between the cyclotron motion and ν_a by imposing a small inhomogeneity on the magnetic field. By girdling the ring electrode with a nickel ring, they distorted the magnetic field in the trap in such a way that ν_a increases very slightly with increasing cyclotron radius. Detecting such shifts of a few hertz in 60 million, the group has been able to observe single $h\nu_c$ quantum jumps in the cyclotron energy and thus measure $g-2$ with heroic precision.

Helpful as such a small imposed inhomogeneity is, it has the advantage of broadening the intrinsic linewidths of the cyclotron-motion quantum levels, thus setting a limit on the precision with which one can measure $g-2$. The group is therefore working on the exploitation of an alternative coupling between the cyclotron and axial motions, namely the relativistic mass increase of the electron. As the cyclotron energy increases, the electron mass increase yields a very small decrease in ν_a, even in a perfectly homogeneous magnetic field. The new technique is difficult, because the relativistic ν_a shift is an order of magnitude smaller than the older field-inhomogeneity shift for a given change in the cyclotron energy. But ultimately, when the group has achieved sensitivity to single quantum jumps with the new technique, they will be able to measure $g-2$ without the field-inhomogeneity broadening that currently sets the limit of precision.

The relativistic-hysteresis experiment, being a part of this program, employed a state-of-the-art 60-kG nmr magnetic system with extremely good homogeneity throughout the active volume of the Penning trap. Gabrielse and his colleagues were able to detect ν_a shifts of *one hertz*, corresponding to cyclotron energy changes of 0.016 eV or 24 quanta ($h\nu_c$). One is therefore justified here in treating the system classically—ignoring quantum effects in the hysteresis experiment. The group is now well on its way to the single-quantum sensitivity required for a new generation of $g-2$ measurements, Gabrielse told us.

Bistability observed. With the new microwave driving system finally in place last summer, the group monitored the cyclotron energy of the lone trapped electron (by way of its relativistic axial-frequency shift) as the driving frequency was swept downward *and* upward through ν_{c0}. On the downward sweep, the electron began to react strongly at ν_{c0}, its cyclotron energy growing linearly for the next several hundred kHz until, having been excited to 10 eV, it exhibited its hysteresis jump, falling abruptly back down to the background noise level. The electron's pronounced response to the downward sweep of the driving frequency was recorded with a signal-to-noise ratio of about 200:1, described by the group as "the best signal-to-noise ratio ever observed with a single elementary particle in a trap." Dehmelt and his colleagues can say this without much fear of contradiction, because the Seattle group has had a virtual monopoly on single-trapped-particle experiments.

Sweeping the driving frequency *upward* through this range, by contrast, they saw no response above the noise—a dramatic demonstration of the hysteretic bistability. With sufficient care, they have shown us, one is able to observe a striking and provocative manifestation of special relativity at electron energies no larger than those one finds in the valence shells of ordinary atoms.

In fact, the University of Washington group likes to think of its Penning trap as a kind of manmade atom, with distinct, detectable quantum numbers describing the states of the electron's cyclotron excitation and spin orientation. They refer to it as "geonium," because "the electron is ultimately bound to the Earth," and also because Dehmelt has a penchant for the letter *g*. The antiproton is the only long-lived elementary particle not yet studied in this device. Gabrielse, when last we spoke, was on his way to CERN to beg some antiprotons for just this purpose. The goal is to measure the parameters of the antiproton to the same precision with which one knows those of the proton, thus putting the symmetry principles of particle physics to a stringent test. Measuring the antiproton mass with great accuracy, Gabrielse points out, would provide our first precision test of the CPT theorem with baryons. —BMS

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Grenoble, it seems, will get European synchrotron facility

The storm of controversy surrounding the site selection for the European Synchrotron Radiation Facility has tended to obscure the prodigious scientific and technological import of this proposed new x-ray source. The ESRF, a 776-meter-circumference storage ring for 5- or 6-GeV electrons, would be the first synchrotron radiation ring designed explicitly for undulator and wiggler sources of hard-x-ray beams. Most high-energy synchrotron light sources, having begun life as electron–positron storage rings for high-energy physics, are not optimized for synchrotron radiation, and they have little room for inserting undulators and wigglers.

The x-ray ring at Brookhaven's National Synchrotron Light Source *was* designed explicitly as an x-ray source, but "it was built too early," says Yves Petroff, director of LURE (Laboratoire pour l'Utilisation du Rayonnement Electromagnetique, Orsay). By that he means that when the NSLS was designed in the late 1970s, the experts had not yet acquired the experience that now leads them to regard wigglers and especially undulators as the best way to get high-intensity light beams out of a synchrotron. The Brookhaven x-ray source is the prototype low-emittance storage ring on which the ESRF design is largely based. But its straight sections have room for only half a dozen wigglers and undulators. Its x-ray beams emanate primarily from the ring's bending magnets.

The Super-ACO ring, currently under construction by Pierre Marin, Petroff and their colleagues at LURE, *is* based on wigglers and undulators. But Super-ACO is a relatively small ring, with a maximum electron energy of only 800 MeV—optimized for vacuum ultraviolet and soft x-rays rather than hard x-ray beams. With its 5- or 6-GeV electron beam, the ESRF is intended primarily to provide hard x-ray beams in the wavelength regime from 1 Å down to about 0.1 Å. Its design is optimized to yield very high-brillance undulator output at 0.9 Å. The bending magnets of the Brookhaven x-ray ring, with a maximum electron beam energy only half that of the ESRF, provide peak output at 2.4 Å. With a superconducting wiggler to be installed next year, the Brookhaven ring will be providing useful intensities down to 0.5 Å.

The most powerful x-ray source now operating in Europe is the 5.6-GeV Doris ring at DESY in Hamburg, a machine built in the early 1970s for high-energy physics. Discussions are under way at DESY to reconfigure the ring when the high-energy physicists give it up, adding perhaps nine more straight sections for wigglers and undulators and operating at somewhat lower energy.

Where to put it. At the 15 March Brussels meeting of representatives of the seven governments considering participation in the ESRF, the French and German (FRG) representatives made it clear that they will stick by their controversial choice of Grenoble as its site. They propose jointly to pay 68% of the $220-million cost of constructing and operating the synchrotron light source for six years if it is built at Grenoble. Counteroffers were put forward at the meeting by Italy, which would pay more than 50% of the capital cost if the facility were sited in Trieste, and by Denmark, which offered 30% if Risø were selected as the ESRF site.

The representatives at Brussels were not empowered to vote on the siting question, but the French and Germans now seem prepared to forge ahead with planning the Grenoble facility, irrespective of what the other governments may decide. The French and German representatives are putting together a committee to chose from among three prospective sites in Grenoble, nominate a director, arrange the legal framework and assemble a scientific council for the facility—all this before the end of June.

Considerable unhappiness had been expressed in a number of quarters last November, when the French and German governments announced that they favored the candidacy of Grenoble, in the French Alps. Within France and Germany, vocal supporters of the rival candidacy of Strasbourg, situated on the German border in Alsace, asserted that a prior commitment by the French government had been betrayed for cynical political reasons.

"We're losing a lot of time with this siting debate," Petroff told us on the eve of the Brussels meeting. "The ring could have been started long ago. Everyone seems to be unhappy about how the site selection has been done." Italian and Danish participants felt that their senior partners had ignored the smaller countries in coming to this private understanding. It was thought that the German government's acquiescence in the Grenoble decision was a *quid pro quo*, France having supported the siting of the European trans-sonic wind tunnel in Cologne. France, as the prospective host, proposes to pay the larger share (39%) of the Franco-German offer of 68%.

The British government has favored the Franco-German choice of Grenoble, although the British, having recently completed their own 2-GeV synchrotron source at Daresbury, have no funds available for participation in the construction of a continental facility. In the wake of the Brussels meeting, Denmark may choose to withdraw altogether, but Austria and Sweden seem disposed to join the Grenoble effort. Italy appears to be looking for some sort of compensatory project as a solace for the rejection of Trieste.

Supporters of Grenoble point to the Laue–Langevin high-flux neutron-beam facility, adjacent to the proposed site, arguing the scientific case for such a link. The biologists, who would be major beneficiaries of this x-ray source of unprecedented power, appear to be split. In opposition to its own government, the Centre National de la Recherche Scientifique, which runs several major biological laboratories in Strasbourg, has favored the Alsatian site. The director of the European Molecular Biology Laboratory at Heidelberg, on the other hand, favors Grenoble, where the EMBL runs a neutron-scattering facility, although, we are informed, his council may not follow him.

Last month a major symposium on x-ray studies by synchrotron radiation was convened at the Council of Europe in Strasbourg. Planned two years ago to coincide with ground breaking for the ESRF in that Alsatian city, it was to have been a festive occasion. But, much water having passed under the bridge in the meantime, the French Minister of Science, addressing the international assemblage, spoke not one word about synchrotron sources, we are informed.

The choice of Grenoble still stands, but for the moment it is a Franco-German proposal rather than an affirmed European undertaking. If the other five participating countries eventually decide not to go along, one has the embarrassing prospect, as one observer put it, of "seven countries doing a major study, and two of them running away with the profits."

Scientific goals. The debate points up the extraordinary range of disciplines that would benefit greatly from the creation of this powerful new x-ray source. From the recently published *Report of the European Synchrotron Research Project*, prepared by Bronislow Buras (RNL, Roskilde, Denmark) and Sergio Tazzari (Frascati, Italy) with the help of about 150 scientists from Europe and elsewhere, we cite a number of examples from the chapter on the scientific goals of the ESRF:

▶ In the biological sciences, for example, the very high "brilliance" (spectral brightness per unit source area) promised by the ESRF design will make it possible to do protein crystallography with much smaller samples than are now routinely required. The preparation of large single crystals has traditionally been one of the major problems plaguing this field. The reduced exposure times required by the very intense ESRF beams will also make it possible to study the kinetics of metallo-enzymes. Such kinetic investigations are not feasible with present x-ray sources. The high brilliance of the ESRF also leads medical researchers to anticipate the extension of energy-subtractive angiography (where one takes the difference between x-ray images collected above and below a prominent absorption edge of an injected radio-opaque fluid) to microscopic regimes—energy-subtractive microradiography, with high spatial and temporal resolution.

▶ In condensed-matter physics, high-brilliance x-ray beams will allow studies of lattice and electron excitations in solids. Although inelastic neutron-scattering studies involve much higher relative energy transfers, high-brilliance x-ray sources should yield very good energy resolution, making possible the study of excitations to which neutrons do not couple strongly, and providing access to an energy range not covered by neutrons. For Mössbauer studies, optimized undulators at the ESRF would be much more powerful radiation sources than are Mössbauer isotopes. This would make possible very-high-resolution scattering experiments and studies of time-dependent phenomena.

▶ Holography and holographic microscopy with x rays become possibilities with the very small divergence of x-ray beams from the ESRF undulators; this divergence results in better spatial coherence than one can get with conventional laser beams. Holography, as a lenseless microscopy, is particularly attractive in the x-ray domain, where refractive indexes are too close to unity to permit the fabrication of ordinary lenses.

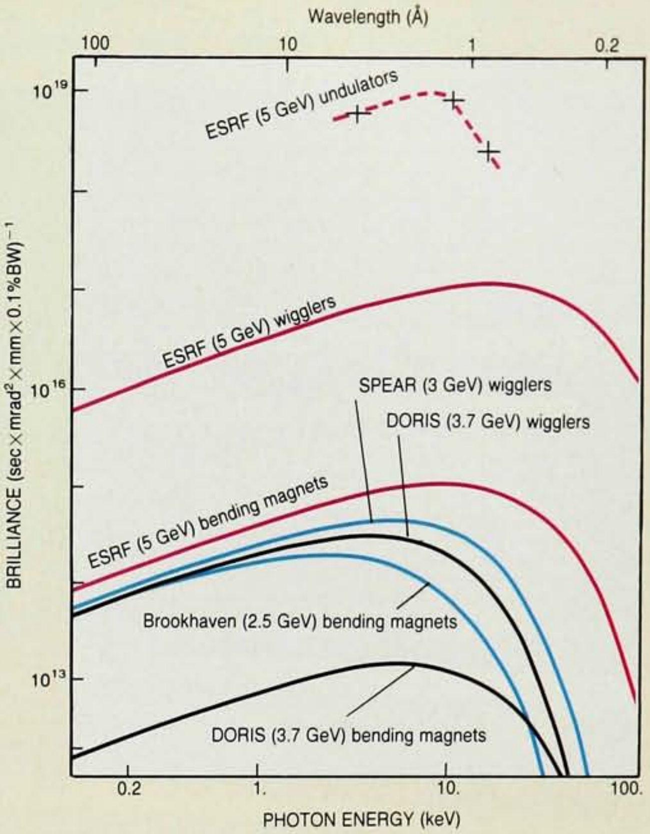
▶ Surface analysis techniques such as SEXAFS (surface extended x-ray absorption fine structure) yield much weaker signals than their bulk analogs—in this case, bulk EXAFS. Thus they require much higher incident photon intensities. The new Facility's high-intensity beams would make SEXAFS measurements routinely available for the study of catalysis and other interface phenomena.

Wigglers and undulators, together with wavelength shifters, make up the class of "insertion devices," which can be inserted into the straight sections of a synchrotron to yield desirable radiation beams without altering the closed electron-beam orbit in the rest of the ring. In the absence of such insertion devices, the radiation from a synchrotron ring comes essentially from its bending magnets, which produce a broad continuous spectrum with peak wavelength inversely proportional to E^2B, the square of the electron energy times the magnet's field strength. For relativistic electron beams, this synchrotron radiation is strongly collimated in the forward direction tangent to the curving beam.

Wigglers and undulators both consist of arrays of magnet gaps of alternating polarity transverse to the beam axis, so that the electron beam experiences an undulatory perturbation as it passes through the device. If the maximum deflection angle produced by these undulations is large compared to the natural angular spread of the cone of synchrotron radiation, the device is called a wiggler. For a given (maximum) field strength, a wiggler produces synchrotron radiation with essentially the same spectral shape as a corresponding bending magnet; but the flux is greatly increased—roughly by a factor equal to the number of magnet poles in the wiggler. A "wavelength shifter" is a simple three-pole wiggler with a field stronger than that of the bending magnets, thus shifting the synchrotron spectrum to shorter wavelengths without appreciably increasing its flux.

If, on the other hand, the deflection is not larger than the natural spread, one has an undulator. Under these conditions, strong interference effects can result in a spectrum of narrow harmonic lines, with the fundamental wavelength given (independent of the field strength to first order) by $(\lambda_0/2)(m_e c^2/E)^2$, where λ_0 is the spatial periodicity of the undulator and m_e is the electron mass. To optimize the intensity of these lines, the storage ring must be designed so that the angular divergence of the circulating electron beam is not larger than $m_e c^2/(E\sqrt{n})$, where n is the number of undulator magnet periods.

Spectral brilliance distribution from undulators, wigglers and bending magnets at the proposed European Synchrotron Radiation Facility and various existing electron storage rings in the US and Europe. Brilliance is defined as $d^4N/dt\,d\Omega\,dS\,d\lambda/\lambda$, the spectral photon intensity per unit area of source. The numerical values, by convention, are given for $d\lambda/\lambda = 0.1\%$.



The proposed ESRF, as it has emerged from the last two years of study of the large group of accelerator designers and synchrotron light users that constitute the European Synchrotron Research Project, under the auspices of the European Science Foundation, is described in the report of Buras and Tazzari. The preliminary "site-independent" design provides room in the ring's ample straight sections for about 30 wigglers and undulators.

This design has evolved substantially since its first incarnation in 1979. In that earlier "Blue Book" design, bending magnets were the main radiation sources; only a few insertion devices were proposed. In the new design, by contrast, most of the radiation beam lines originate from wigglers and undulators. In 1979, the recent ESRP report tells us, "insertion devices represented a possible progress." With the experience and competence gained with insertion devices in the intervening half decade, "they are presently often the only possible option."

The choice of parameters for the ESRF, especially the low emittance (phase-space spread) of its stored electron beam, is "fully optimized" for the wigglers and undulators. The design provides for as many as 50 radiation beam lines for the experimental areas. The electrons are injected into the storage ring at full energy (up to 5 GeV or 6 GeV) from a synchrotron with a racetrack microtron preinjector. The machine could eventually be modified to accommodate positrons by adding an electron linac, a positron converter target and an accumulator ring. Positrons are, of course, harder to come by than electrons, but they repel the positively charged residual-gas ions in the evacuated beam pipe, which electrons would attract, thus permitting circulating beams of greater stability and longevity.

Undulators produce the most brilliant beams. The ESRF is designed to provide intense undulator beams with fundamental wavelengths down to 0.86 Å (14.4 keV). Wigglers, on the other hand, provide the highest photon energies. The multipole wigglers will have peak wavelengths ranging from several angstroms down to 0.5 Å. Three-pole superconducting wavelength shifters will provide useful fluxes at least down to 0.05 Å (240 keV).

High spectral brightness and brilliance require that the electron beam circulating in the storage ring have very small horizontal and vertical emittance (product of spatial and angular spread in each plane). With design emittances of less than 10^{-9} and 10^{-8} meter radians in the vertical and horizontal planes, respectively, and a beam current of 100 (eventually 200) milliamps, the ESRF should provide hard-x-ray undulator beams three to four orders to magnitude more brilliant than any now available.

On this side of the ocean there is also a strong impetus toward building a high-energy synchrotron light source optimized for insertion devices. A Machine Workshop on the 6-GeV Synchrotron Radiation Source was convened at the end of March at the National Bureau of Standards in Gaithersburg, Maryland. The Workshop's purpose was to define the performance goals and major design features of the proposed 6-GeV facility on which the Seitz–Eastman committee on major materials research facilities had bestowed their highest priority last summer (see PHYSICS TODAY, September, page 57).

The imminent prospect of the ESRF is, no doubt, a spur to the American effort. The recently organized 33-member Synchrotron Radiation Steering Committee, headed by Peter Eisenberger (Exxon Research) and David Moncton (Brookhaven), hopes to get the new facility into the fiscal 1988 budget. Argonne, Brookhaven and SLAC already appear to be in the running as possible sites. There is also the possibility that the 6-GeV light source would be the nucleus of a brand-new synchrotron-radiation laboratory.

A 1-GeV synchrotron radiation source similar to super-ACO is planned for Taiwan. A project-review meeting held last December in Taipei was grieved by the sudden death of Robert Poe (University of California, Riverside), whose efforts had been largely responsible for getting the Taiwan project underway. —BMS □