First-Phase Scientific Program

1993/1994

Lawrence Berkeley Laboratory

August 1992

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Beamline 6.0 (3.9-cm-period undulator)

PRT Biological X-Ray Microscopy

Spokespersons David Attwood, LBL

Scientific Program Beamline 6.0 constitutes the first portion of a proposed national user facility for life scientists. Two complementary microscopes are planned: an imaging microscope for highest spatial resolution (approaching 200 Å) and shortest expokeleyscanning microscope for minimum radiation damage. Both microscopes will cover a spectral region that includes the water window at wavelengths from 2.3 to 4.4 nm.

Soft x-ray microscopy offers the potential for the visualization of a broad range of sub-cellular biological materials and processes at the borderline between the smallest organelles and the largest macromolecules, with feature sizes of the order 10–20 nm. It is complementary to optical and electron microscopies in its combination of resolving power, imaging capability in near-native aqueous environments, and natural contrast mechanisms. Imaging will be accomplished without recourse to fixation, sectioning, or staining, as required for electron microscopy. Dynamic observation of certain processes, including response to stimuli, may for the first time be observable on this spatial scale. The success of dynamic experimentation will depend on sensitivities to radiation dose. In combination, these two microscopes should provide a unique capability for studying a wide class of biological materials and processes.

The initial scientific program will include investigation of the higher order packing of chromatin, the complex of genetic material as encoded by DNA and packaged by histone proteins. As seen in the nucleus at metaphase, the 1-meter length of human chromosome is coiled and folded into a geometrically tight complex only a few microns in size. From electron microscopy, neutron scattering, and other techniques, this packaging of DNA is known to involve 11-nm building blocks called nucleosomes, which are further coiled into 30-nm fibers. The fibers, in turn, are folded into higher order packings of as yet undetermined form. Gene expression—or suppression—is affected by the selective opening of these fibrous structures for transcription of particular regions of the DNA molecule—a gene or a family of genes. The visualization of such material in an aqueous environment, which is not currently possible, directly relates to the human genome project and could find application to the repair of damaged genetic material, preventive drug therapies, etc.

Additional topics to be studied include the cellular secretion process and the role of calcium in medically important systems, such as stressed heart cells, cerebral tissue from patients with Alzheimer's Disease, and animal models for arthritis and osteoporosis.

Beamline 6.0 (3.9-cm-period undulator) (continued)

Parameters

Undulator	
Period	3.9 cm
Length	4.5 m
Number of periods	115
Tuning range at 1.5 GeV	
1st harmonic	22.6–73 Å (548–169 eV)
3rd harmonic	7.5–24.5 Å (1.65 keV–506 eV)
5th harmonic	4.5–14.7 Å (2.75 keV–844 eV)
Peak spectral brightness (1.5 GeV, 400 mA)	4×10^{18} photons @ 45 Å/s/mrad ² /mm ² /0.1% BW
Source size σ rms	64 μ m V, 331 μ m H @ 24 Å
Source divergence σ rms	27 μ rad V, 37 μ rad H @ 24 Å
Beamline	
Branch lines	X-ray microscope (XM) Scanning x-ray microscope (SXM) Coherent optics White light
Water-cooled plane mirror to select branch line (pop-up mirror)	Glidcop™ nickel coating, 3° grazing incidence
Monochromators	Because of the different requirements, each branch line has its own monochromator as part of the instrument.
X-Ray Microscopes (XM and SXM)	
Wavelength	24–45 Å, extended tuning range possible
Spatial resolution	Down to 150 Å
Field of view	30 μ m
Position accuracy of scanning stage (SXM only)	50 Å
Spectral resolving power	
XM	1:300
SXM	Adjustable from 1:100 to 1:3000
Exposure times (300-Å resolution, 1000 × 1000 pixels with 1000 counts/pixel)	
XM	0.02 second
SXM	5 seconds

Beamline 6.0 (3.9-cm-period undulator) (continued)

PRT Members

Name	Affiliation
Prof. David Agard	UC San Francisco
Dr. Erik Anderson	IBM Watson Research Center
Dr. David T. Attwood	Lawrence Berkeley Laboratory
Dr. Rodney L. Balhorn	Lawrence Livermore National Lab.
Dr. Jeffrey Bokor	AT&T Bell Laboratories
Prof. E. Morton Bradbury	UC Davis
Dr. John Brown	Lawrence Berkeley Laboratory
Dr. Thomas F. Budinger	Lawrence Berkeley Laboratory
Dr. Anthony V. Carrano	Lawrence Livermore National Lab.
Dr. Natale Ceglio	Lawrence Livermore National Lab.
Prof. Franco Cerrina	University of Wisconsin, Madison
Dr. Aloke Chatterjee	Lawrence Berkeley Laboratory
Prof. Stephen Cramer	Lawrence Berkeley Laboratory and UC Davis
Dr. Luiz Da Silva	Lawrence Livermore National Lab.
Dr. Richard Freeman	AT&T Bell Laboratories
Prof. Robert Glaeser	UC Berkeley
Prof. Joe Gray	UC San Francisco
Dr. James Grendell	San Francisco VA Medical Center
Prof. Jack Griffith	University of North Carolina
Prof. T.K. Gustafson	UC Berkeley
Dr. Thomas L. Hayes	Lawrence Berkeley Laboratory
Prof. John E. Hearst	Howard Hughes Medical Institute
Dr. Malcolm Howells	Lawrence Berkeley Laboratory
Prof. Chris Jacobsen	SUNY, Stony Brook
Dr. Thomas M. Jovin	Max Planck Institute for Biophysical Chemistry (Germany)
Dr. Yasushi Kagoshima	Photon Factory, KEK
Dr. Dieter Kern	IBM Watson Research Center
Prof. Hiroshi Kihara	Jichi Medical School (Japan)
Dr. Brian M. Kincaid	Lawrence Berkeley Laboratory
Prof. Janos Kirz	SUNY, Stony Brook
Dr. Melvin P. Klein	Lawrence Berkeley Laboratory
Dr. Ronald M. Krauss	Lawrence Berkeley Laboratory
Prof. Charles Liebow	SUNY, Buffalo
Dr. Richard A. London	Lawrence Livermore National Lab.
Prof. Robert I. Macey	UC Berkeley

Beamline 6.0 (3.9-cm-period undulator) (continued)

PRT Members (continued)

Name	Affiliation
Dr. Dennis L. Matthews	Lawrence Livermore National Lab.
Prof. J. Richard McIntosh	University of Colorado
Dr. Hector Medeck	Lawrence Livermore National Lab.
Dr. Mortimer L. Mendelsohn	Lawrence Livermore National Lab.
Dr. Werner Meyer-Ilse	Lawrence Berkeley Laboratory
Prof. Peter Moore	Yale University
Dr. Mario M. Moronne	Berkeley, CA
Dr. Mohandas Narla	Lawrence Berkeley Laboratory
Prof. Jean Paul Revel	California Institute of Technology
Prof. M. Robert-Nicoud	Université Josef Fourier (France)
Prof. Stephen Rothman	Lawrence Berkeley Laboratory and UC San Francisco
Dr. Dietbert Rudolph	Universität Göttingen (Germany)
Prof. Günter Schmahl	Universität Göttingen (Germany)
Prof. John Sedat	UC San Francisco
Dr. Paul Selvin	Lawrence Berkeley Laboratory
Dr. Kunio Shinohara	Tokyo Metropolitan Institute of Medical Science (Japan)
Dr. Gary Sommargren	Lawrence Livermore National Lab.
Dr. David H. Templeton	Lawrence Berkeley Laboratory
Dr. James E. Trebes	Lawrence Livermore National Lab.
Dr. James H. Underwood	Lawrence Berkeley Laboratory
Dr. Yuli Vladimirsky	Louisiana State University
Dr. Makoto Watanabe	Tokyo Metropolitan Isotope Research (Japan)
Prof. Yin Yeh	UC Davis

Beamline 6.3 (bend magnet)

PRT Extreme Ultraviolet and Soft X-Ray (EUV/SXR) Metrology and Standards Facility

Spokesperson James H. Underwood, LBL

Scientific Program Beamline 6.3 is dedicated to highly accurate metrology of x-ray optical components, particularly those used in soft x-ray projection lithography. It will also be used to make measurements on small x-ray optical systems such as microscope or telescope optics.

Researchers around the world are working on EUV/SXR lithographic techniques that allow the production patterning of electronic devices on a scale of about 0.1 μm . One such technique is x-ray projection printing, whereby an oversize mask (4 or 5 times larger than the pattern) is imaged onto the device by a reduction optical system operating in the soft x-ray region. The optical systems now being investigated are based on reflection optics using multilayer-coated mirrors. Good metrological facilities, capable of measurements at the wavelength at which the optics will be used, are absolutely essential for the success of such an effort. Unless such facilities are available, it will not be possible to diagnose the causes of bad performance of an optical element or system. X rays from ALS bend magnets are particularly suited to this application because of their intense brightness, tunability, stability, reproducibility, and wavelengths covering the appropriate range.

Beamline 6.3 will have two branches, instrumented to operate in the energy ranges 50–700 eV and 500–4000 eV. Each branch will be able to perform the same type of measurements as a function of energy within its energy range. These measurements include:

- Reflectance of simple mirrors and multilayer reflectors at all angles of incidence.
- Bidirectional reflectance distribution function (BDRF) measurements.
- Efficiency of diffractive optics such as reflection or transmission gratings, zone plates, and crystals.
- Transmission of thin-film filters or multilayer beam splitters.
- Polarizing effect of devices designed to modify the polarization properties of a beam.
- Efficiency of electronic detectors, photographic films, or resist.
- Optical constants in the x-ray and extreme ultraviolet regions.

These measurements will make possible: (1) the evaluation and calibration of optical components and subsystems; and (2) a study of the science underlying the operation of such devices, for example, surface physics and scattering theory in the case of mirrors and multilayers.

Because the beamline will be dedicated to operation as a standards laboratory, great care must be taken to maintain it in a condition that allows accurate, reliable, absolute measurements without the danger of contaminating the optics being tested. This type of use is incompatible with applications that introduce contamination or calibration shifts, or require reconfiguring the beamline with possible loss of alignment and reproducibility. Thus, the beamline will be a single-purpose facility.

Beamline 6.3 (bend magnet) (continued)

Parameters

Source size, σ (μm)	119 (horizontal) $\times$ 38 (vertical)
Mirror box (with two mirrors)	Splits beam into two branches
Monochromators (2) XUV reflectometer branch Soft x-ray reflectometer branch	50-700 eV 500-4000 eV
Differential pumping sections (2)	One per branch
End stations (2)	Reflectometers consisting of a theta-two theta drive for the sample and detector

PRT Members

Name	Affiliation
Dr. David Attwood	Lawrence Berkeley Laboratory
Dr. Franco Cerrina	University of Wisconsin
Dr. Paul Cowan	Argonne National Laboratory
Mark J. Eckart	Lawrence Livermore National Lab.
Dr. David Gaines	Lawrence Berkeley Laboratory
Dr. Eric Gullikson	Lawrence Berkeley Laboratory
Dr. Donald Hofer	IBM Almaden Research Center
Dr. Jeffrey Kortright	Lawrence Berkeley Laboratory
Dr. Geraint Owen	Hewlett-Packard
Dr. Rupert Perera	Lawrence Berkeley Laboratory
Dr. Dan Seligson	Intel Corporation
Dr. James H. Underwood	Lawrence Berkeley Laboratory
Dr. David Windt	AT&T Bell Laboratories

Beamline 7.0 (5-cm-period undulator)

PRT Undulator Spectromicroscopy Facility at the ALS
Spokesperson Brian Tonner, University of Wisconsin—Milwaukee

Scientific Program Beamline 7.0 will eventually have up to four branches with five end stations. Microfocus I, a very high-spectral-resolution, small-spot ESCA station, will be the first to be installed. It will be used for photoelectron spectroscopy, diffraction, and holography. Next to be commissioned will be Microfocus II, devoted primarily to soft x-ray fluorescence, and Nanofocus I, for soft x-ray microscopy. Nanofocus I will have the capability for UHV scanning photoemission microscopy (SPEM) and scanning transmission x-ray microscopy (STXM) of samples at atmospheric pressures. An x-ray interferometry/focalometry station will be used for quantitative evaluation and development of ultra-resolution x-ray optics.

Spectromicroscopy includes several techniques that combine the spatial resolution of microscopy with the chemical information of spectroscopy. This new field is growing at a very rapid pace, owing to the unique capabilities made possible by the combination of (1) high lateral spatial resolution (from about 200 Å to a few microns) due to advanced x-ray and electron optics, (2) detailed chemical-state information through high energy-resolution spectroscopy, (3) high counting rates that permit kinetic studies of surface reactions, and (4) photoelectron holography, which gives a three-dimensional, real-space image of the atoms neighboring the electron emitter.

The research program will be extremely broad and varied. Some examples of proposed topics for investigation include:

- Electronic properties of mesoscopic structures ranging from atom "strings" grown at atomic steps to highly patterned epitaxial structures, such as planar superlattices or ordered nanoclusters.
- Spatially resolved surface chemical reactions that occur in catalysis, chemisorption, epitaxial film growth, corrosion, tribology, x-ray-induced processes and materials modification, and lithography.
- Film growth kinetics in heteroepitaxy, including metastable phases of magnetic multilayers, role of defects in non-equilibrium growth, island formation, and impurity segregation.
- Lateral electronic inhomogeneities in semiconductor interfaces, including metal overlayer islands that affect Fermi-level pinning and the position dependence of heterojunction band discontinuities with resolution comparable to the Debye screening length of carriers.
- Correlated electron systems, including Fermi-energy spectroscopy of narrow-band ternary alloys, proximity effects in ceramic superconductors, and lateral superconducting-gap variations near metal overlayers.
- Interface formation of fragile materials, such as growth of polymer-semiconductor interfaces or protein adsorption on inorganic substrates.
- Novel interface phenomena, such as chemistry at grain boundaries.

Beamline 7.0 (5-cm-period undulator) (continued)

Parameters

Undulator	
Number of periods	89
Length	4.5 meters
Minimum field	0.16 tesla, $K = 0.75$, magnetic gap = 4.0 cm
Maximum field	0.86 tesla, $K = 4.0$, magnetic gap = 1.6 cm
Maximum power (400 mA, 1.5 GeV)	1.9 kW
Useful harmonics	1, 3, and 5
Maximum rms beam divergence of the first harmonic	$\sigma'_v = 75 \mu\text{rad}$, $\sigma'_h = 78 \mu\text{rad}$
Beamline	
Photon energy	70–1200 eV
Vertical condensing mirror	Gold, 2° grazing, water-cooled, spherical Demagnification factor: 15
Monochromator	
Entrance slit	Stationary, water-cooled, typically $10 \mu\text{m}$, minimum width $5 \mu\text{m}$
Interchangeable diffraction gratings (3)	1. 150 l/mm, laminar profile, gold coating (70–200 eV) 2. 375 l/mm, laminar profile, gold coating (180–500 eV) 3. 950 l/mm, laminar profile, platinum coating (450–1200 eV)
Exit slit	Uncooled, movable, minimum width $5 \mu\text{m}$
Refocusing mirrors	
Vertical	Variable radius, nickel coating, 3° grazing.
Horizontal	Gold, 2° or 3° grazing, interchangeable. Demagnification factor: 14.
Spot size at sample	$50 \mu\text{m} \times 50 \mu\text{m}$ (FWHM)

Beamline 7.0 (5-cm-period undulator) (continued)

PRT Members

Name	Affiliation
Prof. James Allen	University of Michigan
Dr. David Attwood	Lawrence Berkeley Laboratory
Dr. Jeffrey Bokor	AT&T Bell Laboratories
Prof. Stephen Kevan	University of Oregon
Prof. Giorgio Margaritondo	University of Wisconsin, Madison
Prof. Marjorie Olmstead	University of Washington
Dr. Piero Pianetta	Stanford Synchrotron Radiation Lab.
Dr. James Tobin	Lawrence Livermore National Lab.
Prof. Brian Tonner	University of Wisconsin, Milwaukee
Dr. Anthony Warwick	Lawrence Berkeley Laboratory
Prof. Roy Willis, Jr.	Pennsylvania State University

Beamline 8.0 (5-cm-period undulator)

PRT

Core Level Spectroscopies and Spectromicroscopies

Spokespersons

Joachim Stöhr, IBM Almaden Research Center, and Franz Himpsel, IBM T. J. Watson Research Center

Scientific Program

Beamline 8.0 will eventually have five end stations for (1) spectromicroscopy, (2) photoelectron spectroscopy, (3) photoelectron diffraction and holography, (4) photoabsorption and photodissociation of cluster ions, and (5) soft x-ray emission spectroscopy. The branch for emission spectroscopy is discussed separately in the next section.

The research program will begin with well-established techniques, such as core-level photoelectron spectroscopy, near-edge x-ray absorption spectroscopy, and photon-stimulated desorption (PSD), for investigation of the electronic and crystallographic structure of surfaces. For example, core-level shifts of adsorbates at surfaces and interfaces will provide essential information on chemical reactions during the processing of semiconductors. In addition, PSD will measure localized electronic structure on surfaces that contain a variety of surface species, such as semiconductor surfaces subjected to chemical reactions during processing.

The spectromicroscopy station will provide for several spatially resolved techniques: photoelectron microscopy, micro-NEXAFS, soft x-ray fluorescence microscopy, and photon-stimulated ion microscopy. Important surface processes, such as chemical transformation and adsorbate nucleation, which are often governed by local structures such as defects and grain boundaries, can be observed directly. For example, in integrated circuits fabricated by lithography, important surface and interface processes arise from edges and corners.

Spin-polarized photoelectron spectroscopy and magnetic circular dichroism will be used to study magnetism near surfaces and interfaces as part of a program to study information-storage materials. Typical problems include (1) magnitude of magnetic moments and magnetic anisotropies in ultrathin layers on substrates, (2) structurally induced changes in the magnetic moments or the magnetic exchange term due to segregation or interfacial mixing, (3) changes in surface and near-surface magnetic properties due to atomic and molecular adsorbates, and (4) changes in short-range magnetic order as a function of temperature.

Cluster ions are intermediate in size between isolated atoms and solids. Measurements of the electronic and crystallographic structure of cluster ions as a function of size will provide information regarding the elemental bonding-structure relationship of matter. Ion cyclotron resonance will be the primary detection technique for core-level absorption spectroscopy of cluster ions, PSD from cluster ions, and photodissociation of cluster ions.

Beamline 8.0 (5-cm-period undulator) (continued)

Parameters

Undulator	
Number of periods	89
Length	4.5 meters
Minimum field	0.16 tesla, $K = 0.75$, magnetic gap = 4.0 cm
Maximum field	0.86 tesla, $K = 4.0$, magnetic gap = 1.6 cm
Maximum power (400 mA, 1.5 GeV)	1.9 kW
Useful harmonics	1, 3, and 5
Maximum rms beam divergence of the first harmonic	$\sigma'_v = 75 \mu\text{rad}$, $\sigma'_h = 78 \mu\text{rad}$
Beamline	
Photon energy	70–1200 eV
Vertical condensing mirror	Silicon carbide, 2° grazing, water-cooled Demagnification factor: 5
Monochromator	
Entrance slit	Movable, water-cooled, typically 10 μm
Interchangeable diffraction gratings (3)	1. 200 l/mm, laminar profile, gold coating (70–200 eV) 2. 500 l/mm, laminar profile, gold coating (180–500 eV) 3. 1200 l/mm, laminar profile, gold coating (450–1200 eV)
Exit slit	Uncooled, movable
Horizontal refocusing mirror	Gold-coated, 2° grazing

Beamline 8.0 (5-cm-period undulator) (continued)

PRT Members

Name	Affiliation
Dr. J. J. Barton	IBM Watson Research Center
Prof. Thomas Callcott	University of Tennessee
Dr. George Castro	IBM Almaden Research Center
Dr. David L. Ederer	Tulane University
Dr. A. Ellis	IBM Yorktown
Dr. Franz Himpsel	IBM Watson Research Center
Dr. Donald R. Mueller	National Institute for Standards and Technology
Dr. Rupert Perera	Lawrence Berkeley Laboratory

Beamline 8.0 (5-cm-period undulator), branch

PRT

Soft X-Ray Spectroscopy

Spokespersons

Thomas Callcott, University of Tennessee, and David Ederer, Tulane University

Scientific Program

This branch will share the facilities of the "Core Level Spectroscopies and Spectromicroscopies" beamline—from the undulator through the monochromator. It will be used to measure the soft x-ray emission (SXE) and absorption (SXA) spectra of solids. Its unique capabilities are the measurement of photon-excited SXE spectra and joint SXE and SXA spectra.

In soft x-ray absorption spectroscopy (SXA), photons excite electrons from the core level of a particular atom to empty conduction band states. Near the onset of absorption, these SXA spectra provide information about the density of empty states, and thus SXA is, to first order, an empty-state spectroscopy. Soft x-ray emission (SXE) spectra, on the other hand, are produced when valence electrons of the solid make radiative transitions to empty core levels previously produced by energetic electrons or photons. These spectra thus carry information about the filled electron states responsible for bonding in a solid.

Several features of SX spectroscopies are particularly noteworthy. First, the transitions involve atomic core levels, so that SXE (or SXA) spectra provide a measure of the local density of states (LDOS) of filled (or empty) valence states for each element of a solid. This chemical selectivity is particularly valuable for analyzing complex materials containing many elements. Second, the radiative transitions obey dipole selection rules, so that the spectra provide a measure of a local partial density of states (LPDOS) selected for angular-momentum symmetries. This added selectivity has important advantages for making detailed comparisons to theory and for the study of electronic bonding in solids, because electrons in different angular-momentum states have very different bonding behavior. Third, the attenuation lengths of soft x rays of the order of 1000 Å make the SX spectroscopies bulk probes rather than surface probes. Consequently, the LPDOSs of bulk impurities and inclusions, of buried interfaces of multilayer compounds, and of bulk materials beneath oxide or contamination overlayers can be measured.

The initial scientific program will emphasize threshold excitation studies of solid-state systems in which high-intensity, monochromatized photons in a narrow bandwidth excite specific atoms in a precisely known way, and emission spectroscopy of the same atoms measures the local response of the valence electrons to the local excitation. Systems to be investigated include isolated impurities in semiconductors (doping impurities, chalcogens, and transition metals in Si, Si in GaAs, and GaAs), ferromagnetic materials (Fe and others) with spin-split energy bands, and molecules chemisorbed on surfaces (O₂, N₂, CO, and other molecules containing O, N, C, or F).

Beamline 8.0 (5-cm-period undulator), branch (continued)

Parameters

Undulator	
Number of periods	89
Length	4.5 meters
Minimum field	0.16 tesla, $K = 0.75$, magnetic gap = 4.0 cm
Maximum field	0.86 tesla, $K = 4.0$, magnetic gap = 1.6 cm
Maximum power (400 mA, 1.5 GeV)	1.9 kW
Useful harmonics	1, 3, and 5
Maximum rms beam divergence of the first harmonic	$\sigma'_v = 75 \mu\text{rad}$, $\sigma'_h = 78 \mu\text{rad}$
Beamline	
Photon energy	70–1200 eV
Vertical condensing mirror	Silicon carbide, 2° grazing, water-cooled Demagnification factor: 5
Monochromator	
Entrance slit	Movable, water-cooled, typically 10 μm
Interchangeable diffraction gratings (3)	1. 200 l/mm, laminar profile, gold coating (70–200 eV) 2. 500 l/mm, laminar profile, gold coating (180–500 eV) 3. 1200 l/mm, laminar profile, platinum coating (450–1200 eV)
Exit slit	Uncooled, movable
Horizontal refocusing mirror	Gold-coated, spherical, 4° grazing
Spot size at sample	1 mm (vertical) $\times$ 100 μm (horizontal)

PRT Members

Name	Affiliation
Prof. Edward T. Arakawa	Oak Ridge National Laboratory
Prof. Thomas Callcott	University of Tennessee
Dr. David L. Ederer	Tulane University
Dr. Donald R. Mueller	National Institute for Standards and Technology
Dr. Rupert Perera	Lawrence Berkeley Laboratory

Beamline 9.0 (8-cm-period undulator)

PRT Photoprocesses in Atoms, Molecules, and Ions
Spokesperson Denise Caldwell, University of Central Florida

Scientific Program Beamline 9.0 will initially have one branch for atomic and molecular photoelectron, photoionization, and fluorescence spectroscopy. The spectral region extends from that available with lasers at the low-energy end to the carbon K edge at the high-energy end—a range covering thresholds and the outer core levels of atoms, molecules, and ions.

Major research topics planned include:

- *High-resolution electron spectrometry.* Analyses of photoprocesses involving atoms and molecules in the gas phase to produce electrons, photons, ions, and/or molecular fragments in various internal states have been among the most productive uses of synchrotron radiation. Attention will be given to the finer details of electronic correlation in simple atoms and molecules, particularly to "outer core" electrons lying just below the valence shell. Within this energy regime, electron correlations play a significant role, leading to much structure directly at threshold. Open-shell atoms and other tenuous species will be investigated. Experimental techniques include high-resolution and angle-resolved threshold time-of-flight (TTOF) photoelectron spectroscopy.
- *Coincidence measurements.* At higher excitation energies, angular-resolved electron-electron and electron-ion coincidence measurements can isolate the influence of electron correlation in dynamical phenomena because of their ability to follow fragmentation patterns in great detail.
- *Fluorescence detection.* The ability to measure small energy differences between photons emitted from different ion states (fluorescence detection) will be required to increase the spectral resolution in photoionization spectroscopy beyond that readily obtained with electron detection. Studies of branching ratios and alignment of excited states are planned.
- *Electron correlation at high excitation energies.* Very-high-resolution studies of helium and of other atomic systems will be carried out by photoionization, TTOF, and angle-resolved TTOF spectroscopy in order to detect ultra-narrow double-excitation resonances that are sensitive tests of theories for electron correlation.
- *Core excitation and femtosecond dynamics.* Selective core excitation of specific carbon K-edge features in small molecules and the analysis of decay products by time-of-flight mass spectrometry ("state-to-state" photodissociation) will give a detailed microscopic understanding of which chemical bonds are broken in a given resonant excitation and how the electronic charge is distributed in the process.
- *High-energy molecular spectroscopy.* Absorption, photoionization, and photoelectron spectroscopy of core levels in free and adsorbed molecules will be used to determine changes in geometry, bond length, and electronic structure due to the adsorption process.

Beamline 9.0 (8-cm-period undulator) (continued)

Parameters

Undulator	
Number of periods	55
Length	4.5 meters
Minimum field	0.40 tesla, $K = 3.0$, magnetic gap = 4.0 cm
Maximum field	1.0 tesla, $K = 7.5$, magnetic gap = 1.9 cm
Maximum power (400 mA, 1.5 GeV)	2.6 kW
Useful harmonics	1, 3, and 5
Maximum rms beam divergence of the first harmonic	$\sigma'_v = 150 \mu\text{rad}$, $\sigma'_h = 150 \mu\text{rad}$
Beamline	
Photon energy	20–300 eV
Horizontal focusing mirror	Water-cooled, 3° grazing, has two coatings to absorb photons at different energies: Carbon (20–260 eV) and Nickel (up to 300 eV)
Vertical condensing mirror	Nickel, 4.5° grazing, water-cooled, spherical Demagnification factor: 15
Monochromator	
Entrance slit	Stationary, water-cooled, typically $10 \mu\text{m}$, minimum width $5 \mu\text{m}$
Interchangeable diffraction gratings (3)	1. 385 l/mm, laminar profile, gold coating (20–60 eV). 2. 900 l/mm, laminar profile, gold coating (47–140 eV). 3. 2100 l/mm, laminar profile, nickel coating (109–300 eV).
Exit slit	Uncooled, movable, minimum width $5 \mu\text{m}$
Vertical refocusing mirror	Variable radius, nickel coating, 3° grazing.
Spot size at sample	$50 \mu\text{m} \times 800 \mu\text{m}$ (FWHM)

Beamline 9.0 (8-cm-period undulator) (continued)

PRT Members

Name	Affiliation
Group A	
Dr. Yoshiro Azuma	Argonne National Laboratory
Prof. Thomas Baer	University of North Carolina
Prof. Michael Bancroft	University of Western Ontario (Canada)
Dr. Nora Berrah-Mansour	Argonne National Laboratory
Dr. C. Denise Caldwell	University of Central Florida
Dr. Tricia Ferrett	Carleton College
Prof. David Hansen	State University of New York, Stony Brook
Prof. Robert G. Hayes	University of Notre Dame
Prof. José Jiménez-Mier	UNAM (Mexico)
Dr. Manfred O. Krause	Oak Ridge National Laboratory
Dr. Dennis W. Lindle	University of Nevada, Las Vegas
Dr. James A. R. Samson	University of Nebraska
Dr. David A. Shirley	Pennsylvania State University
Dr. Michele Siggel	Daresbury (UK)
Dr. Steve Southworth	National Institute of Standards and Technology
Dr. Scott B. Whitfield	Fritz-Haber Institut der Max-Planck Gesellschaft (Germany)
Group B	
Dr. A.J. Arko	Los Alamos National Laboratory
William T. Carnall	Argonne National Laboratory
Dr. Carlos Colmenares	Lawrence Livermore National Lab.
Dr. Larry Cox	Los Alamos National Laboratory
Dr. Norman Edelstein	Lawrence Berkeley Laboratory
Dr. Walton P. Ellis	Los Alamos National Laboratory
Dr. J. Fuger	European Institute for Transuranium Elements (Germany)
J.K. Gibson	Oak Ridge National Laboratory
Dr. R.G. Haire	Oak Ridge National Laboratory
P.D. Kleinschmidt	Los Alamos National Laboratory
Dr. Manfred O. Krause	Oak Ridge National Laboratory
Claude M. Lyneis	Lawrence Berkeley Laboratory
R. Mlekody	Oak Ridge National Laboratory
Dr. J.R. Naegele	European Institute for Transuranium Elements (Germany)

Beamline 9.0 (8-cm-period undulator) (continued)

PRT Members (continued)

Name	Affiliation
Group B (continued)	
Mr. J.R. Peterson	University of Tennessee
Dr. J.W. Ward	Los Alamos National Laboratory
Group C	
Dr. Carmen Cisneros	UNAM (Mexico)
Prof. Thomas J. Morgan	Wesleyan University
Dr. Alfred S. Schlachter	Lawrence Berkeley Laboratory
Dr. Dieter Schneider	Lawrence Livermore National Lab.

Beamline 9.3.1 (bend magnet)

PRT

X-Ray Spectroscopy at the ALS

Spokesperson

Dennis Lindle, University of Nevada, Las Vegas

Scientific Program

This beamline, a branch from bend-magnet port 9.3, will be unique at the ALS in the early years of operation with its use of a double-crystal monochromator for high-resolution gas-phase, solid-state, and biological spectroscopy in the multi-keV photon-energy range from 700 eV to 6 keV.

The overall goal of the research program is to determine the basic physical and chemical effects of primary importance to core-level processes in atoms, molecules, ions, and condensed matter. The program spans four general areas:

- *Atomic, molecular, and optical science.* Polarization and angular distribution in x-ray emission spectroscopy will be used to investigate molecular geometry and orientation and molecular-orbital symmetry. The Auger-electron resonant-Raman scattering effect makes it possible to decompose x-ray absorption edges into individual components and map the widths and shapes of core hole-state energy levels. Photoelectron spectroscopy will be used to investigate photoionization of atoms and of molecules. Ion-yield spectroscopy will be used to unravel complicated decay patterns associated with core-hole creation by x-ray absorption.
- *Surface and interface science.* The new technique of photoelectron holography will be applied to surfaces and adsorbed species with elements having K edges in the 1 to 3 keV range (Al, Si, P, S, Cl, etc.). Holographic images of the environment around the emitting atoms will be compared to those obtained with the scanning tunneling microscope, an instrument with complementary strengths and weaknesses, to obtain reliable overall site geometries. Energy-dependent photoelectron diffraction will be added to obtain quantitative values of structural parameters (e.g., bond lengths).
- *Biology.* Experiments will emphasize enzymes containing metals in very low concentrations (100 ppm or less), such as Mo or Fe in nitrogenase or Mn in photosystem II. In addition to a general EXAFS program on metalloproteins, time-resolved "flow-pump-probe" x-ray absorption spectroscopy (EXAFS or XANES) will be used to monitor photochemical reactions initiated by a laser. Site-selective x-ray fluorescence spectroscopy will be used to investigate metalloprotein oxidation states.
- *X-ray optics.* Robust, high-resolution, multilayer-coated, x-ray diffracting elements in the photon-energy range from 700 eV to 2 keV will be developed. Multilayer-coated diffracting elements that operate at grazing angles of incidence to pass circularly polarized x-rays will be developed.

Beamline 9.3.1 (bend magnet) (continued)

Parameters

Source size, σ (μm)	119 (horizontal) $\times$ 38 (vertical)
Photon energy	700 eV–6 keV
Photon flux	10^{11} photons/s in a ≤ 0.5 -eV bandpass
Collimating mirror Substrate Coating Grazing-incidence angle (deg)	Metal Nickel 0–3
Monochromator Figure Bragg angle (deg) Silicon (111) Resolving power ($E/\Delta E$) Germanium (111) Resolving power ($E/\Delta E$) YB ₆₆ (400) Resolving power ($E/\Delta E$) Beryl (10 $\bar{1}0$) Resolving power ($E/\Delta E$) Maximum horizontal angular acceptance (mrad) for all crystals	Double crystal Planar 14–70 7000–8000 3500–4000 2000 2500–4000 8.0
Focusing mirror Substrate Coating Grazing-incidence angle (mrad) Magnification	Metal Nickel 10–15 1:1
Spot size	Variable from 0.1 to 1 mm ² , depending on horizontal acceptance

Beamline 9.3.1 (bend magnet) (continued)

PRT Members

Name	Affiliation
Atomic, Molecular, and Optical Science	
Dr. Bernd Crasemann	University of Oregon
Dr. Dennis W. Lindle	University of Nevada, Las Vegas
Dr. Rupert Perera	Lawrence Berkeley Laboratory
Dr. Alfred S. Schlachter	Lawrence Berkeley Laboratory
Dr. David A. Shirley	Pennsylvania State University
Surface and Interface Science	
Dr. Charles S. Fadley	Lawrence Berkeley Laboratory and UC Davis
Dr. Zahid Hussain	Lawrence Berkeley Laboratory
Dr. David A. Shirley	Pennsylvania State University
Biology	
Dr. Stephen Cramer	Lawrence Berkeley Laboratory and UC Davis
X-Ray Optics	
Dr. Brian Kincaid	Lawrence Berkeley Laboratory
Dr. Rupert Perera	Lawrence Berkeley Laboratory

Beamline 9.3.2 (bend magnet)

PRT

High-Resolution Synchrotron Radiation Spectroscopy

Spokesperson

Charles Fadley, LBL and University of California at Davis

Scientific Program

Beamline 9.3.2, another branch from bend-magnet port 9.3, was formerly in operation as Beamline 6-1 at the Stanford Synchrotron Radiation Laboratory. It will be wavelength-tunable over a wide spectral range, while providing ultra-high spectral resolution for a wide variety of photon and electron spectroscopies.

The research program will include a broad range of problems in materials and chemical sciences. The major sectors of the research program include:

- *High-energy chemical physics.* Threshold photoionization of free molecules will be studied by means of time-of-flight photoelectron spectroscopy, with special attention to electron-correlation effects and vibrational fine structure. Surface structures will be determined by high-resolution angle-resolved photoemission extended fine structure (ARPEFS) with special attention to surface-atom relaxation on clean surfaces and the use of chemical shifts to distinguish structures containing the same atom in different chemical environments. Photoionization shape resonances in condensed matter will be investigated by means of the polarization dependence of angle-resolved photoelectron spectroscopy of core levels in molecular adsorbates, ligands of solid coordination compounds, and ionic crystals.
- *Surface, interface, and nanostructure studies.* Research will combine the use of synchrotron radiation with complementary techniques to study the electronic, atomic, and magnetic structures of technologically important metal and semiconductor surfaces, as well as interface, nanostructure, and microcluster growth on these surfaces. High-resolution angle-resolved photoelectron spectroscopy, including chemical-state-specific surface structure determinations from angle-resolved core-level emission (photoelectron diffraction and photoelectron holography) will be emphasized. Photoelectron spectroscopy and diffraction will be combined with scanning tunneling microscopy and spectroscopy to characterize nanostructure morphologies and statistical size distributions.
- *Interaction of solvated ions with metal surfaces.* The co-adsorption of water with either alkali metal or halide atoms produces a solvated ion structure that appears to be directly analogous to the structure of the ionic double layer at the metal-solution interface. The structure of the water solvation shell around adsorbed ions and the deformation in the positions of metal atoms around the ion site will be studied by means of ARPEFS.
- *Molecules adsorbed on surfaces.* The electronic structure of reaction intermediates on transition-metal surfaces will be studied by ultraviolet and x-ray photoelectron spectroscopy and by high-resolution angle-resolved Auger electron spectroscopy. Near-edge absorption fine structure (NEXAFS or XANES), surface extended x-ray absorption fine structure (SEXAFS), and photoelectron diffraction will be used to study interatomic distances and molecular orientations.

Beamline 9.3.2 (bend magnet) (continued)

Parameters

Source size, σ (μm)	119 (horizontal) $\times$ 38 (vertical)
Photon energy	30–1500 eV
Horizontal focusing mirror	Tangential cylinder, water-cooled
Substrate	Glidcop
Coating	Gold
Grazing incidence angle (deg)	2.5
Vertical focusing mirror	Spherical
Substrate	Glidcop
Coating	Gold
Grazing incidence angle (deg)	3.0
Monochromator	SGM
Entrance slit	
Location	Movable
Opening	Precision adjustable from 5 μm to 2 mm
Diffraction gratings	Three interchangeable, gold-coated spherical gratings: 100 l/mm (30–200 eV, water-cooled) 600 l/mm (180–820 eV) 1200 l/mm (370–1500 eV, water-cooled)
Resolving power ($E/\Delta E$)	10,000 (using 10- μm entrance and exit slits)
Exit slit	
Location	Movable
Opening	Precision adjustable from 5 μm to 2 mm
Refocusing mirror	
Figure	Toroidal
Substrate	Quartz
Coating	Gold
Grazing incidence angle	2.0°
Spot size at sample (FWHM)	100 μm (H) $\times$ 800 μm (V)
Photon intensity at sample	5×10^{10} photons/s (0.01% bw) at 500 eV

Beamline 9.3.2 (bend magnet) (continued)

PRT Members

Name	Affiliation
Dr. Charles S. Fadley	Lawrence Berkeley Laboratory and UC Davis
Dr. Philip Heimann	Lawrence Berkeley Laboratory
Dr. Zahid Hussain	Lawrence Berkeley Laboratory
Dr. Philip N. Ross, Jr.	Lawrence Berkeley Laboratory
Dr. David A. Shirley	Pennsylvania State University

Beamline 10.3 (bend magnet)

PRT X-Ray Microprobe Bend-Magnet Beamline for Materials Science

Spokesperson Albert Thompson, LBL

Scientific Program Beamline 10.3 will have two white-radiation branches that enter the same hutch. One experimental station will be dedicated to materials science experiments; the other will be used to develop advanced microprobe instrumentation.

Elemental analysis by means of a high-energy x-ray microprobe using focused x rays from a synchrotron source is characterized by high sensitivity, spatial resolution approaching 1 μm , ease of operation, and the ability to examine samples in a variety of environments. Elements are quantitatively and nondestructively detected by means of the characteristic fluorescent x rays emitted by the irradiated sample. Their photon energy identifies the element, and their intensity measures its quantity. At present, elemental sensitivity of the microprobe reaches the femtogram level for elements from potassium to zinc in the periodic table. Additional detection sensitivity is imparted by the ability to select the x-ray photon energy to avoid excitation of interfering fluorescence from elements other than those being sought. A major advantage of the x-ray microprobe is that the specimen does not have to be kept in vacuum or subjected to special contrast-enhancing preparation. With tomographic techniques, it is possible to obtain depth distributions of elements within samples.

The research planned for this beamline emphasizes quantitative, spatially resolved trace-element analysis of materials science samples. The trace element distribution within samples often determines their structural properties. The x-ray microprobe will provide a nondestructive, sensitive tool for two-dimensional distributions of trace elements with a spatial resolution of 1 μm . The microprobe will be particularly useful for the characterization of defects and cracks in ceramic materials. Of particular interest are (1) cleavage or ductile fracture in bulk ceramics, such as partially stabilized zirconia, alumina, silicon carbide, and silicon nitride, or in ceramic composites, such as silicon carbide in alumina; (2) subcritical crack growth by stress corrosion or fatigue; and (3) fracture at the ceramic/metal interface in metal-matrix composites, such as $\text{SiC-Al}_2\text{O}_3$. It is particularly important to determine whether crack processes occur in the bulk or only at the surface.

Additional applications of the microprobe occur in materials science (distribution of doping materials in semiconductors), geology (composition of inclusions in geological materials), environmental science (profiles of pollutants in animal tissue), biology (trace element analysis of biological materials), and archeology (analysis of ancient documents and artwork).

Beamline 10.3 (bend magnet) (continued)

Parameters

Source size, σ (μm)	119 (horizontal) $\times$ 38 (vertical)
Photon Energy	2–10 keV
Horizontal focusing mirror	Elliptical
Substrate	Nickel
Coating	Tungsten-carbon multilayer
Grazing incidence angle	Variable
Vertical focusing mirror	Elliptical
Substrate	Nickel
Coating	Tungsten-carbon multilayer
Grazing incidence angle	Variable
Spot size at sample (FWHM)	1 μm $\times$ 1 μm
Photon intensity at sample	$>10^{13}$ photons/s (10% bw) at 10 keV

PRT Members

Name	Affiliation
Karen Chapman	Lawrence Berkeley Laboratory
Dr. Lutgard DeJonghe	Lawrence Berkeley Laboratory
Robert L. Giauque	Lawrence Berkeley Laboratory
Dr. Gene Ice	Oak Ridge National Laboratory
Dr. Dale L. Perry	Lawrence Berkeley Laboratory
Dr. Philip N. Ross	Lawrence Berkeley Laboratory
Dr Carolyn S. Rossington	Lawrence Berkeley Laboratory
Dr. Richard Ryon	Lawrence Livermore National Laboratory
Dr. Cullie Sparks	Oak Ridge National Laboratory
Ron Tackaberry	Lawrence Berkeley Laboratory
Dr. Albert C. Thompson	Lawrence Berkeley Laboratory
Dr. James H. Underwood	Lawrence Berkeley Laboratory
Dr. Marvin J. Weber	Lawrence Livermore National Laboratory

Beamline 12.0 (5.5- or 8.0-cm-period undulator)

PRT

Extreme Ultraviolet/Soft X-Ray (EUV/SXR) Interferometry Facility

Spokesperson

Natale M. Ceglio, Lawrence Livermore National Laboratory

Scientific Program

As the semiconductor industry begins to consider the challenge of lithography and pattern transfer at minimum dimensions below 0.25 μm , it has become increasingly clear that advanced x-ray optical techniques are required for the evolution of semiconductor manufacturing. In particular, extreme EUV/SXR projection lithography has emerged as an important candidate technology. The requirements for optical components and systems for soft x-ray lithography are extremely stringent and beyond the current state of the art in optical fabrication and testing. For soft x-ray lithography to be developed in time to meet the industrial market window (approximately the year 2000), an aggressive program to advance x-ray optical systems is needed. A prerequisite for the advancement of soft x-ray optical technology is the development of optical testing and characterization at soft x-ray wavelengths.

The goal of this scientific program is to develop the metrological capability for measuring the surface figure of individual reflective optics and the wavefront from assembled systems with the accuracy required for EUV/SXR projection lithography. The optics will be coated with angle- and wavelength-sensitive multilayer reflection coatings. Consequently, their surfaces must be tested at the wavelength of operation. Partially coherent undulator radiation from 40 $\text{\AA}$ to 200 $\text{\AA}$ will make the characterization of high-numerical-aperture, multilayer-coated optical elements possible.

An essential part of the program is the development of EUV/SXR interferometry, which requires spatially coherent radiation at the coating wavelength. The interferometers under consideration for this program are of the common-path configuration, in which the reference and measurement beams travel nearly identical optical paths through the interferometer. Both are reflected from the optic under test. The advantages of this configuration are insensitivity to vibration, relaxed requirements for spatial and temporal coherence, and a minimum number of components. Also no reference surface or high-quality beam splitters are required.

Beyond the need for testing optics used in EUV/SXR projection lithography, this program will serve other purposes. As scientific communities, such as material sciences and x-ray astronomy, pursue high-resolution, reflective optics at these wavelengths, they too will benefit from this test facility. The very fact of its availability is expected to prompt the development of optics with higher spatial resolution, for example, for materials science surface probes and for EUV/SXR telescopes used in solar physics. Furthermore, the facility could be used to test and evaluate new concepts based on diffractive optics and holographic projection techniques.

In addition to the "production" branch of Beamline 12.0 for interferometric testing of optics, two additional branches are planned:

- *X-ray interferometry development station.* For the continued development of interferometer concepts especially for x-ray lithographic purposes. Once perfected, these ideas would be used on the production branch line.

Beamline 12.0 (5.5- or 8.0-cm-period undulator) (continued)

Scientific Program (continued)

- *ELIV coherent x-ray optics station.* For the rapid assembly and evaluation of coherent optics experiments. For example, experiments could be conducted to measure the effects of long exposure to soft x rays on multilayer mirrors to determine the extent of degradation by radiation damage, contamination, or other mechanisms.

Parameters

Undulator (two leading candidates: 5.5- and 8.0-cm period)		
	U5.5	U8.0
Number of periods	98	61
Length (meters)	4.5	4.5
K (magnetic deflection parameter)*	1.54 @ 70 Å 2.48 @ 130 Å	1.01 @ 70 Å 1.9 @ 130 Å
Total power (watts)*	252 @ 70 Å 649 @ 130 Å	50 @ 70 Å 179 @ 130 Å
Beamline		
Photon energy/wavelength range	60–280 eV (200–44 Å)	
Principal energies/wavelengths	95 eV and 175 eV (130 Å and 70 Å)	
Horizontal beam-defining aperture	Water-cooled	
Horizontal focusing mirror	2° grazing, water-cooled	
Vertical focusing mirror	2° grazing	
Monochromator	Variable line space grating	
Entrance slit	Stationary, uncooled	
Diffraction grating		
Exit slit	Stationary, uncooled	

* These entries apply to the fundamental $n = 1$ of the two undulators.

Beamline 12.0 (5.5- or 8.0-cm-period undulator) (continued)

PRT Members

Name	Affiliation
Dr. William Arnold	Advanced Micro Devices
Dr. David Attwood	Lawrence Berkeley Laboratory
Dr. John Bjorkholm	AT&T, Holmdel, NJ
Dr. Jeffrey Bokor	AT&T, Holmdel, NJ
Dr. John Brunning	GSA Tropel
Dr. John Carruthers	Intel
Dr. Natale Ceglio	Lawrence Livermore National Lab.
Dr. Franco Cerrina	University of Wisconsin, Madison
Dr. Charles Gwyn	Sandia National Laboratories, Albuquerque
Dr Keith Jackson	Lawrence Berkeley Laboratory
Dr. David Markel	Ultratech Stepper
Dr. Andrew Neureuther	UC Berkeley
Dr. William Oldham	UC Berkeley
Dr. Daniel Seligson	Intel
Dr. Lynn Seppala	Lawrence Livermore National Lab.
Dr. William Siegle	Advanced Micro Devices
Dr. Gary Sommargren	Lawrence Livermore National Lab.
Dr. Donald Sweeney	Sandia National Laboratories, Livermore
Dr. James Underwood	Lawrence Berkeley Laboratory
Dr. Anthony Warwick	Lawrence Berkeley Laboratory
Dr. Martin Zombeck	Harvard-Smithsonian Observatory

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