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THE CANADIAN LIGHT SOURCE – CANADA'S SYNCHROTRON

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THE CANADIAN LIGHT SOURCE – CANADA'S SYNCHROTRON

The Canadian Light Source (CLS), Canada's first synchrotron radiation facility, is scheduled to begin operating in the fall of 2004. This paper provides an overview of how synchrotrons work and the scientific importance of synchrotron radiation. The paper also discusses the value of the CLS to Canadian science, how it is being funded, and the challenges that lie ahead for this national facility once it is fully operational.

WHAT IS A SYNCHROTRON AND WHAT IS IT USED FOR?

A synchrotron light source is a large (generally about the size of a football field), doughnut-shaped particle accelerator that produces a highly focussed source of extremely bright radiation, known as synchrotron radiation, that covers over one-half of the electromagnetic spectrum from the far infrared through the infrared, visible and ultraviolet to the soft and hard X-ray(1) regions. Synchrotron radiation is emitted when charged particles (usually electrons)(2) travelling close to the speed of light are forced to move in a circular path under the action of a magnetic field. As the particles approach the speed of light, the intensity and frequency of synchrotron radiation emitted increases rapidly.

The broad spectral range of synchrotron radiation, along with several other qualities (its extreme brightness, spectral tunability, high polarization, high collimation [i.e., the parallel alignment of photons], and emission in very short pulses), makes it a powerful tool for a variety of different applications in fundamental and applied science, and in industrial technology.

(1) Lower-energy (longer-wavelength) X-rays are referred to as *soft* X-rays, as opposed to higher-energy (shorter-wavelength) *hard* X-rays.

(2) Electrons are the charged particles used in most synchrotrons, since they are much lighter than protons, and the energy emitted (through synchrotron radiation) from an electron is much greater than it is from an equal-energy proton in the same synchrotron. Proton synchrotrons are used chiefly for particle physics experiments.

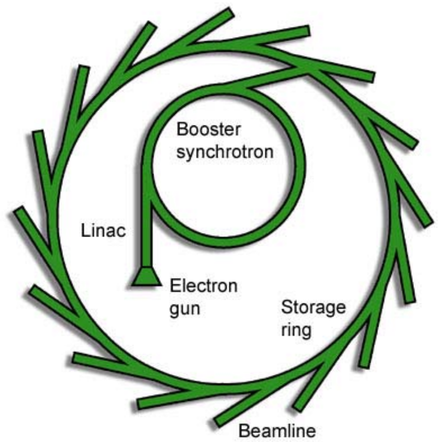
Because synchrotron radiation covers the soft and hard X-ray regions of the electromagnetic spectrum, it can be used to probe the structure of materials at the molecular and atomic levels.(3) Synchrotron radiation can allow scientists to determine the shape of molecules and the structure of surfaces, and to monitor living cells as biochemical reactions are occurring. It can help in the design of everything from solar cells to motor oil. Synchrotron light can also be used as an industrial tool; for example, X-rays can be focused to such a fine point that they can cut out tiny machine components from silicon or plastic on a scale smaller than the width of a human hair. Synchrotron light can also be used to etch patterns in microchips, and weld advanced ceramics that cannot be joined in any other way.

HOW DOES A SYNCHROTRON WORK?

An electron synchrotron produces light by accelerating electrons (fired from an electron gun) through a linear accelerator or "linac" and then through a booster ring. Electrons travelling at almost the speed of light are then injected into a circular storage ring where they pass through different types of magnets. As they travel around the ring, the electrons tangentially lose energy that is emitted in the form of a continuous spectrum of light, from infrared to X-ray, known as synchrotron radiation. To restore the electron beam energy lost through synchrotron radiation, the storage ring contains a radio-frequency accelerating chamber. Each time electrons pass this chamber, they receive a "boost" of energy. The synchrotron radiation emitted is transmitted down pipes, called beamlines, to scientists' work areas (see Figure 1).

(3) With visible light microscopy, it is impossible to resolve features smaller than those perceptible at the wavelength of visible light (approximately 500 nanometres [nm]). In order to visualize structures at the atomic scale, it is necessary to work with wavelengths of the order of atomic bond distances (approximately 0.1 nm or 1 angstrom [Å]). X-rays have such wavelengths.

Figure 1: A Typical Synchrotron Light Source Layout[(4)]



Each beamline contains monochromators (optics) that scientists employ to select the energies or wavelengths (usually X-rays) in the photon beam that are best suited to their work. The selected energy is transferred down the beamline to a hutch, which contains the sample under investigation. The hutch contains additional optics and detectors required to collect data on the characteristics of the sample (by measuring, for example, diffraction, fluorescence or absorption patterns as the radiation passes through the sample). These data are transferred to a computer that determines the structure of the sample using mathematical calculations.

One of the major applications for synchrotron radiation is for X-ray crystallography, which is used extensively to ascertain the structure of proteins. When X-rays hit a crystalline sample, the ordering of the atoms in the sample causes a particular pattern of diffraction of the X-rays. The intensities of the diffracted waves are measured experimentally and sent to a computer that determines the atomic structure of the sample, based on diffraction theory.

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(4) Diamond Light Source, http://www.diamond.ac.uk/Activity/ACTIVITY=Tour;SECTION=1812.

THE CURRENT STATE OF SYNCHROTRON TECHNOLOGY

First-generation synchrotrons were particle accelerators ("atom smashers") built to study subatomic physics. The synchrotron radiation emitted by electrons was problematic for researchers because it meant that the electrons were losing energy every time they passed through a bending magnet. Once the exceptional properties of synchrotron radiation were appreciated, however, second-generation synchrotrons were built specifically to harness this light. Third-generation synchrotrons have magnets (called wigglers and undulators) that are inserted into the straight sections of the storage ring. These insertion devices cause the electron stream to oscillate, greatly increasing the intensity of the beam. By this means, much smaller objects can be observed than was possible with earlier synchrotrons.

More than 50 synchrotrons have either been built or are under construction around the world.(5) Until the construction of Canada's synchrotron, known as the Canadian Light Source, Canada was the only G8 nation without such a facility. The CLS is one of only 17 third-generation synchrotrons either in existence or planned. (Most other synchrotrons in operation are second-generation facilities.) It operates at a mid-range electron-beam energy of 2.9 gigaelectron volts (GeV), which allows for the emission of hard X-rays.(6) The world's most powerful synchrotron is the third-generation SPring-8(7) facility located in Japan.

THE CANADIAN LIGHT SOURCE

The CLS is located at the University of Saskatchewan in Saskatoon. Construction of the six-storey building that houses the 54-metre diameter storage ring and the other synchrotron components was completed in December 2000. The Phase I experimental beamlines at the facility are expected to be in operation by the fall of 2004. Canadian Light Source Inc. is wholly owned by the University of Saskatchewan and is funded by government, industrial and academic sources. The National Research Council (NRC) will work with the University of Saskatchewan in managing the CLS as a national facility.

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(5) World's Synchrotron Radiation Facilities, http://www-ssrl.slac.stanford.edu/sr_sources.html.

(6) Hard X-rays are produced by electrons accelerated to higher energies, from 2.6 to 8 GeV.

(7) Acronym for Super Photon ring-8 GeV.

A. The Importance of the Canadian Light Source to Canadian Science

Currently, Canadian scientists who need to use synchrotron radiation in their work have to travel outside the country to facilities in the United States, Europe and other countries. Canadian scientists have operated a Canadian Synchrotron Radiation Facility (CSRF) at the Synchrotron Radiation Center of the University of Wisconsin-Madison since 1979.(8) There are currently two Canadian beamlines at that facility; a third has been disassembled and transferred to the CLS. Like other synchrotron facilities around the world, the CSRF has long waiting lists, and scientists have to work extended hours over short periods of time to complete their experiments. Furthermore, most of the synchrotrons currently in operation are second-generation facilities.

The CLS offers Canadian scientists the opportunity to conduct research with a state-of-the-art synchrotron radiation facility on Canadian soil. The facility is also expected to attract scientists from around the world on a temporary and permanent basis. Several renowned synchrotron scientists have already joined the University of Saskatchewan in anticipation of beginning work at the CLS, and additional researchers have been hired by other Canadian universities specifically to take advantage of the facility.(9)

B. Capital Costs

The CLS's capital costs of $173.5 million (new construction costs of $140.9 million, and $32.6 million for an existing building and other equipment) represent Canada's most expensive science project in more than 30 years. Capital costs were funded by federal, provincial, municipal, industrial and academic sources. The Canada Foundation for Innovation (CFI) provided a $56.4-million contribution, approximately 40% of the new construction costs. Under CFI funding rules, the remaining 60% of the capital funding had to be contributed by other partners. The breakdown of the capital investments is presented below:(10)

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(8) See the Canadian Synchrotron Radiation Facility's Web site at: http://www.uwo.ca/csrf.

(9) Michael Smith, "Lights on in Saskatoon," in *University Affairs*, Association of Universities and Colleges of Canada, January 2004, http://www.universityaffairs.ca/pdf/past_articles/2004/january/feature01a_e.html.

(10) Canadian Light Source Inc., "Science at the Speed of Light: The Canadian Light Source Project," http://cls-ccrs.usask.ca.

- $56.4 million from the CFI;
- $36.7 million from Saskatchewan sources ($25.0 million from Saskatchewan Economic and Co-operative Development, $7.3 million from the University of Saskatchewan, $2.4 million from the City of Saskatoon, and $2.0 million from SaskPower);
- $28.3 million from the federal government (includes money from the NRC, Western Economic Diversification, and Natural Resources Canada);
- $9.7 million from Ontario sources ($9.4 million from the Ontario Innovation Trust through the Ontario Synchrotron Consortium, and $300,000 from the University of Western Ontario);
- $9.5 million from Alberta sources ($6.7 million from the Alberta Science and Research Authority, $2.5 million from the Alberta Heritage Foundation for Medical Research, and $300,000 from the University of Alberta); and
- $500,000 from the pharmaceutical firm Boehringer Ingelheim.

The basic synchrotron ring components and the seven Phase I experimental beamlines are fully funded. The CFI recently committed additional funding for the construction of five Phase II beamlines. It will provide up to 40% (or $18 million) of the total $44.5 million for the beamline projects; the balance will have to be secured from other funding partners. The cost for each of the five Phase II beamlines ranges from $4.5 million to $17 million.(11) Eventually, the CLS hopes to have more than 30 beamlines in operation, but this will require a large injection of both capital and operating funds.

C. Operating Costs

The operating costs of the CLS's Phase I beamlines are estimated to be approximately $89.8 million over five years. Since no single federal agency funds the operating costs of such national facilities, the CLS has to secure financing from a number of sources. Of the total operating costs, $45.3 million will be contributed by the Natural Sciences and Engineering Research Council of Canada, $15.75 million by the NRC, $10.5 million by the Canadian Institutes of Health Research, $10.25 million by the University of Saskatchewan and $3 million by Western Economic Diversification. The remaining $5 million is expected to come from fee-

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(11) University of Saskatchewan News, "CFI Awards $18 Million to Help Fund Canadian Light Source Beamlines," 8 March 2004, http://www.usask.ca/events/news/articles/20040308-4.html.

for-service revenue from industrial users of the CLS. The CLS has set a target for industrial usage of up to 25% for certain beamlines. GlaxoSmithKline, a pharmaceutical company, has agreed to provide a $500,000 endowment to help create Canada's first designated university research chair in synchrotron science. The Saskatchewan government will match the research chair funding.

D. Commissioning Schedule

Commissioning of the synchrotron booster and storage rings was completed at the end of 2003. First light from the diagnostic beamline, which will be used to monitor the performance of the electron beam in the storage ring, was produced in December 2003. The CLS has begun commissioning the facility's seven experimental Phase I beamlines. Before the facility can begin routine operations, it will need to obtain an operating licence, for which an application is in progress, from the Canadian Nuclear Safety Commission. Five of the seven Phase I beamlines are expected to be operational in mid-2004, and the remaining two beamlines at the end of 2004.

E. Challenges for the Canadian Light Source

The CLS's biggest challenge in the medium to long term will be to obtain enough funds to construct the additional beamlines envisioned and keep the facility running. The operating monies currently committed by the various funding sources are sufficient to maintain the Phase I beamlines only. Additional operating funds will be required for the Phase II beamlines. Industrial fee-for-use revenue will be lower than originally anticipated, especially for the first few years of operation.

Some members of the scientific community are calling for an improved, standardized review process for deciding which national facilities receive federal support. Part of this process would involve making sure that all of the costs (construction, operating and decommissioning) are properly accounted for in the initial proposal to construct such a facility, and that sources for the funds are identified. Such "due diligence" would help to ensure that national, "big science" facilities, such as the CLS, do not have to scramble to obtain operating funds once they have been constructed.

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