

with an even number of photons. To satisfy angular-momentum conservation, then, the spin orientations of the incoming and diffracted spin- $1/2$  electrons had to be the same. Batelaan noted, however, that things are different if electrons encounter two counterpropagating, suitably polarized lasers, one of whose wavelength is half that of the other. In that case, electrons can flip their spins by interacting with an odd number of photons. Electrons whose spins are flipped up receive momentum kicks in the opposite direction to those whose spins are flipped down.

Light gratings split electron beams coherently, and it may be possible to use them as splitting, bending, and recombining elements for an electron interferometer. Electron interferometers are not new, but the interferometers currently being used split electron beams of higher energies than those used by the Nebraska group. The lower energies allowed by light gratings would provide physicists with greater sensitivity to a variety of interactions, such as electron-atom forward scattering or the interactions of electrons with metallic surfaces.

The applications just described may not come to fruition. The experimental parameters that yield clean electron diffraction patterns are not suited to studying quantum chaos with electrons, and it remains to be seen if, for instance, relaxing the focus of the electron beam will allow for interesting studies. According to Batelaan, the spin separator he imagines may require prohibitively high laser intensities. But Mark Kasevich of Yale University notes that no one can predict how the field of quantum optics will evolve: Perhaps light gratings will see applications in quantum devices or in quantum computing. "We're weaving some kind of quilt," he explains, "and it's hard to know where the connections are going to be made in even five years. Bringing the energy down for the coherent optics is pushing things to a new regime."

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## Gamble Pays Off at the Advanced Light Source

The workers below are lowering one of three new superconducting bending magnets into the beamline at Lawrence Berkeley National Laboratory's Advanced Light Source this past August. These new magnets have added hard x rays to the accelerator's offerings of synchrotron radiation beams. The demand for such x-ray sources has grown explosively in recent years, thanks primarily to work on protein crystallography.

The ALS was built more than a decade ago as a high-brightness synchrotron radiation facility optimized to operate in the vacuum ultraviolet (VUV) and soft x-ray spectral regions (with photon energies ranging from 10 eV to 1.5 keV). Providing such radiation is still the lab's main mission, and it currently serves 1000 users per year. Soon after the facility was completed, however, ALS designers had an idea of how they might add some higher energy beamlines (up to 40 keV) without sacrificing the accelerator's existing capabilities.

Synchrotron radiation is produced as bending magnets steer electrons around the curves of the storage ring. It can also be produced by inserting devices such as undulators or wigglers into some of the straight sections of the ring. (These devices cause electrons to wiggle back and forth and hence radiate.) The standard way to add a hard x-ray capability to an existing storage ring is to insert a high-field wiggler, but the number of straight sections available for that purpose at the ALS is very limited.

ALS designers proposed instead to produce hard x rays in bending magnets. The peak energy radiated by electrons as they curve through a magnetic field is proportional to the square of the electron energy and to the magnetic field. At the ALS, the beam energy is fixed at 1.9 GeV, so the designers suggested raising the maximum photon energy by increasing the field strength of the bending magnet. In place of three of the normal 1.3-T bending magnets used at the ALS for VUV or soft x-ray beams, they proposed three 5-T superconducting magnets to yield hard x-ray beams. The three "superbend" magnets, can feed 12 user beamlines.

How could such superbend magnets be incorporated into an existing storage ring with minimal reconfiguration? The chief constraint was one of space: The new 5-T magnets were not allowed to bend the circulating electron beam by more than  $10^\circ$ , the bending angle given to electrons by the magnets that were being replaced. Thus, each of the three new magnets, while four times stronger, was only one fourth as long.

After years of studying this plan, the Berkeley lab started its Superbend Project in 1998, with David Robin at the helm. By this past August, the team was ready to implement the retrofit. It was a gamble, though, because the superbend magnets had to be added without affecting the established performance of the accelerator in the VUV and soft x-ray regions. And the shutdown for retrofit work had to be short, to avoid interruption of the scheduled experiments.

The changeover was made in just two weeks, and the first experiment on one of the new hard x-ray beams began in early October. Experiments are being built on another five of the new beamlines, and proposals are being made for the remaining six. The higher-energy beams are brighter than those produced by the normal magnets, but not as bright as the undulator beams at Argonne National Laboratory's Advanced Photon Source, which was specifically designed for the higher-energy radiation. Still, said Robin, the size and flux of the new ALS beams are well suited to protein crystallography and other experiments.

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