The Stanford Synchrotron Radiation Project is a new national facility which makes use of the intense radiation produced by the SPEAR storage ring at SLAC to carry out important research in several fields of the physical and biological sciences. This article describes the SSRP facility and its early experimental program. It also gives some of the basic technical information needed to understand how the facility works and why its research program has already started to yield significant results.

**A. INTRODUCTION**

The Stanford Synchrotron Radiation Project (SSRP) is a new national facility for research in a variety of scientific disciplines, including physics, chemistry, biology, metallurgy and astrophysics. Although the Project is located at SLAC, adjacent to the SPEAR storage ring, it is funded by the National Science Foundation under a contract with the W. W. Hansen Laboratories of Physics on the Stanford campus. In addition to NSF support, contributions to the Project have been made by the U.S. Navy's Michelson Lab at China Lake, California; by Xerox Corporation; and by Bell Telephone Laboratories. The originators of SSRP are Professors Sebastian Doniach and William Spicer of Stanford (now the Director and Consulting Director, respectively), with much early help from SLAC's Gerry Fischer.

Experiments at SSRP make use of the intense synchrotron radiation that is given off as a "by-product" of the operation of the SPEAR storage ring. This "free" radiation has several remarkable properties: (a) high intensity, (b) a broad range of energies including some that are difficult to produce at useful intensities by other means, (c) natural collimation, (d) high polarization, and (e) pulsed time structure. (More information on these properties is given later.) Perhaps most important is the intensity, which is so high that even a very narrow band of energies will contain enough flux for a great variety of experiments. Before turning to a description of SSRP itself, we now want to review, in Section B, some physics background.

**B. SOME BACKGROUND INFORMATION**

1. **Light And Other Radiation**

Most people at SLAC have heard about the comparison that is often made between an accelerator and a microscope. With a conventional microscope, which uses visible light, we can see objects such as parts of living cells that may be less than $0.001$ centimeter ($10^{-3}$ cm) long. By using a more powerful kind of light (x-rays or electrons which have energies of some thousands of volts), we can get a picture of some of the smallest living things, such as viruses, that may be only $10^{-6}$ cm in size. And usually the next step we talk about at SLAC is the great leap inward that takes us all the way down to the realm of the elementary particles, such as the proton, whose size is about $10^{-13}$ cm.

To illuminate protons we make use of a special kind of 'light' that is actually a beam of electrons which has been accelerated to billions of volts by the SLAC two-mile accelerator. Thus the 'resolving power' of the SLAC accelerator is about $10^{10}$ times greater than that of a conventional light microscope.

2. **Atoms, Molecules And Angstroms**

But hold on a minute. When we jumped from viruses all the way down to protons, we skipped right over a whole class of objects—atoms and molecules—that are almost completely responsible for making the world the way it is. So this time let's go back for a closer look at what we missed. To begin with, we'll need a
new yardstick to give us a convenient unit of size for measuring atoms. This unit is called the angstrom. Its symbol is 'Å' and it is this big:

\[ 1 \text{Å} = 0.0000001 \text{ centimeter} = 10^{-8} \text{ cm} \]

The angstrom is convenient because it is close to the size of an atom; the radius of a hydrogen atom is about 0.5 Å, and the radius of a uranium atom is about 2.0 Å. Although those physicists who study the elementary particles have passed the atom by in their search for the smaller game that lives within the very small nuclei of atoms (about \(10^{-4} \text{Å}\), or 10,000 times smaller than the whole atom), it is worth remembering that the nucleus itself plays an almost totally insignificant role in the substance and activity of our everyday experience. But the whole atom, on the other hand, is definitely where it's at. It is because of the structure of atoms and their interactions with each other—and the tremendous variety of both—that steel is strong, water is wet, roses are red, and soap is slippery. In fact, it is because of atoms that almost everything is anything.

3. What 'Size' Light Do we Need?

Thus the realm of the atom and of the combinations of atoms that form molecules is the starting place for trying to understand any of the larger units of matter, both physical and biological, that occur in nature. In order to explore this realm successfully, we will need to select (as we did for viruses and for protons) just the right kind of light to shine on the atoms. The essential requirement is that the light be of a 'size' (wavelength) that matches the dimensions of the particular atomic or molecular structures we shall be studying. We can get an idea of the range of sizes that will be useful in this work by consulting Fig. 1, which shows some of the characteristics of electromagnetic radiation.

From this figure we see that the size of an atom, about 1 ångström, is matched by radiation that lies in the x-ray region of the spectrum. For a wavelength of 1 Å, the corresponding x-ray energy is about 12,000 electron volts, or 12 keV. In order to study some of the inner electronic structure of atoms we will want to use x-rays that are somewhat 'harder' than 12 keV—say up to energies of 20 or 25 keV. In addition, structures up to several atoms in size will need 'softer' radiation from the ultraviolet portion of the spectrum. Ideally, then, our bag of radiation tricks should include the following range of energies and wavelengths:

*Metrication note: In the International System of units (SI), the preferred unit of length for the sizes we're talking about is the nanometer, which \(10^{-9}\) meter, or 1 Å.
4. Speaking In Colors

All electromagnetic radiation comes in discrete "packets" or units called photons. We have already seen that there is a simple inverse relationship between the energy carried by a photon and its "size" or wavelength: the higher the energy, the shorter the wavelength. For the very narrow band of radiation that human beings can actually see (roughly between 4000 and 7000 Å), a change in wavelength or energy is also seen as a change in color. To us, radiation at 6500 Å is simply red light, while 4700 Å is seen as blue light. Because of this, scientists sometimes extend the idea of colors to describe radiation even when they are referring to parts of the electromagnetic spectrum that cannot actually be seen. Thus ultraviolet radiation is said to be bluer than visible light, and a beam of gamma rays which all have the same energy is sometimes described not only as monoenergetic but also as monochromatic (all of the same color). In general, then, the following rather loose talk is used:

bluer = harder = higher energy
redder = softer = lower energy

Which is probably a good place to stop the loose talk and get on with the subject at hand.

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C. THE SSRP FACILITY

We turn now to a discussion of the SSRP facility itself, starting with the synchrotron radiation produced by SPEAR. We then follow this radiation from SPEAR into SSRP, describe the SSRP layout, and finally call attention to some of the special research apparatus at SSRP.

1. SPEAR's Rainbow Of Light

The SSRP facility is located at SPEAR in order to take advantage of the intense radiation that SPEAR gives off as a natural by-product of its normal operation. This radiation is caused by the fact that the electrons traveling in a curved path around the SPEAR ring lose a certain amount of their energy on each revolution. The radiation from SPEAR is emitted in the orbital plane of the electrons—flying off from the circular beam path in much the same way that mud flies off from a spinning automobile tire. This kind of centrifugal or "thrown-off" radiation is characteristic of the class of accelerators called "electron synchrotrons" (which includes SPEAR), and for this reason it has been given the name synchrotron radiation. For SLAC's purposes, the synchrotron radiation given off by SPEAR is more of a nuisance than a benefit, as Fig. 2 illustrates.

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<tr>
<th>Energy Of One 20-milliamper Beam (GeV)</th>
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Fig. 2—Synchrotron radiation energy loss at SPEAR and at (proposed) PEP. This synchrotron "mud" thrown off by the circulating beams heats up the inner walls of the SPEAR vacuum chamber and also knocks gas molecules out of the chamber walls. Thus both a water-cooling system and an elaborate vacuum-pumping system are required. In addition, a strong radio-frequency accelerating system is needed to give the beam particles a carefully timed "kick" on each revolution in order to make up for the energy lost by synchrotron radiation. These problems rapidly become more difficult as the energy of the beams is increased. For example, doubling the energy of one stored beam in SPEAR results in a 16-fold increase in the power lost to synchrotron radiation.
So synchrotron radiation is a natural by-product of the operation of SPEAR, and the next step in our investigation of SSRP is to find out a little more about this radiation—how many photons are given off per second, what energies do they carry, and so on. Information of this kind about a radiating source is called a spectrum. The spectrum of synchrotron radiation from SPEAR is shown in Fig. 3.

The problem of getting the radiation out of SPEAR can be divided into two parts: (1) hard x-rays, with energies above about 3500 electron volts, and (2) all the rest of the lower energy x- and ultraviolet radiation. For the hard stuff, the solution is fairly simple. X-rays of 3.5 keV and higher will readily pass through a vacuum-tight 'window' which consists of a thin foil of beryllium metal. This window acts as a dependable barrier between SPEAR's good vacuum and the outside world. Once through the window, the hard x-rays continue in an atmosphere of helium to the experimental stations.

For the remaining, lower energy radiation, the solution that has been adopted is to extend SPEAR's vacuum system tangentially out in a 'finger' toward the SSRP facility (see next page). This extended vacuum system is potentially vulnerable to leaks that may occur in various pieces of SSRP experimental apparatus. For this reason, a special fast-acting vacuum

---Photo by Joe Faust

SSRP vacuum specialist Ralph Gaxiola is shown opening a high-vacuum valve on the 40 beam line at SSRP. Protection of the SPEAR vacuum and of the experimental vacuum systems is a prime concern of SSRP. Ralph gained much of his knowledge of ultra-high-vacuum systems while working in Norm Dean's SPEAR vacuum group. His responsibilities include interfacing with experimenters who want to connect their equipment into the extended SPEAR vacuum system.
valve (supplied by the CERN ISR group) has been installed near the SPEAR end of the extended finger. This valve can close in .03 second if triggered by any of several ionization gauges or other "gas sniffers" around the system. Care has also been taken to avoid contaminating either the SPEAR or SSRP systems with such materials as heavy hydrocarbons.

3. The Layout Of SSRP

The general arrangement of beams and experimental apparatus in the SSRP facility is illustrated in Fig. 4. Inside the vacuum chamber coming from SPEAR there are two special mirrors which split the narrow spray of synchrotron radiation into three separate beams: (1) The straight-ahead undeflected beam consists of hard x-rays with energies of 3.5 keV and above. (2) A second beam is reflected sideways through a 40° angle; it consists of ultraviolet and x-radiation with energies less than about 2 keV. (3) The third beam is reflected upward through an 80° angle; it consists of the softer ultraviolet radiation of 300 eV or less energy.

The straight-ahead, hard x-ray beam is simultaneously shared by three different experimental areas. If the need should arise, more elaborate switching and splitting systems can be added to provide additional experimental areas for any of the three main beams.

Stanford Synchrotron Radiation Project
April 1974
Fig. 4—SSRP Layout
The two beam-splitting mirrors at the front end of the SSRP beam system are particularly important and thus worth some special attention (see Fig. 5). Each is constructed of a thick copper block, polished to an exceptionally smooth finish, and plated with a thin layer of platinum. One of the mirrors is plane (flat), while the other has a very slightly concave cylindrical surface which focuses the radiation in the horizontal plane. The synchrotron radiation from SPEAR is sufficiently intense so that the mirrors must be able to dissipate something like 50 or 100 watts. Normally this heat load would be handled by a water-cooling system, but in this case it was decided that a rapid flow of water might cause a mechanical disturbance of the mirrors and thus affect the reflection of the synchrotron radiation beam. Since the alignment of the beams is critical (they must be precisely directed to monochromator entrance slits that are only .001 centimeter wide), the cooling technique that has been adopted for the mirrors is the novel thermo-electric method.

4. Monochromators

As we noted earlier monochrome means 'one color,' so a monochromator is a device for getting radiation of a single color (or energy or wavelength). Perhaps it will come as a surprise that you are already familiar with a monochromator of a certain kind: a prism. As a reminder, Fig. 6 shows how the combination of a prism and a slit can be used to select one color of radiation from a mixed bag of colors.

![Fig. 6--Use of a prism and a slit to form a simple 'green-light' monochromator.](image)

The fancier monochromators used at SSRP and elsewhere produce somewhat the same result as a prism, but they do it in a different way. The white light passing through a prism is spread out into its constituent colors by a process called refraction. This color separation can also be achieved by the diffraction of light from either of two kinds of special surfaces: (1) a man-made diffraction grating, or (2) any of a number of natural crystal materials. Let's look at these two monochromator possibilities in turn (next page).

---Photo by Joe Faust

Fig.5--Vic Rehn of the U.S. Navy's Michelson Lab at China Lake, California, is shown with one of the two beam-splitting mirrors that are used to separate the synchrotron radiation from SPEAR into high-, medium- and low-energy components. Vic's group has pioneered in the design and construction of such ultra-smooth mirrors. The mirror shown here has an average surface roughness of less than 30 Å, and is probably the smoothest piece of metal of this size ever made. Two such mirrors are used at SSRP.

---Photo by Herm Winick

Ben Salsburg (left) and Axel Golde of the SSRP staff are shown checking the helium flow in the straight-ahead x-ray beam line. This view is taken looking back toward SPEAR. Axel is responsible for mechanical facilities at SSRP. He works with experimenters to fit their equipment into the appropriate beam line, and also designs shielding, helium systems, beam shutters, and other mechanical components.
**Diffraction gratings.** The original form of diffraction grating, devised by a man named Fraunhofer, consisted of a series of parallel wires spaced an equal distance apart, as shown in Fig. 7.

Fig. 7--A diffraction grating made of four parallel wires. The two sketches, (a) and (b) show how different wavelengths of radiation are diffracted at different angles by the wires. This is an example of a *transmission* grating, in which diffraction occurs as the radiation passes through the wire grid. The more common form, described in the text, is a *reflection* grating, in which the diffracted radiation reflects back from a grooved solid surface. All diffraction gratings serve the purpose of separating radiation into constituent 'colors' or wavelengths, and are thus the key elements in monochromators.

We used the parallel-wire form of diffraction grating to illustrate the principle because it is easy to draw. However, the more common form of grating is a smooth surface into which many parallel grooves have been cut by a sharp scribing instrument. Since the spacing between grooves (or wires) will determine the range of wavelengths that can be separated (or dispersed) by a grating, short wavelengths will require very close spacing. A machine called a 'ruling engine' is used to cut or scribe the grooves, and the most accurate of these machines can cut as many as several thousand grooves per centimeter on a suitable surface. If we recall, however, that our studies of atoms may require x-rays with wavelengths of less than a millionth of a centimeter, then it's obvious that even the best of man-made diffraction gratings will not be good enough, and we'll have to look elsewhere for a 'one-color-maker.'

**Crystal monochromators.** The ultimate diffraction gratings are those produced by nature. On the surface of such crystalline solids as quartz, for example, the regular spacing of the rows of atoms in the crystal lattice produces the same effect as the parallel grooves in a ruled grating. And since the distance between the parallel rows of atoms in a crystal is roughly a few angstroms, such crystals can be used to sort out x-ray wavelengths into their constituent 'colors.' As an example of the kind of resolution that can be achieved, there is a monochromator presently in use at SSRP which successively diffracts an x-ray beam from two separate crystals. This device yields an 8 keV x-ray beam in which the energies of the individual photons are the same to within about 0.2 electron-volts.

---Photo by Joe Faust

Visiting experimenter Gus Apai, from Lawrence Berkeley Laboratory, is shown at the teletype control for the ultra-high-vacuum, grazing-incidence monochromator, an instrument that was designed and built at Xerox Corporation and at the University of Wisconsin.
Ben Salsburg of SSRP is shown communicating with the SPEAR control room in order to adjust the position of the SSRP beam. Unlike charged-particle beams, which can be steered and focused magnetically, the synchrotron radiation beam emerges along a path that is tangential to the orbit of the circulating electrons in SPEAR. Thus the synchrotron radiation beam is steered by adjusting the orbit of the SPEAR electron beam. A simple and effective orbit-control circuit was designed by Ewan Paterson and was installed by the SPEAR operators working under Tom Taylor. This system has made it possible to position the synchrotron radiation beam with an accuracy of a fraction of a millimeter at a distance of 20 meters from SPEAR, thus eliminating the need for frequent realignment that is the norm at other synchrotron radiation labs.

Ben Salsburg is in charge of electrical systems at SSRP, working with experimenters to get their equipment set up and operating properly. He is presently designing a readout system for a multi-wire proportional chamber array that will be used in x-ray diffraction studies—an example of high-energy-physics technology adapted to other research uses.

D. THE SSRP EXPERIMENTS

Although SSRP has only been in operation since May 1974, it has already achieved experimental results that have attracted a good deal of attention. Six papers based on work done at SSRP were presented at the International Conference on Ultraviolet Radiation Physics held in Hamburg, Germany, in July. In addition, about 80 scientists from all parts of the U.S. and from Western Europe recently attended an SSRP Users Conference at SLAC to discuss the research possibilities at SSRP.

In the following paragraphs we first describe the mechanism by which experimental proposals are acted upon at SSRP, after which we go on to a description of some of the actual experiments that have already been carried out or are presently planned.

1. Proposals And Decisions

Like SLAC, SSRP is a national facility for basic research. This means that SSRP's facilities are available to any qualified user. Experiments presently under way at SSRP include scientists from the University of Washington, from Caltech, from Xerox Corporation, from Bell Telephone Labs, from the University of Illinois, from UC-Berkeley, and of course from Stanford. More than a dozen new proposals have been received from these and other institutions, including Argonne National Laboratory, Harvard University, and the National Bureau of Standards.

Proposals for experiments are sent to SSRP's Director, Professor Doniach, who seeks advice from several different sources before reaching his decision. The proposals are reviewed for scientific merit by SSRP's Program Review Panel, a group that is similar to SLAC's Program Advisory Committee. In addition, outside referees (not football) are called upon for advice in their particular fields of expert knowledge. And SSRP's staff provides advice about technical feasibility in much the same way that SLAC's Experimental Facilities Department advises the Director of SLAC. The only role which SLAC itself plays in this process is to exercise control in safety matters—particularly radiation safety—and to set vacuum standards for those experiments that will be connected to the line leading to the SPEAR vacuum system. Once a proposal has been accepted, it is scheduled into the overall SSRP program, and is eventually carried out with the assistance of the SSRP staff.

The construction of SSRP was funded by the National Science Foundation, starting in June 1973. Because of the fact that the SPEAR designers had had the foresight to fit the ring with a small tangential 'spout' which merely had to be uncapped (the open spout lets out less than .002 of SPEAR's total synchrotron radiation)
it was possible to begin some preliminary pilot studies with the radiation as early as July 1973. By May 1974 the facility was fully operational, thanks in large measure to the outstanding cooperation and assistance provided by SLAC (see separate box on this page). Thus SSRP was able to get in about 7 weeks of solid experimental running before the scheduled shutdown of the storage ring for conversion to SPEAR II. During this run there were three types of experiments of considerable interest carried out at SSRP, which we'll describe in the next three sections of this article.

2. EXAFS: Extended X-Ray Absorption Fine Structure

The apparatus used in the EXAFS experiments consists of a variable-energy monochromator that directs x-rays with a well-defined energy (+1 electron volt at about 10 keV) onto a target material at intervals of about one pulse second. Some of these x-rays knock loose inner-shell electrons (those closest to the nucleus) from the atoms in the material. That is, in the right circumstances an electron will absorb the energy of an incoming x-ray and recoil completely out of the atom. Ion chambers placed just in front of and just behind the target material are used to measure the x-ray flux that arrives at, and is transmitted through, the target. A computer calculates the ratio of these measurements (which is the absorption), steps the monochromator to a new energy setting, then makes a new measurement. Several thousand measurements, each of which lasts from 1 to 5 seconds, are made in rapid succession, and the results are plotted on-line as well as stored in the computer memory for later analysis.

The absorption of x-rays by matter follows the characteristic pattern shown in Fig. 8. The absorption peaks at a certain critical energy (different for each element), then tails off fairly slowly at still higher energies.

Increasing x-ray energy

Fig. 8--Typical pattern of x-ray absorption by inner-shell atomic electrons. If the emitted electron interacts with neighboring atoms, the interactions will show up as fine structure in the absorption curve.

To understand what happens to the freed electron, we have to recall that electrons, like other elementary particles, are not only little bits of stuff but also that they can just as well be thought of as waves. And when an outgoing electron wave leaves its home atom it is quite likely to get scattered (bounced around) by the neighboring atoms. This scattering or interaction with the neighbors shows up in the absorption measurements as a series of small bumps or wiggles (that is, as fine structure) in the energy region just above the main absorption peak. Therefore—and this is the point—any change in the arrangement of the neighboring atoms will show up as a change in the fine structure.

Thus the EXAFS technique gives us a powerful tool for gaining detailed information about the local environment of an x-ray absorbing atom.

A SPECIAL VOTE OF THANKS

Although the original SSRP plans called for a construction schedule of 18 months, the facility actually began operating after only 10 months. We want to acknowledge this remarkable achievement by mentioning some of the people, both from SSRP and from SLAC, who made it possible.

Much of the individual credit goes to Axel Golde, Ray Dannemiller and Ben Salsburg of the SSRP staff. The vacuum system for SSRP was designed by Fred Johnson, and was built, assembled, tested and installed by Mark Baldwin (now replaced by Ralph Gaxiola); Norm Dean and Joe Jurow gave much valuable assistance in this work.

The special thin beryllium and carbon foils were developed by Earl Hoyt. Gary Warren defined the shielding requirements and also helped develop the access procedures; Gary now monitors SSRP activities for radiation safety. Bob Baker helped in designing and in supervising the installation of the cable plant.

Control logic for the vacuum and personnel protection systems was designed by Bob Melen, Bruce Humphrey and Jack Miljan, and was mostly constructed in Frank Generali's shop. Bill Savage, Alex Tseng, Morris Beck and Ray Robbers led the Plant Engineering effort in the design and in supervising the construction of the SSRP Building (No. 120). Ray Larsen and John Harris provided technical advice and liaison between SSRP and SLAC.

The SSRP staff would like to thank everyone who helped for a job well done.
This technique has been known for many years (it was first explained by Kronig in 1931), but there were practical problems connected with doing the experiments. When conventional x-ray tubes are used to produce the radiation, it is not uncommon for one complete energy scan of a single material to take a few days, or even weeks, to be completed. During such long running periods there are fluctuations in tube output and in detector sensitivity, with the result that the experiments were both painfully long and not very precise.

The high intensity and excellent collimation of SPEAR's synchrotron radiation makes it possible to measure a complete absorption spectrum with excellent accuracy in a typical period of about 25 minutes, or roughly 1000 times faster than with earlier methods. An example of an EXAFS measurement done at SSRP is shown in Fig. 9. This experiment was a study of the copper-atom environment in the compound copper sulphate (CuSO₄). The first measurement was on the crystalline material itself, and the second after it had been dissolved in water. A completely different spectrum appeared for the second measurement, and it is now thought that the change resulted from a surrounding 'cage' of water molecules that had been established around the copper atom in solution. On a later measurement ammonia was added to the solution, and again the spectrum changed as a result of the formation of copper-ammonium ions. This experiment marks the first time that direct structural data of this kind has been possible in the field of solution chemistry.

One additional EXAFS application is worth noting. There are certain biological processes, in particular enzyme mechanisms, which depend critically on the precise location of a specific atom in a complex biological molecule. Since EXAFS probes the surroundings of a particular x-ray absorbing atom, the technique can be used, for example, to measure the slight shift in position that the iron atom in a hemoglobin molecule makes when the hemoglobin (in red blood cells) picks up or releases the oxygen it carries.
3. Photo-Electron Emission

The process by which ultraviolet light or x-rays knocks an electron out of an atom is called the photo-electric effect (it was first explained by Einstein in 1905). By measuring the energies and angular distributions of the knocked-out electrons it is possible to learn a good deal about the electronic structure of the various elements. Some electrons in atoms are held tightly in an inner shell, while others wander more freely around the atom's outer periphery.

Three different experimental groups are presently pursuing studies of this kind at SSRP. Much of this work takes advantage of the fact that the synchrotron radiation from SPEAR has a unique time structure. Although the circumference of the SPEAR ring is about 800 feet, the machine is operated in the 'one-bunch mode,' which means that the single bunch of electrons circulating in the ring only takes up a space about 15 inches long (SPEAR II's new RF system reduces the bunch length to about 3 inches). Thus an observer standing in the SSRP facility and looking at SPEAR would see a flash of light that lasts for about $10^{-10}$ second, then darkness for about $10^{-6}$ second, and so on.

Experiments at SSRP take advantage of this comparatively long period of darkness between flashes to make time-of-flight measurements of the velocity of the knocked-out photo-electrons. This is done simply by measuring how long it takes the electron to travel from the target to the detecting apparatus. Knowing the velocity, the electron's energy and momentum can be calculated, and this information, together with the measured angular distribution patterns, is what is needed to infer the particular atomic structure from which the electron came.

Information about the way in which an atom's structure is determined by the particular configurations of its electrons is of paramount importance in trying to understand the properties of materials. SSRP's work in this field seems likely to be an important contributor to understanding the surface properties of metals, semiconductors and insulators, with applications to such practical areas as the fabrication of electronics components and the catalysis of chemical reactions.

4. Biological X-Ray Diffraction

The apparatus for using monochromatized synchrotron radiation to study the structure, and changes in structure, of biological systems has been used for some preliminary experimental work to date. X-ray diffraction patterns have been obtained from frog's-leg muscle and also from rat-tail collagen. (SSRPers are now in the habit of opening packages rather slowly, after several one-pound-size bullfrogs jumped out of one box.) The earliest exposures took several minutes, but recent apparatus improvements, coupled with the expected higher intensity from SPEAR II, make it likely that exposure times of less than one second will be feasible. So short an exposure time opens up the exciting possibility of studying the rapid changes that occur in many biological systems—for example, muscle and retinal tissue. Toward this end, there is work now being done on possible electronic detection techniques (e.g., wire chambers) to replace the film that is commonly used.
E. SPEAR II AND BEYOND

As far as SSRP is concerned, SPEAR II is even more of a good thing. We've already mentioned the increase in synchrotron radiation intensity that is expected. The combination of higher energy and greater beam current in SPEAR II will result in synchrotron radiation energy losses of up to 150 kilowatts per beam. This compares with the previous value of about 12 kW from SPEAR I. This roughly 12-fold increase in power also applies to the radiation that comes out to SSRP through the little peephole in SPEAR.

The prospective research potential of SSRP has already produced a great deal of interest among potential experimenters throughout the U.S. As we noted earlier, the physical facilities at SSRP are now set up to handle as many as 5 simultaneous experiments. In response to the expected demand, it may be possible to squeeze in another 1 or 2 set-ups in the present space. In the longer run, however, the better solution would be to have a second main beam run from SPEAR into the new part of an expanded SSRP facility. Plans for such a possible expansion are now being worked on.

For the even longer term, there has been some thought given to the relationship, if any, between SSRP and the proposed PEP storage ring facility at SLAC. Even if PEP is authorized for Fiscal Year 1976, as proposed, it will not be on the air until 1979 or 1980, so there is enough time to consider SSRP's lot in life in the meantime. Speculatively, however, we could imagine a situation in which SPEAR would eventually be operated solely for SSRP to capitalize on the higher energy and intensity, and other factors.

But then SSRP still has to learn to walk before it starts to run, since we've done little more than scratch the surface of the present exciting research possibilities. Once we have a few years of experimentation under our belts, the future will doubtless seem clearer.

We'll sign off here with an invitation: if anyone at SLAC would like to take a look around the SSRP facility, we'd be happy to arrange something. Just give a little advance notice by phoning SLAC Ext. 2874.

--Herm Winick & Bill Kirk

MORE ABOUT EXAFS AND SSRP

In their first experiments at Stanford, the [SSRP] experimenters studied some simple systems to check out the characteristics of the new source. They studied atoms, simple molecules, pure crystalline materials and simple compounds and confirmed earlier measurements made with traditional sources. With the potassium atom they showed there was no marked x-ray structure. Next, with the Br2 molecule they measured the phase shifts the electrons experienced when scattered from the surrounding atoms. Then GeCl4 and Ni(CO)4 were studied to investigate the possible effects of multiple scattering and shadowing. They also studied semiconductor systems such as CuBr and GaAs and Ge to investigate the effect of ionicity of the band on the EXAFS structure.

The experimenters then wanted to demonstrate some of the potentialities of the technique. To show possible biological applications, they studied nickel and copper porphyrin and hemoglobin. In the porphyrins the metal atom is present to only one part in 50 or 100; the group was able to show that a good spectrum was still obtainable under these conditions. In hemoglobin, the iron atom in the porphyrin ring represents only about one part in 10,000; even in such a small proportion the experimenters found significant EXAFS structure. [They are] hopeful that the technique may be applied to oxygenation—by taking a spectrum of unoxygenated hemoglobin and then one for oxygenated hemoglobin one could learn how the immediate structure around the iron is affected by the presence of oxygen.

The technique has much potential in applications where the local environment around a given atom is of special interest, particularly for noncrystalline systems . . . . To demonstrate potential applications to chemistry, the experimenters compared spectra for bromine salts in solid form and in a water solution. The formation of hydrated bromine ions was demonstrated by the identity of bromine EXAFS structure for dilute solutions of different bromine salts . . . . it should be possible to extract information on the structure of the hydrated ion by more detailed analysis of the spectra.

It might be possible to study a variety of chemical reactions . . . on a real-time basis by looking at reaction intermediates. To be feasible, one would like a factor of ten higher intensity (which will be available as a result of the upgrading program) for the x-ray source and measurement times in the 1-100 millisecond range.

--Physics Today, October 1974