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A CENTURY OF CANADIAN PHYSICS

UN SIÈCLE DE PHYSIQUE AU CANADA

Vol. 56 No. 2

PHYSICS IN CANADA
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This issue is a celebration of the personalities, the institutions, and the ideas that spanned a century of Canadian physics: 1900 - 2000.

Ce numéro rend hommage aux individus, institutions et concepts qui ont composé ce siècle de physique au Canada : 1900 - 2000.

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– FOREWORD / PRÉFACE –

A CENTURY OF CANADIAN PHYSICS

UN SIÈCLE DE PHYSIQUE AU CANADA

The invitation to edit this Millennium Issue of *Physics in Canada* came to me as a surprise and a pleasure. And then it became a significant - but not unenjoyable - responsibility. The "Millennium" for this purpose rapidly became a "Centennial" because there appears to have been almost no physics in Canada before 1900. The past century, however, has been very eventful and there is much to celebrate.

Rather than attempt a well researched history of the past century of Canadian physics I proposed an anecdotal approach and provided a plan to the Editorial Board of *Physics in Canada*. It endorsed my plan and, happily, almost every one of the authors whom I approached accepted their assigned task. Any merit that this issue possesses belongs to these authors collectively while any failures and omissions are clearly my responsibility.

It was also my proposal to salt the issue with short pieces, or vignettes, about some of the key players in Canadian physics during the past century. The Editorial Board also accepted this proposal and endorsed my plan to restrict such vignettes to two classes of people: Canadian Nobel Laureates and some distinguished Canadian physicists who are deceased. The choices of such individuals is somewhat less controversial than trying to choose among the many distinguished Canadians who are still living. I wanted to retain at least a few friends! Those living Canadian physicists who aspire to be among the icons can console themselves by the fact that they are still alive! My selection of deceased icons is subjective and surely incomplete, but perhaps those chosen are representative of the strong individual personalities who have dominated Canadian physics.

The choice of articles and my own introduction to them (see article in this issue on "A Century of Canadian Physics: Much to Celebrate") are also clearly subjective. The history of the century of physics and of Canada's role, in my overview, are clearly influenced by my personal experiences but I have tried, within my limitations, to take a broad view. Others would have seen it differently. The end of the millennium is clearly a time for all of us to reflect on the development of Canadian physics. Perhaps we can march forward more confidently if we share our views of the past.

The various articles differ not only in subject matter but also in style. This is deliberate. Perhaps the variety of material will also make this issue a worthwhile chronicle or archive for much of our past. Hopefully, also, the articles will provide some knowledge, pleasure and entertainment to the readers.

I want to thank Francine Ford for her extraordinary help in the preparation of this issue.

Erich Vogt, Honorary Editor
Professor Emeritus, University of British Columbia

UN SIÈCLE DE PHYSIQUE AU CANADA

J'ai été agréablement surpris de recevoir l'invitation d'éditer ce "numéro millénaire" de *La Physique au Canada*. Et puis cette tâche est ensuite devenu une responsabilité considérable, mais plaisante. Le "millénaire" s'est rapidement transformé en "siècle" parce qu'il semble qu'il n'y avait que très peu de physique au Canada avant 1900. Le dernier siècle, en revanche, s'est prouvé très fructueux et nous donne beaucoup à célébrer.

Plutôt que de tenter de présenter une histoire bien documentée de la physique canadienne du siècle passé, j'ai proposé une approche anecdotique et en ai présenté un plan au Comité de rédaction de *La Physique au Canada*. Mon plan a été adopté et, heureusement, presque tous les auteurs que j'avais contactés ont accepté leurs tâches assignées. Tous les mérites de ce numéro reviennent collectivement à ces auteurs, tandis que les erreurs et omissions éventuelles sont clairement ma responsabilité.

Il faisait aussi parti de mon approche de saupoudrer ce numéro de courtes pièces, ou d'esquisses biographiques, à propos des personnages-clés de la physique canadienne du siècle dernier. Le Comité de rédaction a aussi accepté cette proposition et a endossé mon plan pour restreindre ces esquisses à deux classes de personnes : les Prix Nobel canadiens et certains/nes physicien/nes canadien/nes décédés/es de renom. Choisir parmi ces individus/es est plus facile et moins sujet à la controverse qu'essayer de choisir parmi les innombrables canadien/nes renommés/es toujours vivants/es. Je voulais au moins garder quelques amis/es! Les physiciens/nes canadiens/nes vivants/es qui aspirent à faire partie de ce club sélect peuvent se consoler avec le fait qu'ils/elles sont toujours en vie! Mes choix d'icônes décédés sont subjectifs et sûrement incomplets mais ceux choisis sont propablement représentatifs des fortes personnalités individuelles qui ont dominé la physique au Canada.

Le choix des articles et l'introduction que je leur donne (se reporter à l'article de ce numéro intitulé "A Century of Canadian Phyics: Much to Celebrate") sont aussi clairement subjectifs. L'histoire du siècle en physique et le rôle joué par le Canada dans mon survol sont clairement influencés par mes expériences personnelles, mais j'ai essayé, selon mes limites, d'adopter un vision générale. D'autres auraient vu les choses différemment. La fin du millénaire est évidemment un bon moment pour nous tous de réfléchir au développement de la physique canadienne. Peut-être pourrons-nous marcher d'avant avec plus d'assurance si nous partageons nos vues sur le passé.

Les différents articles varient non seulement sur le sujet mais aussi sur le style. Ceci est fait délibérémment. Peut-être que la variété dans le matériel fera aussi de ce numéro une chronique ou une archive de valeur sur notre passé. Espérons, aussi, que ces articles amèneront un peu de savoir, de plaisir et de divertissement aux lecteurs.

Je veux remercier Francine Ford pour l'appui exceptionnel qu'elle a su offrir tout au long de la préparation de ce numéro.

Erich Vogt, Rédacteur honoraire
Professeur émérite, Université de la Colombie-Britannique

LETTERS / *LETTRES*

NOBEL LAUREATES

(November/December 1999 issue of *Physics in Canada*)

I enjoyed the recent article in PiC of Nobel Laureates with Canadian connections. I was surprised, however, that there was no mention of Myron Scholes (economics 1997). Although a winner in economics, Scholes has been a great inspiration to the legion of physicists who are now working in finance. All of these rocket scientists are familiar with the Black-Scholes equation for risk management, a mathematical theory that has made (and lost!) billions. Scholes was born in Timmins, Ontario and studied at McMaster University before making the journey southward.

Hamish Johnston (Dr.), Acting Editor
Vacuum Solutions, Institute of Physics Publishing

EASE HIS PAIN: JOSEPH GRAY OR ARTHUR COMPTON

(January/February 2000 issue of *Physics in Canada*)

The article by Innes K. MacKenzie in *Physics in Canada* (Vol. **56**, p. 43) provokes me to offer a comment on the background behind the confirmation of DeBroglie's equation relating wavelength with the momentum of travelling particles, and the fact that important roles were played by people who are scarcely, if ever, mentioned, one of them a Canadian.

My Professor of Physics when I was an undergraduate was G.P. (Sir George) Thomson, who is credited with one of the first demonstrations of the phenomenon of electron diffraction. Thomson's main interest had been the con-conduction of electricity through gases, for which his father (J.J. Thomson) was awarded the Nobel Prize (although it was said that G.P. had done most of the work!). While at the University of Aberdeen in 1925, G.P. had a young graduate student named Reid, and suggested that he insert a piece of celluloid into the electron beam in a tube similar to a Crookes Tube, and see what happened. It produced rings corresponding to a Debye-Scherrer pattern on the screen. The preliminary results were published jointly by Thomson and Reid (Nature, **119**, p. 890, 1927) and more definitively by Reid alone (Proc. Roy. Soc. A **119**, p. 663, 1928). However, Reid was, it seems, a keen motorcyclist, and within just a few days of the appearance of the Royal Society paper, he had a collision and was killed. But Thomson later received half the Nobel Prize for the discovery. Nobody ever mentions Reid, although G.P. himself, when he lectured to us on this subject, always spoke of "Mr. Reid and I".

While Thomson and Reid were working in Aberdeen, Davisson and Germer were working in the Bell laboratories in New Jersey, where they had just recruited a young Canadian named Chester Calbick. I had come to know Chester through conferences on electron microscopy in the 1960's, establishing a friendship cemented when we and our wives shared a compartment on a very uncomfortable train journey between Prague and Vienna in 1964. Calbick grew up in Nelson B.C. (where he learned to drive on the left hand side of the road!), and ultimately achieved a Ph.D. from Toronto, from whence he went to the Bell Labs.

In 1926, Davisson and Germer were attempting to demonstrate electron diffraction using a low energy beam and a reflection grating (a nickel crystal), collecting the scattered electrons with a Faraday Cylinder. They made scans, attempting to find a minimum between the central maximum of the diffusely scattered electrons, and where they calculated the first order diffraction maximum to lie, and failed. Frustrated, they went off to have coffee, leaving Calbick alone with the equipment. It seems he had been virtually only an observer in the experiment, and not really integrated into the discussions, but while Davisson and Germer were at coffee, he jacked up the voltage of the accelerator toward its maximum, and made another scan, demonstrating a minimum in the right place. When Davisson and Germer returned, Calbick said to them "Here - is this what you were looking for?". I don't remember exactly what Calbick said about what happened then, but I think they went and consumed something more interesting than coffee! Their results were published in Phys. Rev. **30**, p. 707, 1927. Davisson later received the other half of the prize along with Thomson.

Having told me this story, I asked Chester "Don't you feel at least a bit miffed that you did not get even a mention in this discovery?" He replied "Naw - I really had no idea what I was doing". However, although I feel he was being overly modest, he did go on to say he thought Germer was short changed, in that only Davisson shared the prize with Thomson.

Cyril E. Challice, Professor Emeritus of Physics
University of Calgary

ERRATUM

On page 7, in the January / February issue of *Physics in Canada*, we published a list of the recipients of the Premier of Ontario's Research Excellence Awards. The list was compiled from an announcement received from the Premier's Office. Unfortunately, we were not aware that other CAP members had received similar awards in earlier rounds. These include:

Z.Y. Jeff Chen; statistical physics of biological macromolecules.
Marc Michael Dignam for theoretical investigations in semiconductor nanostructures.
John R. Dutcher for investigation of the mobility and thermal stability of polymer molecules confined to thin films.
Michel J.P. Gingras for theoretical investigation of the influence of random disorder on superconducting and magnetic systems.
David Holdsworth - (no details available at this time).
André Longtin for biophysical and computational studies of sensory information processing using an electric fish model.
Donna Strickland; coherently controlling dissociation of molecules.
Christina Diana Wilson; case studies in the Milky Way and other galaxies.

CALENDAR / CALENDRIER

2000 MARCH/MARS

17-19 **Quantum Physics Centennial Symposium**, University of Saskatchewan, Saskatchewan. For further information, contact: T.G. Steele at tel.: (306) 966-6427 or e-mail: Tom.Steele@usask.ca.

23 **How We Measure Up: The Government's Contribution to Canadian Research**. Industry Canada - Executive Complex, 11th Floor, East Tower, 235 Queen Street, Ottawa, Ontario. R.S.V.P.: Isabelle Masse, tel.: (514) 499-4085 or mail to: isabelle_masse@inrs-urb.uquebec.ca.

La R-D en milieu gouvernemental : mesure des résultats. Industrie Canada - Complexe exécutif, 11ième étage, Tour de l'est, 235, rue Queen, Ottawa, Ontario. R.S.V.P. : Isabelle Masse, tél. : (514) 499-4085 ou consultez : isabelle_masse@inrs-urb.uquebec.ca.

2000 MAY/MAI

7-11 **The 2000 ANS International Topical Meeting on Advances in Reactor Physics and Mathematics and Computation into the Next Millenium**, Westin William Penn Hotel, Pittsburgh, Pennsylvania, USA. See Web site for instructions: http://ans-pgh.commerce.wec.com/rp2000.htm.

22-24 **17th Canadian Conference on Surface Science, University of Western** Ontario, London, Ontario. For further information visit http://www.uwo.ca/isw/sc2k/ or contact Keith Griffiths, Chair, at griff@uwo.ca.

2000 JUNE/JUIN

4-7 CAP Congress/Congrès de l'ACP, Université York University. For more information see the CAP website - http://www.cap.ca.

12-16 **ICAPT'2000 International Conference on Applied Photonic Technology 2000**, Hôtel Loews Le Concorde, Québec. For more information please contact: Roger Lessard by e-mail at ralessard@phy.ulaval.ca

16-21 **19thInternational Conference on Neutrino Physics and Astrophysics - NEUTRINO 2000**, Laurentian University, Sudbury, Ontario. For further information, contact: NEUTRINO 2000 Secretariat at www.nrc.ca/confserv/nu2000, e-mail: nu2000@nrc.ca, fax: (613) 993-7250.

18-23 **Sixth Annual Summer School on Neutron Scattering**, Chalk River, Ontario. For more information, please contact John Katsaras at (613) 584-8811, ext. 3984 or visit http://neutron.nrc.ca.

18-23 **Optics in Computing 2000**, Hotel Hilton, Québec. For more information please contact: Tigran Galstyan by e-mail at galstian@phy.ulaval.ca or visit their website http://oc2000.ulaval.ca.

2000 JULY/JUILLET

3-7 **VII Inter American Conference on Physics Education, Porto Alegre** (Canela), Brazil. For more information please contact: Marco Antonio Moreira, Chair, e-mail: iacpe7@if.ufrgs.br or M.L. Ligatto-Slobodrian, email: mligatto@slc.qc.ca

23-28 **World Congress (WC 2000) on Medical Physics and Bioengineering**, Chicago, Illinois, USA. For more information please contact: William Hendee by e-mail at whendee@post.its.mcw.edu

2000 AUGUST/AOÛT

6-11 **16th IUPAC Conference on Chemical Thermodynamics** (concurrent with 55th Calorimetry Conference and 10th Symposium on Thermodynamics of Nuclear Materials), Halifax, NS, Canada. For more information contact Mary Anne White, Dept. of Chemistry, Dalhousie Univ., Halifax NS B3H 4J3; Tel: (902) 494-3894; email: ICCT@is.dal.ca, website: http://is.dal.ca/~icct

24-26 **Millennium Symposium on Science, Society and Human Rights**, University of Regina, Saskatchewan. For further information, consult: http://www.uregina.ca/arts/ms2000.

2000 OCTOBER/OCTOBRE

16-20 **IUPAP International Conference on the Fractal Aspects of Complex Systems (FACS 2000)**, Maceio. The Conference will be hosted by the Statistical Physics Group of the Departamento de Fisica (Universidade Federal de Alagoas). For more information please contact Dr. Marcelo Lyra, email: marcelo@ising.fis.ufal.br or visit their website: http://facs2000.fis.ufal.br

2000 DECEMBER/DÉCEMBRE

15-16 **Third World Congress of Physical Societies**, Berlin, Germany. For more information contact: Mireille Cubizolles, Main Secretariat, EPS, at e-mail: m.cubizolles@univ-mulhouse.fr.

2001 -

European Federation for Information Technology in Agriculture, Food and the Environment (EFITA) Congress, Montpellier, South of France. For more information, contact Francis Sevilla at sevilla@ensam.inra.fr.

FUTURE CAP CONFERENCES

2000 Annual Congress, June 4-7, 2000
York University, Toronto, ON.
2001 Annual Congress, June 17-20, 2001
University of Victoria, Victoria, BC.
2002 Annual Congress, June 9-12
Laval University, Québec, QC

For more information, checkout - www.cap.ca, then go to the Congress Section

APS MEETINGS 2000 and Beyond

2000 March Meeting, March 20th -24th, 2000, Minneapolis, MN

2001 March Meeting, March 12-16, 2001, Seattle, WA

2002 March Meeting, March 19-22, 2002, Indianapolis, IN

WALTER KOHN, 1923 -

Walter Kohn
(Photograph reprinted with permission from *Physics Today*, 51(12), 1998, pp 21. Copyright 1998, American Institute of Physics.)

For fifty years Walter Kohn has been one of the world's most outstanding condensed matter theorists. He was born in Vienna, Austria, on March 9, 1923 and came to Canada during WWII. He obtained his B.A. (1945) and his M.A. (1946) from the University of Toronto prior to proceeding to Harvard for his Ph.D. under Julian Schwinger. Before leaving for Harvard, he spent part of his time as a geophysicist in Quebec and also worked part-time as an industrial physicist in Toronto. Most of his scientific career has been in the United States. In 1998, he received the Nobel prize in Chemistry for creating density functional theory. This theory became the method of choice for condensed matter physicists studying the dynamics of electrons. It also, according to the Swedish Academy, made Kohn one of "the two most prominent figures" in the "enormous theoretical and computational development" leading to the emergence of quantum chemistry.

Kohn's entry into Canada was not smooth. Since he was born of Jewish parents he needed to escape Nazi-occupied Austria. In 1938, at age 16, he was just young enough to qualify for the last Kindertransport out of Austria. He stayed for two years with a family in England before being sent to Canada for detention as an "enemy alien". He eventually served in the Canadian armed forces during WWII. He may not have been truly welcomed by Canada but he has retained very warm attachments to our country.

He was a professor at the Carnegie Institute of Technology for a decade (1950-1960) and then spent almost two decades at the University of California, San Diego, before moving, in 1979 to become the first director of the new Institute of Theoretical Physics at the University of California, Santa Barbara. He has ranged widely over condensed matter theory but the density functional work for which he won the Nobel Prize was carried out during the 1960's at the University of California, San Diego. Its development involved Kohn's collaboration with Pierre Hohenberg and Lu Sham.

For his large circle of friends and admirers, Kohn is a delightful person. He is full of Viennese urbanity and charm, and always very generous and supportive. We are very fortunate to have enjoyed his strong association with Canada.

Erich Vogt, Professor Emeritus
University of British Columbia

NEWS / *NOUVELLES*

NEW MEMBERS APPOINTED TO NATIONAL RESEARCH COUNCIL OF CANADA

On February 8, 2000, John Manley, Minister of Industry, and Dr. Gilbert Normand, Secretary of State (Science, Research and Development), announced the appointment of Dr. André Gosselin, a senior researcher and former Dean at Laval University, and Pascale Michaud, a Partner in SECOR Consulting Group, to the governing Council of the National Research Council of Canada .

Dr. Gosselin is not only a highly respected educator, scientist and research leader who has published hundreds of papers, received many national and international honours, and introduced many innovations as Doyen de la Faculté des sciences de l'agriculture et de l'alimentation at Laval University, he is also an entrepreneur and active in the innovative business community. His honours include Fellow of the American Horticultural Society, Prix Roland-Harnois of the Conseil québécois de l'horticulture, and the Médaille de distinction agronomique of the Ordre des agronomes du Québec.

Ms. Michaud is an international expert on the process of innovation and the governance of complex projects. She was the co-developer of the IMEC International Research Program, an important worldwide initiative concerning the management of large-scale engineering and construction projects. As a researcher, policy consultant, and Partner in SECOR, she provides strategic advice to organizations including Hydro-Québec, Usinor, Bristol Myers Squibb and the National Advisory Board on Science and Technology.

A CENTURY OF CANADIAN PHYSICS - MUCH TO CELEBRATE -

by Erich Vogt

There is much to be proud of in the past century of Canadian physics. In spite of almost continuous neglect of research funding by Canadian governments, some wonderful physics emerged from Canadian physicists working both in Canada and abroad. Perhaps the success of individual Canadian physicists is the result of a long tradition of excellent undergraduate physics training in Canada combined with the fact that Canada's geography evokes a strong response for the natural sciences. We shall discuss how the century of physics evolved in Canada in terms of the development of physics worldwide.

In spite of almost continuous neglect of research funding by Canadian governments, some wonderful physics emerged from Canadian physicists working both in Canada and abroad.

HOW PHYSICS EVOLVED IN THE WORLD

Just before the end of the last century the main issues in physics appeared to be settled. Two centuries earlier Newton had created classical mechanics, which seemed to describe the motions of all objects on the earth or in the sky. Three decades before 1900 Maxwell had accomplished a remarkable synthesis of all phenomena pertaining to electricity, magnetism and light. Many of the important issues pertaining to gases and liquids were addressed by the new thermodynamics. A few issues remained; for example, about the atomistic nature of matter. Such issues were few enough that Lord Kelvin - clearly afflicted by an end-of-century malaise which also exists as the current century is turning - was led to surmise that all the principal problems of physics had been solved.

But Nature has a sense of humour, and so the present century began with a remarkable set of physics discoveries which launched an equally remarkable expansion of science as a whole. We begin by describing these discoveries and this expansion and then discuss the role that Canada played and how it responded to the new opportunities for physics and science.

The first three of these discoveries, about X-rays and radioactivity and the existence of the electron, came just before the turn of the century, almost as Lord Kelvin was uttering his unfortunate pronouncement. Roentgen's discovery, in 1895, of the penetrating radiation from a Crookes tube sparked great immediate interest worldwide, and many applications. Becquerel's discovery, in 1898, of radio-activity - the spontaneous radiation from the uranium salts whose fluorescence he was studying - did not spark quite such a strong immediate reaction from the world science community but had greater long range implications for physics. The Curies and Rutherford immediately explored the nature of radioactivity and its wide occurrence among the elements. Thomson's discovery of the electron, in 1897, was a cornerstone for the understanding of the atom, the development of quantum mechanics and a great deal of the whole edifice of modern physics.

Then, in 1900, Max Planck was led to postulate that thermal radiation was quantized with atoms radiating photons only at discrete energies. He knew at once that his conjecture, if true, would be world-shaking. Soon after, in 1905, which was undoubtedly the most miraculous year of discovery for any individual scientist, Einstein pushed the quantum idea further with his work on the photoelectric effect (for which he won the Nobel prize), published his Special Theory of Relativity and also his treatment of Brownian motion.

E. Vogt (vogt@triumf.ca), Professor Emeritus, University of British Columbia, 4004 Wesbrook Mall, Vancouver BC, V6T 1Z1

But Nature was not yet finished with its sequence of discoveries to launch 20th century science. An understanding of the atom was needed to fully develop the quantum ideas.

It was in 1911 that Rutherford discovered the true nature of the atom as a "planetary" system with almost all of its mass concentrated in a very small, central, positively-charged nucleus surrounded by electrons. In a very simple experiment, alpha particles were aimed at a gold foil and the scattering of the alpha particles was observed. Geiger and Rutherford found that some of the alpha particles bounced right back. Using the Scattering Law for alpha particles which Rutherford derived very elegantly from his knowledge of the Kepler laws of planetary motion (he was a very good theorist in spite of his healthy disdain for theoretical physicists) a very good fit to Geiger's data was obtained. Thus Rutherford proved that the planetary model was valid for the atom and he was even able to find an upper limit for the size of the nucleus. Bohr was at Manchester with Rutherford at the time and very soon produced the Bohr atom in which the electrons surround the nucleus in discrete orbits. The atomic spectra corresponded to the emission of photons when electrons in excited orbits make transitions to lower orbits. Although initially he got it slightly wrong, Bohr's concept was momentous. Very rapidly Bohr's atom and the atomic spectra became the test bed for the proper development of quantum mechanics.

Quantum mechanics burst into prominence in 1925-26, largely through the work of Heisenberg, Schroedinger, Born, and Dirac. The concept of quantized spin was required for the understanding of atomic spectra. The strange concepts of quantum mechanics (discreteness rather than continuity, intrinsic uncertainty, probabilistic interpretations, etc.) and the requisite strange mathematics constituted a revolution in thinking about the physical world. Like all revolutions, this one ended with dogma: the Copenhagen Interpretation, accompanying the framework of quantum mechanics, has been an astonishingly successful description of the subatomic world. It is amusing that, in spite of all of the effort devoted to quantum mechanics, it is only now, after 70 years, that some of the dogma is being removed. We may eventually be able to teach our students about the systematics of quantum mechanics without the baggage of unphysical concepts such as wave function collapse. The convergence of theory to Nature's truth is asymptotic.

When, very early in the century, it became possible to liquify helium and to attain very low temperatures, some startling phenomena were observed, such as the discovery, in 1911, of superconductivity by Kamerlingh Onnes in Holland. Its understanding was a long time challenge for the new quantum mechanics.

Einstein's General Relativity, in 1920, reinterpreted gravity as space curvature. This discovery, quickly verified, is of huge consequence for physics. It underlies a great deal of modern cosmology. The reconciliation of gravity with quantum mechanics eluded Einstein and remains a major open problem today.

Just as Rutherford's 1911 experiment at Manchester created the study of the atom, the discovery of the neutron, in 1932, by Chadwick, in Rutherford's Cavendish Laboratory in Cambridge, created nuclear physics. Only a few years later fission was discovered and, during WWII, nuclear physicists lost their innocence with the creation of atomic weapons.

Through the discoveries just outlined, physics dominated fundamental science for the first half of the past century. Nuclear physics became, at mid-century, the leading field of physics. But then quantum mechanics and the experience during WWII of large teams of physicists creating radar, the Manhattan Project, etc., led to a very impressive worldwide expansion of science. Entirely new fields of science emerged - such as cosmology, microbiology, materials science and microelectronics, particle physics, etc. - which challenged and even displaced nuclear physics from its place on centre stage. Almost all physicists active in Canada today are personally familiar only with this expansionary era in the second half of the century.

For several decades following WWII, nuclear physics remained a prime vehicle for exploring the laws of quantum mechanics as they applied to subatomic systems. Almost every university in the Western world acquired a small accelerator. The detailed properties of thousands of nuclear energy levels were explored and elegant models emerged for nuclear spectroscopy, the study of the oscillation, vibration, and rotation of systems of neutrons and protons. In recent decades the focus on nuclear spectroscopy declined somewhat and the interests of nuclear physics turned to the use of higher energy accelerators for the elucidation of strong interaction physics (including the possible impact of the quark substructure of the nucleons), Big Bang physics, fundamental symmetries, nuclear astrophysics, and exploration of the farthest reaches of the nuclear landscape. This landscape includes the ridge of stable isotopes but continues to the unstable isotopes whose neutron and proton numbers place them far from the ridge. One can proceed to superheavy elements beyond uranium or to the regions of ligther isotopes far from the stable ridge. These regions extend up to the neutron or proton drip lines at which nucleons can no longer be held. The physics in these exotic regions is very different from that of the stable nuclei and is a new challenge for the field.

Perhaps future generations will consider the biggest achievement of the past century of science the fact that with modern cosmology we have been able to articulate the history of the universe in which we live from its earliest moments to the present. This cosmology owes its creation to quantum mechanics, to General Relativity, and to nuclear physics. We can observe remnants of the initial Big Bang and now, both in particle physics and in space astronomy, we can trace the history of the universe back to a million-billionth of a second after the Big Bang. We also understand the various processes of stellar collapse including the final explosive stage in which a white dwarf, a neutron star, or a black hole is generated. The very lightest isotopes of all of the elements were generated in the initial Big Bang and the isotopes of all of the heavier elements in the various stages of a star's evolution. The final collapse of a star involves all of the thousands of isotopes of the entire nuclear landscape. It remains a challenge for current nuclear astrophysics to understand, experimentally and theoretically, all of the reactions involved.

Particle physics emerged from nuclear physics after WWII, through the development of higher energy accelerators and also through theoretical tools to describe the fundamental building blocks and forces of Nature. The experimental tools of nuclear physics were accelerators with beams of protons, electrons, etc. with energies below about 100 MeV, commensurate with the energies of nuclear states. The tools also included ever more sophisticated (and sometimes larger) detectors to measure the reaction products. Since 1930, accelerator energies have leapt by an order of magnitude every six years, starting with Lawrence's cyclotron, in 1930, whose energy was below 1 MeV. Accelerators to create pions emerged soon after the war. Very rapidly one found hundreds of new particles, especially mesons (related to the pion) and baryons (related to the nucleon). What to make of this zoo? It is not surprising that the scientific method, applied to this data, soon led to the discovery of the building blocks (quarks) for these strongly-interacting "elementary" particles. Evidence for the existence of quarks first came in 1967, at Stanford University, from the deep-inelastic scattering of very high energy electrons from protons. A Canadian, Richard Taylor, was one of the Nobel Laureates in physics, in 1990, for this work at Stanford University. Six quarks were soon joined by six leptons (weakly interacting particles such as the electron and its neutrino) to complete the new understanding of Nature's basic building blocks.

In the postwar decades a unified description of the fundamental forces of nature began to emerge. First, in the late 1940's, quantum electrodynamics (QED) was liberated from the infinities which had plagued it. This renormalization of QED, by Feynman, Schwinger, Tomonaga, and Dyson was possible because of the local gauge symmetry of Maxwell's electromagnetism according to which the theory had a "gauge" freely adjustable at every position. QED was the first quantum field theory with local gauge symmetry. It became a template for the quantum field theories for other interactions, especially for the weak interaction. In a unified description of electromagnetism and the weak interaction through a local gauge theory (the electroweak theory), neutral currents emerged and the quantum of electromagnetism, the massless photon, was joined by three very massive vector bosons, the positive and negative W and the neutral Z. The quadruplet of bosons (the vector bosons and the photon) were the quanta of the electroweak field. In parallel a local quantum field theory, quantum chromodynamics (QCD), with gluons as the exchange particles, emerged for the strong interaction. Further, candidate theories for the unification of the electroweak theory with QCD (Grand Unification Theories) emerged. In all cases the local gauge symmetry was essential for renormalization and, as a side effect, gave very interesting new properties to the vacuum. Ideas about the inclusion of gravity in a unified description of all of the fundamental forces have come forward, and there are hopes of reconciling gravity with quantum mechanics. However, the realization of these hopes, through superstring theory, may still be decades away.

The so-called Standard Model of quarks, leptons and partially unified forces achieved its greatest confirmation with the discovery, at CERN, in 1982, of the gauge bosons of the electroweak theory. The large team which made this discovery was led by Carlo Rubbia of Italy; Alan Astbury, now director of TRIUMF, was the deputy leader. Since then the goal of particle physics has been to try to find what lies beyond the Standard Model. Where is the Higgs particle, the quantum of the fields which give mass to the basic building blocks? Why does the Standard Model have so many dozens of parameters? Is there some Supersymmetry or do we live in a world of Superstrings? Will the new supercollider at CERN, scheduled to begin operation in 2005, provide answers? As the century closed the Standard Model remained remarkably resilient. Perhaps Nature is poised again to surprise us at the beginning of this next century.

The basic concepts of materials science began to emerge after the birth of quantum mechanics in the 1920's. For a quantum description of solids one needed phonons, the quanta of vibration of the atoms in their lattice, and also the dynamics of electrons moving in bands in the periodic lattice. The events which brought condensed matter physics into prominence occurred in the 1950's, first with the experimental discovery of the properties of semiconductors which led to transistor devices, and secondly with the theoretical understanding of superconductivity in terms of electron-phonon interactions. The transistor was discovered by Bardeen, Brattain and Shockley at Bell Telephone Laboratories and the superconductor theory by Bardeen, Cooper and Schrieffer at the University of Illinois. The burst of activity which soon followed made condensed matter the largest subfield or constituency of physics. A Canadian physicist, Walter Kohn, received the Nobel prize for chemistry in 1998 for his work in understanding the electronic structure of materials. Many elegant ideas emerged in condensed matter physics which had impact on all of physics. These ideas and discoveries pertained to superfluids, high-temperature superconductors, quantum Hall effect, etc. They are ample testimony to the fact that the human sense of wonder is excited not only by questions about the basic building blocks and forces but also by complexity in the wonderful systems of atoms and molecules which our world provides.

The field of microelectronics, which derived from condensed matter physics, is now all-pervasive in modern life. The way we communicate, the way we travel, the way we relax, and even the way in which we do physics is driven by microelectronics. Proper communication was so important for particle physics that physicists at CERN invented the World-Wide-Web. Although microelectronics can be regarded now as a large field of its own, it continues to count on physics, especially such new subfields as nanophysics - and possibly quantum computing - for ideas for its future development.

In the second half of the century many other fields of physics emerged, owing their impetus largely to quantum mechanics. The development of lasers in atomic physics and of much beautiful science associated with plasma physics are two examples. Arthur Schawlow, a Canadian physicist working at Stanford University, received the Nobel Prize in physics in 1981 for his contributions to laser spectroscopy. He had also been a co-inventor of the laser, along with Charles Townes, in 1958. A field in which Canada became very strong was geophysics. Professor Tuzo Wilson of the University of Toronto, a towering figure in the field, was the father of plate tectonics which is now crucial for the understanding of the earth's crust and the movement of the continents.

The very important advances in microbiology began, in the early 1950's with the discovery by two physicists, Crick and Watson, of the structure of DNA. By the end of the century this became a large and separate discipline, competing with the best of physics for centre stage in the world effort in science.

Physics has been on a roll. Will it continue? Judging from the open problems in cosmology, particle physics and the science of complex systems the challenges are as great as at any time in the past century. There is certainly no grounds for the end-of-century malaise evident in Lord Kelvin's pessimism a hundred years ago, and now echoed by John Horgan's new book, "The End of Science". Nature is whimsical and does not deal kindly with experts who make predictions. Challenges and opportunities abound.

CANADIAN PHYSICS IN A WORLD PERSPECTIVE

We describe what happened in Canada during the past century in terms of the development of physics worldwide, as discussed above. It is a story of strong individual accomplishments rather than Canada as a country vigorously seizing science opportunities. Similarly, with a few notable exceptions, Canadian governments of all parties have largely ignored science throughout the century. Their rhetoric has often included science but the performance of Canadian governments in supporting science initiatives, even ones of great potential benefit to the country, has been generally very weak compared to that of governments of other countries with whom Canada is competing economically. Why?

Canada is a vast and beautiful country with abundant natural resources and blessed, throughout the century, by the ideas and energy of immigrants. It has achieved a living standard and social services envied worldwide, using its natural resources and its influx of immigrants. Therefore Canada has not had to aggressively harness its brainpower for economic advancement in the way that Japan, Britain or even the United States have done. It has also attained an outstanding educational system so that every Canadian with a natural gift for physics can achieve excellent training in the subject. But our national culture does not nurture science. It is not that Canadians do not have national pride or do not value achievements by Canadians in science: they do. It is rather that collectively we never seem to have understood the value of science, especially fundamental science, as a driver of our economy. Other countries have understood and have reaped the benefits of physics research much more than Canada. Many of our best scientists have found opportunities abroad, and continue to do so.

Much of the often discussed Canadian brain drain is natural. Physics is a universal subject and those driven to make a career of it can cast their net widely. Canada is a relatively small country compared to the United States. Even if the playing field were completely even - which it isn't - a large number of Canadian physicists should be expected to drift to the United States. Similarly a large fraction of physicists raised in California (a pool of scientists comparable to that of Canada) end up in careers out of that state. Considering the unevenness of the playing field it is then a minor miracle that a substantial fraction of our scientists stayed in Canada. Their number has been augmented by a substantial influx of scientists into Canada from abroad, especially from Europe. But it is not an even slate. Probably almost every Canadian physicist throughout the century, whether working at home or abroad, has believed that Canada could have benefited even more from science. Our physics history is one of outstanding individual leaders and of world-class accomplishments. But it could have been even more. Here we celebrate what did happen.

Although many of the leaders of Canadian physics were born in Canada, Canadian physics, like Canada itself, benefited greatly from immigration. Among the outstanding individuals from abroad were Rutherford at McGill, Herzberg at Saskatchewan and NRC, Rasetti at Laval, Lewis at Chalk River, Pringle at Manitoba, D.KC. MacDonald at NRC, etc. Many of them are featured in the articles or brief vignettes of this issue. Canada welcomed and accommodated some of the world's best.

The history of Canadian physics appears to have no important milestones before the century began. There were a few universities in Ontario, Quebec and the Maritimes, and only a handful of physics professors. In most of the smaller universities there were one or two teachers for science as a whole. McGill University and the University of Toronto had physicists on their staff teaching physics. The universities were often innovative. For example, the first woman to obtain a science degree from a university in the British Empire was Grace Annie Lockhart who graduated from Mount Allison University in 1875. (Her grandson, Professor Kenneth Dawson, had a distinguished physics career at the University of Alberta and at TRIUMF).

In western Canada the only university which began before the turn of the century was the University of Manitoba, founded in 1877. However, the first physics professor at this university was Professor Frank Allen, appointed in 1904. The university was located then on its Broadway campus, near the Manitoba Parliament buildings. The life of the campus was disrupted, occasionally, by the hanging of a prisoner in the gaol next door. In his fine history of this department Robin Connor (PiC, **50**, page 340, 1994) has described how physics in Winnipeg obtained an enormous boost when the British Association for the Advancement of Science held its meeting there in August, 1909. Among the 1468 participants were Sir J.J. Thomson, Ernest Rutherford, Lord Rayleigh, and Professors Helmholtz, W.K. Roentgen, A.E.H. Love and J.H. Poynting. It was a real intellectual feast for a frontier outpost. Winnipeg was then a city with a population approaching 100,000 but it was at the edge of the world. It was only a few decades since the Canadian Pacific Railroad had marched west into virgin territory from which the buffalo were just disappearing.

The appointment of Ernest Rutherford as a Professor at McGill University in 1898 (see John Robson's article on Rutherford in this issue) and the appointment, a few years later of John McLennan at the University of Toronto (see Craig Brown's article in this issue) can be regarded as the initiation of physics research in Canada. Rutherford was very young and energetic and at the height of his powers. Singlehandedly he brought world leadership to McGill in the hottest new physics subject at the time, radioactivity. He teamed with Frederic Soddy to elucidate the chemistry of the radioactive isotopes and he discovered at McGill many of the most important properties of radioactivity. As Robson describes in his article in this issue, Rutherford's decade in Canada and his subsequent nurturing of a whole generation of Canadian physicists had profound influence on Canada.

John McLennan was home grown but he also singlehandedly placed Toronto on the world map in physics research. Working in the early decades of this century, he began with a virtually unknown physics department and made it into one of the top few on the continent. He was strongly influenced and supported by Rutherford at McGill. McLennan ranged widely in research, including the exploration of atmospheric radioactivity, which he thought came from the earth rather than from cosmic rays originating in outer space. (He should have looked up rather than down!) Therefore he missed the boat. He eventually focussed on low temperature physics and was among the first in North America to liquify helium. He was very self assured - perhaps too self assured as people from Toronto have been known to be - and travelled to Europe frequently, boosting the University of Toronto and in search of ideas and physicists. As a result he wasn't always liked. Sir Rudolf Peierls told me how, in 1935, he had been in Lord Cherwell's office at Oxford when someone came in and informed Cherwell that McLennan had died. Without hesitation Cherwell replied: "He won't be worrying about low temperatures now." The physics department which McLennan created in Toronto has remained, throughout the century, as Canada's strongest. One of Canada's outstanding scientists, Harry Welsh, personally supervised about 65 Ph.D. students at the University of Toronto.

The only times when the Canadian government left its normal state of inertia to create substantial science enterprises was during the two world wars. In WWI the National Research Council (NRC) was created; in WWII the Chalk River Nuclear Laboratory was initiated. These two national laboratories had greater impact on Canada's physics during the past century than anything else. We dwell on them at some length here not only because of their glory but also because the recent decline of their physics is an exceptionally poignant story. The university scene in Canada is less melodramatic.

In this issue Paul Redhead describes, very impressively, the history of accomplishments of NRC. Created in 1916 as the Honorary Advisory Council for Scientific and Industrial Research it immediately funded science fellowships at Canadian universities and created a research inventory. In 1928, during the presidency of H.M. Tory, the NRC Laboratory was authorized and grew steadily to a total staff of several hundred by the time WWII began. During that war it played a central role in many fields: medicine, synthetic fuels, weapons, etc. NRC was fortunate to be led by two great presidents in succession, C.J. MacKenzie (1939-1952) and E.W.R. Steacie (1952-1962). Under their visionary leadership the staff of the NRC Laboratory grew to several thousand and embraced a large variety of programs in science and engineering. It was MacKenzie, an engineer, who established a stronger basis for fundamental science. Steacie raised the extramural funding of research grants to Canadian universities to roughly equal the NRC Laboratory funding. The extraordinary development of university research in physics and of graduate training after WWII, as described by Preston and Howard-Lock in this issue, was due to this inspired stewardship of grant funding by NRC.

NRC gave birth to a number of other agencies, important not only for physics research in Canada but for more general science. Atomic Energy of Canada Ltd. was spun off soon after the war. So was defence research to the Defence Research Board (DRB). The Medical Research Council (MRC) became a separate entity in 1966 and the Natural Sciences and Engineering Research Council (NSERC) in 1978. Also science policy for Canada, which had been part of NRC's mandate for almost five decades, became the function of the Science Secretariat and the Science Council in 1964.

What we need to celebrate most about NRC is not its growth in numbers or its progeny but the quality of its science during its prime years, the first few decades after the war. A beacon of excellence was needed by Canadian physics and NRC was it. C.J. MacKenzie sought outstanding scientists and found them in

Herzberg, D.K.C. MacDonald and many others. The NRC Laboratory became a place to which outstanding young scientists from around the world flocked. Many stayed. Perhaps, also, many Canadians who had gone abroad returned to Canada, despite the uneven playing field, because it was a country which nurtured the NRC, whose work was honoured around the globe. NRC matured into the soul of Canadian science.

Great science is catching and there was an epidemic of good physics at NRC. Some of the best of it was assembled within the NRC Laboratory into the Herzberg Laboratory for Astrophysics. It is very sad for Canada that NRC did not continue to receive the visionary leadership which created its scientific momentum. Even in the areas of physics in which NRC was traditionally strong it could have remained a world centre for high quality physics. Looking at NRC from a distance it is not hard to envisage that it could have pioneered Bose-Einstein condensates or fourth-generation synchrotron radiation facilities for Canada or fast-laser physics or nascent efforts with thermonuclear fusion. Instead, beginning in about 1980, much of its best science withered, many of its best scientists fled or were invited to leave, the Herzberg Institute decamped, and the fusion program was cancelled even though it had many excellent scientists. Again, why? There were some well intentioned leaders and a lot of government neglect which changed conditions. However, in its science programs Canada seems to have been afflicted more than other western nations by the impact of government bureaucrats infected with a disease called "science policy" and who did not possess either the knowledge of science or the vision, and the feeling about the wonder of it all and of its impact on the economy. Governed by this malaise, the bureaucrats demanded that the large institutions be steered to achieve spin-offs directly relevant to the national economy. Sometimes the bureaucrats were aided and abetted by special advisory panels, established for this purpose, from a divided community of academic scientists. The realignment was a major obstacle for NRC's leaders and, for a while, they did not appear to be able to overcome it. Only recently have there been signs of positive change in NRC. But a significant fraction of what constituted NRC's (and Canada's) science glory has fled and it will not be easy to restore it. We should all wish NRC well for the next century.

There is a truism which Canada needs to relearn about science and the economy. If you want to be world class in the impact of science on the economy what you need is world-class ideas and world-class scientists provided with the right culture. For this purpose fundamental science is at least as good a vehicle as science more closely related to the desired spin-offs, in part because it often attracts better scientists. Governments in many countries resonate with this truism, as do their constituents, even when the bureaucracy develops contrary views. For example, even the most right-wing parties in countries like the United States advocate a strong central role of government in long-range research. By being directed to focus on the stimulation of Canadian industry, rather than keeping an important component of fundamental research and the top notch scientists who go with it, NRC was weakening its ability for that very mission. The NRC of Gerhard Herzberg and D.K.C. MacDonald was a great vehicle for fundamental research and for spin-offs. It would be wonderful for Canada if, in the new century, NRC were encouraged to sparkle like that again.

Canada had moments when visionary scientists interacted directly with senior elected politicians and initiated major science programs. The handshake of C.J. Mackenzie with C.D. Howe for the creation of Chalk River was one such moment; the interaction of George Laurence with his Minister, Jean-Luc Pépin, for the creation of TRIUMF was another. More recently the possible science programs have been carried by non-visionary bureaucrats fettered with unnecessary science policy concerns. In the crucial game of science, since 1980, the removal of much of NRC's fundamental science made the score: Bureaucrats 1, Canada 0.

The development of Canada's nuclear energy program and the physics research of the Chalk River Nuclear Laboratories (CRNL) are the subject of three articles in this issue. Phillip Wallace gives a vivid first hand account of the Montreal Laboratory during WWII, at which Canada's nuclear program was initiated. Jim Geiger and Tom Alexander give a history of nuclear physics at CRNL. Bill Buyers describes the personalities involved in the creation of Canada's neutron program.

Greatness was thrust upon Canada in nuclear physics. Ernest Rutherford, whose impact on Canada is described by John Robson in this issue, literally created nuclear physics. In the first decade of this century he was at McGill University and then, during several decades at the Cavendish Laboratory in Cambridge, England, he trained a number of Canadian scientists who were key to the development of Canada's program. Soon after fission was discovered, one of Rutherford's students, George Laurence, began work at the wartime NRC laboratories in Ottawa on building a reactor. The future program was shaped by a thrilling wartime story in which most of the world's supply of heavy water was spirited out of Norway, just before the Germans could get hold of it, and sent to Canada, via France and Britain. The dice were cast in the Quebec City meeting, in August 1943, of Churchill, Roosevelt and Mackenzie King, at which the Allies assigned to Canada the role of exploring heavy-water reactors. This was a part of the overall effort to exploit fission, of which the Manhattan project was the biggest component. As Wallace describes, French, British, American and Canadian physicists of the top rank then worked at a secret laboratory located at the University of Montreal. This was the cradle of CRNL. There was great concern about the state of the German fission program and significant suspicion about collaboration with the USSR: there were tensions about the connections of the initial French management of the Montreal laboratory with Frederic Joliot-Curie in France, a known Communist and possible informant for the USSR. In wartime secrecy, with a cast of international luminaries, CRNL was conceived and then created by the famous handshake of NRC's visionary president, C.J. Mackenzie with the great cabinet minister, C.D. Howe. Great Canadian physics followed.

The 70th birthday of W. Bennett Lewis at the home of Erich Vogt in Vancouver. In the photo from left to right are: Mrs. Barbara Vogt, W. Bennett Lewis, Gordon Shrum, Akito Arima (currently the science Minister of Japan), George Volkoff and Mrs. Olga Volkoff.

It was great to be a young Canadian physicist when CRNL began. Physics emerged from WWII as the queen of the sciences and nuclear physics was the dominant field. The CANDU reactor program was the lodestar and the NRX reactor, coming into operation, was the stepping stone. It led the world in neutron flux and, indeed, CRNL soon was among the strongest laboratories in the world in nuclear physics. There was a "Golden Era" of several decades after the war in which CRNL placed Canada on centre stage in the world science effort as at no other time.

The "Golden Era" was an exciting mix of people and ideas. Propelling the program was W. Bennett Lewis who commandeered great science to bring CANDU to fruition. First Bernice Sargeant, and then Lloyd Elliott, gave great personal leadership to the physics research. John Robson gave the first accurate measurement of the lifetime of the neutron. Pontecorvo and Hincks measured the lifetime of the muon and studied the muon's rare decays. Hanna and Pontecorvo were the first to pursue solar neutrinos by the chlorine radiochemical technique and to search for neutrino mass from the beta decay of tritium. Kinsey and Bartholemew initiated high resolution neutron capture gamma-ray studies. Brockhouse and his colleagues began the Nobel-Prize winning work on the use of neutrons for the dynamics of condensed matter. Elliott and Bell used new scintillation counters for a wide ranging program of beta and gamma ray spectroscopy. Graham, Ewan and Geiger used a superb beta spectrometer for beta spectroscopy and later Ewan, Fowler and Tavendale developed Li-drifted Germanium detectors which revolutionized nuclear spectroscopy. Milton and Fraser carried out systematic measurements of neutron emission from fission fragments. These are just a few examples of the experiments which characterized CRNL during the "Golden Era". The supporting programs in theory, electronics and detector development were also outstanding. A strong characteristic of CRNL was the extraordinary intensity with which physics was pursued and the correspondingly strong personalities of the physicists involved.

,The most celebrated science in this "Golden Era" pertained to the Chalk River tandem in the late 1950's and beyond. Eric Paul, Einar Almqvist and others had pioneered work at CRNL with low-energy electrostatic accelerators but it was the world's first tandem accelerator at CRNL which established the importance of high quality beams for nuclear spectroscopy and led to hundreds of similar machines being built elsewhere. The initial leaders of this tandem work were Bromley, Gove and Litherland, who all subsequently had brilliant careers at other institutions, as well as Ferguson, Kuehner and Almqvist. They were followed by Haeusser and Hardy and many others who, through many decades, maintained the very high quality of nuclear physics at CRNL as decribed by Geiger and Alexander in this issue.

During the "Golden Era", while neutron physics was born at CRNL and nuclear physics flourished, Alistair Cameron became a leader in the new field of nuclear astrophysics. The field of nucleosynthesis and stellar evolution began in the late 1950's with the work at Cal. Tech. of Burbidge, Burbidge, Fowler and Hoyle (for which Fowler subsequently received the Nobel Prize). Cameron's work at CRNL was contemporaneous and of great importance for the field. After leaving Chalk River in the early 1960's Cameron remained one of the key leaders of the field.

Why, then, was the nuclear physics program at CRNL terminated three years ago and the Nobel-Prize winning neutron program handed off to NRC? Certainly fiscal pressures from the federal government existed and perhaps the culture at CRNL no longer commandeered fundamental science for CANDU as it had in Lewis' day. However almost all of the full blame must be assigned to the lack of vision at Atomic Energy of Canada Limited (AECL), which had forgotten the powerful role that fundamental science can play for its main mission of economic nuclear power. It was a failure of the system, of AECL management, and of its prestigious Advisory Councils. It was the same lack of visionary leadership which led to the reduction of fundamental physics at NRC (Game score: Bureaucrats 2, Canada 0).

The failure of leadership was the subject of an editorial by Fred Boyd in the Bulletin of the Canadian Nuclear Society (Vol.20,No.3, October, 1999). Entitled "Leadership" the editorial said: "From our (worm's eye?) view, an element that has been sadly lacking in our Canadian nuclear program over the past few years is leadership" .... "Each organization appears to be going its own way, concerned with only its particular interest and only for the immediate future"... He then quotes some questions posed by the AECB president, Agnes Bishop: "What about the research and development necessary not only for safety but to maintain the industry and move it forward? There are few young people in the nuclear program - where is the next generation of nuclear scientists, engineers and technicians to come from? What about the credibility of the nuclear industry in the eyes of the public?" In the special case of Chalk River there is a splendid new opportunity for AECL for redemption and to return to fundamental physics for the support of the reactor program. The proposed Canadian Neutron Facility may now be funded by the federal government. It is a very important research opportunity for Canada and, although it is now under the aegis of NRC, its physical location at Chalk River could be helpful to CRNL to make CANDU prosper.

CANDU must prosper. The world will need CANDU in the next century and Nature intends that nuclear power should thrive in Canada. We celebrate CANDU as Canada's greatest scientific and engineering accomplishment. For a world needing clean energy sources, CANDU is the ideal vehicle which does not induce global warming. Canada had the initiative for CANDU thrust upon it during WWII and now Nature has provided us with the uranium "potatoes" in our northland so that we have the world's best source of nuclear fuel. These "potatoes" are spectacularly-rich newly-discovered deposits of uranium a few hundred meters underground and shaped like a potato, with dimensions of about a hundred meters. For example, the McArthur River "potato" 620 km north of Saskatoon has 416 million pounds of uranium oxide at an average grade of 13%, with some core drillings averaging 35%. Nowhere else on our globe is there anything close to such richness. This is not only a miracle but also a signal that CANDU is our destiny.

The fate of our two large national laboratories makes it useful to ponder about them. Alone among the western nations, Canada terminates rather than redirects its national science programs. The termination of nuclear physics at AECL and of fusion research at IREQ in Quebec (Bureaucrats 3, Canada 0), as well as the great curtailment of fundamental science at NRC, are great blows to Canadian physics. There are very few examples of similar terminations abroad. For example, a few years ago when the LAMPF accelerator project was cancelled at Los Alamos National Laboratory, the large group of scientists involved were directed to other projects, mostly also in fundamental science. It takes much time to establish a world-class science laboratory which unthinking Canadian bureaucrats can terminate at once. The kind of options for NRC given above also could have been used for any redirection of CRNL and the fusion laboratory, although it must be said that, in the case of the fusion program, we in Canada had no other active laboratory and therefore the cancellation terminated our ability to remain literate in the field. Compared to all other competing western countries, Canada has very few national laboratories and very little "Big Science", and it is most frivolous in terminating what it has.

As the century closes, we can celebrate the wonderful science which we have enjoyed from our national laboratories and look forward with optimism at those which still continue. We have the continuation of TRIUMF in Vancouver, the full exploitation of the Sudbury Neutrino Observatory (Bureaucrats 3, Canada 1), the beginning of a synchrotron radiation facility in Saskatoon (although this was preceded by the cancellation of the very active linac laboratory in Saskatoon and therefore the score was: Bureaucrats 4, Canada 2) and also the prospect of a major new neutron research facility at Chalk River. They all contribute to our hope for the future.

University physics research emerged and flourished after WWII as described in this issue by Mel Preston and Helen Howard-Lock. There had been strong graduate schools in Europe and the United States since the beginning of the century, and almost all Canadian physicists received their graduate degrees abroad. With the help of the NRC graduate support programs, a few dozen Ph.D. degrees in physics had been awarded in Canada during the first half of the century. Then the flow erupted. In the second half of the century more than a thousand Canadians - and many foreign students - received Ph.D. degrees in physics at Canadian universities. Correspondingly, physics research at Canadian universities flourished, first through grants from NRC but, in the last quarter of the century, from a special agency - The National Science and Engineering Research Council (NSERC) established for this purpose. NSERC has given vital support through innovative programs but has consistently been starved for funds.

In Quebec there had been virtually no francophone physicists until a refugee from Italy, Franco Rasetti, came to Laval University during WWII. There had been a strong tradition of classical colleges, preparing students for the law or for medicine. Any francophone seeking to enter a science career needed first to graduate from one of the classical colleges and almost no one overcame that hurdle. Rasetti had been one of Fermi's principal colleagues at Rome. The impact of his stay at Laval is described in the article in this issue by Le Tourneux. Simultaneously, physics research and graduate training began at the University of Montreal and subsequently at many other Quebec post-secondary institutions. Within very few decades a disproportionate number of Canada's best physicists emerged from Quebec. The so-called "Quiet Revolution" which swept Quebec four decades ago clearly carried with it deep intellectual components from which this momentum for physics arose.

Postwar university physics research first developed strongly in experimental nuclear physics and in theoretical physics, with the continuation of some longer-standing programs in atomic and molecular spectroscopy and in low temperature physics. The focus on nuclear physics was not surprising considering the worldwide development of physics and Canada's strength at Chalk River. The first major nuclear physics accelerator at a Canadian university was the McGill cyclotron (see the vignette on J.S. Foster in this issue). The second was the Saskatoon linear accelerator (see the article in this issue by Preston and Howard-Lock). When the Chalk River tandem led to a worldwide network of low energy accelerators for nuclear spectroscopy many Canadian universities followed. They were in no special order and probably an incomplete list: McMaster, Manitoba, Laval, Montreal, Queens, Ottawa, Toronto, Alberta, and British Columbia. They were supported initially by grants from the Atomic Energy Control Board (AECB) and later by NSERC. Most of these university accelerators have been decommissioned or adapted to uses other than nuclear spectroscopy. As the worldwide interest in subatomic physics changed to higher energies and larger machines for nuclear physics, and to very large centers for particle physics, the Canadian program followed.

There was some vision evident at the AECB, led by George Laurence, when a large, multi-university project, TRIUMF, was funded in 1968. This project was a natural one for Canada. John Warren had trained a large group of excellent nuclear physicists at UBC who needed a challenge. They were joined by physicists and chemists from the University of Alberta and from two new universities, Simon Fraser and Victoria. Reg Richardson, who had come from B.C. to work with Ernest Lawrence at Berkeley, had just proposed a very innovative cyclotron, a negative-ion, sector-focused machine to produce protons at the 500 MeV. Such a facility with its continuous, high-intensity beams at medium energy was then sought, worldwide, for the new directions of nuclear physics. TRIUMF has now worked for several decades as a very successful meson factory and has also developed major opportunities for condensed matter research with muons as well as for medical applications. The vision which created TRIUMF was no longer evident in the Canadian government when the proposed KAON Factory was turned down in 1994 (Bureaucrats 5, Canada 2). However, TRIUMF remains strong and enters the new century with world-leading new facilities for radioactive beam research.

At this moment the eyes of the world are on the Sudbury Neutrino Observatory (SNO) which was funded a decade ago and is now in its initial year of operation. There is a great deal of new interest in neutrinos, pertaining to the questions of whether or not they have mass (with the consequence that the different neutrino species oscillate among each other) and about the flux of neutrinos from the central core of our sun (the solar neutrino problem). A number of large neutrino observatories have been built among which SNO is very special. Its detector uses Canada's large reserve of heavy water for CANDU - a gift which makes SNO possible only in Canada. With SNO's heavy-water detector deep underground in a Sudbury mine, one measures deuterium dissociation by neutrinos as well as neutrino scattering from the electrons of deuterium. Consequently this unique observatory can distinguish the species of neutrinos, their direction, and the flux of each species. It promises to be a major new tool for resolving the long-standing solar neutrino problem. SNO is an imaginative idea and involves scientists from across Canada. We celebrate its promise.

Canada continues to struggle for a role in particle physics. In the absence of KAON we have no home-based accelerator laboratory, but there are reasonably strong user groups at many universities who continue to be welcomed at large, particle physics facilities abroad, especially at CERN in Geneva, Switzerland, where the large proton-proton collider (LHC) is scheduled for completion in 2005. It will search for the field quanta (Higgs particles) which may tell us how the quarks and leptons acquire mass, for evidence of supersymmetric particles and for any possible surprises at the energy frontier. Other involvements include the B-Factory at SLAC, just beginning operation, and also the electron-proton collider (HERA) in Hamburg, Germany. In each case significant contributions are made by Canada to the detectors and/or to the accelerators. Although the university groups involved are strong and NSERC has continued to nobly support these groups with its meagre total funds, Canada's expenditures on subatomic physics remain at a very low level, per capita, compared to those of other G7 nations.

Responding to world-wide opportunities, condensed matter physics gradually became a strong component of the research profile of most Canadian universities. At a few universities, such as Waterloo and Simon Fraser, it dominated the interests of the department. In Canada it lacked the stimulus of very active industrial research laboratories working in this field. We had no equivalent of Bell Telephone Laboratories or IBM, etc., which contributed so greatly to condensed matter physics in the U.S.A. It has been a wonder that Canada, which was able to negotiate agreements with the U.S.A. for automobile production and defence production, never even attempted to do so for the research laboratories of large multinationals, an agreement which was arguably even more vital for its national interests. Our so-called science policy appears to have been sterile rhetoric. For the new microelectronics laboratories the scene is different and they have significant impact on Canadian industrial research in general and the employment of physicists in particular. Recently Nortel has emerged in Canada as a truly global telecommunications company which has impacted on the research on silicon devices in Canadian universities. There is now a significant community of users at Canadian universities for the synchrotron radiation facilities and for the proposed new neutron facility and, if both materialize, then condensed matter physics will remain strong.

There are many other Canadian achievements to celebrate. The wide spectrum of such achievements is illustrated with the work of the winners of the CAP prizes listed in the article in this issue, by F.M. Ford, on the "Evolution of CAP/ACP Activities". A few examples of achievements worth special mention are, in no particular order:

1. The creation of the Canadian Institute of Theoretical Institute of Astronomy (CITA) at the University of Toronto. This

institute has been a world leader in its field for several decades.

2. The establishment of the Canadian Institute of Advanced Research (CIAR), with Fraser Mustard as its first head. This institute has been very effective at funnelling private sector funds to some of Canada's finest physics research.

3. The pioneering work of Harold Johns in radiation therapy and the development of the company Nordion, a world leader in isotope production.

4. The strength of Canadian research in Geophysics and Oceanography, for which Tuzo Wilson pioneered continental drift and Robert Stewart and others did outstanding work on the air-sea interaction.

5. The development of great strength in atomic physics at the University of Windsor, York University, Laval University and several others.

6. The role Canada played in the Pugwash conferences which played a prominent role in nuclear disarmament and in the reprochment between East and West in the hottest years of the Cold War. Pugwash was founded by the Canadian-born industrialist, Cyrus Eaton, and is named after his home town, Pugwash, Nova Scotia, where the movement's first meetings were held. Major figures in Pugwash included Sir Josef Rotblatt (recent Nobel Peace Prize winner) and Sir Rudolph Peierls, who influenced many Canadian physicists.

7. Theoretical physics has been at considerable strength for much of the century but, recently, is more outstanding than ever.

8. The birth of the Canadian Association of Physicists (CAP) after WWII and its interesting subsequent history and evolution of activities as described by Donald Betts and Francine Ford in this issue. The strong individuals who led Canadian physics are given not only by the vignettes of prominent physicists sprinkled throughout this issue but also by the lists of CAP presidents and prize winners which appear as Tables in the article by F.M. Ford in this issue.

The lack of an even playing field has continued to be a factor in luring many of our best physicists abroad, especially to the United States. They include Nobel Laureates, such as Kohn, Schawlow and Taylor, and many other prominent scientists. For example, D. Allan Bromley became Presidential Science Advisor in Washington during the recent Bush administration (1990-94). He is also regarded as the father of heavy-ion physics and has more honorary degrees (>40) than, probably, any other Canadian scientist. He would have been among the Canadian icons for whom we have vignettes in this issue if he were not so very alive and well.

In summary, during the past century there have been many exceptionally fine achievements in Canadian physics. The very best occurred in our two large national laboratories which recently have been jolted by major perturbations, but which may now have opportunities to again play an important role for physics and for Canada. We should celebrate and remember what was achieved.

Whither Canadian physics in the next century or Millenium? The challenges for physics are as great as they have ever been. The conditions for physics in Canada are basically sound for us to respond to the challenges and, therefore, for Canadian physics to prosper. The wonder remains. It is foolish to forecast where it will lead us, but some of the challenges can be envisaged. Some young Canadian may help to discover how gravity fits into a unified description of Nature's fundamental forces. Others may help us to learn more about the structure of the early universe and its dynamics. A new interpretation of quantum mechanics, supplanting the Copenhagen Interpretation, may take hold. Large steps in our understanding of complexity seem to lie just ahead. There is much scope for Nature to continue to surprise and amuse us. Therefore many young Canadians will continue to be stimulated and will want to respond.

For our national response to the new physics opportunities, it is important that the high quality of Canadian physics undergraduate education continues at our universities. The possibility of good graduate training in almost any field of physics can now be found at our universities. We have abundant natural resources and a high quality of living which allow us - nay, they should compel us - to employ more science for the economic benefit of the nation. We are poised for greatness.

There are some indications that a balanced physics program in Canada can be hoped for with strength in all three sectors: universities, government and industry. In the recent past we have developed strong university programs, supported by NSERC, which, however, remain underfunded. The corresponding development, for balance, of industrial research and of national laboratories has been lagging. In microelectronics the industrial component is improving. The two large national laboratories, NRC and CRNL, have opportunities for evolving toward their strong former position in the national program of physics research. With less focus on the national debt and more on our international competitiveness, the federal government has the opportunity now to provide more leadership in science. By celebrating what has been best in our past we may help to direct our future to even finer physics. Canada deserves it.

RICHARD EDWARD TAYLOR, 1929 -

Richard E. Taylor

Richard Taylor was a deeply-deserving co-recipient of the Nobel Prize for the epoch-making discovery of quarks. However, when you first meet him he doesn't strike you as a typical Nobel laureate: he lacks the urbanity and the deep intellectual gaze which one customarily looks for in this role. Instead, he is an archetypal western Canadian. Huge in stature, with a booming voice carrying over miles of rangeland and a wide, confident stride normally associated with years of following horses through the deep prairie furrows, one thinks of him as the product of pioneers. Which he is. He was born in Medicine Hat, Alberta on November 2, 1929. He and his wife Rita return each year to a home they own in Blairmore, Alberta. Taylor was, and is, a prominent performer, with his wife, in the Gilbert and Sullivan Society's offerings at Stanford.

Although most of his research career has been out of Canada - because of the uneven playing field within Canada for particle physics - he is about as Canadian as you can get. He remains concerned about Canadian physics and has been a very supportive, influential and outspoken advisor for its development. None of the honours he has received have changed his basic personality.

Taylor did not excel in the Medicine Hat High School. While experimenting with explosives he blew off three fingers from his left hand (any more and he might have become a theorist). He obtained his first degrees at the University of Alberta and then went to Stanford University to work on high energy physics. After his Ph.D. at Stanford he spent three years at the École normale supérieure in Paris working on experimental facilities for a new linac. When he returned to Stanford, work on the new Stanford Linear Accelerator (SLAC) was just beginning. Taylor thus was a member of the first group to plan SLAC experiments. The 20 GeV SLAC electron linac was ideal for exploring nucleon structure at a time that the concept of the quark substructure of the nucleon surfaced. The leaders of this deep-inelastic scattering work were Taylor (of SLAC) and Jerry Friedman and Henry Kendall of M.I.T., while Pief Panofsky, the director of SLAC, was a staunch mentor. The trio of leaders won the 1990 Nobel prize in physics for this 1967 work. Why the long wait for the prize for such a great discovery?

Quarks were not born easily. Although the "zoo" of particles discovered in the 1950's argued for elementary building blocks, when the quarks were first proposed in the early 1960's, their fractional charge and the failure to find any free quarks raised general disbelief and even ridicule about their actual existence. The quark proponents became cautious and some argued that they were merely a mathematical construct. At the same time, a battle was raging about whether the field theory (local gauge symmetry) for quarks should be taken seriously or whether, alternatively, all particles merely corresponded to analytic properties of the scattering matrix. Eventually field theory won, but the substantial arguments against quarks were resolved only in the 1970's when a proper renormalizable theory of the strong interaction (QCD) emerged. Before that only a few foolhardy theorists, like Bjorken and Feynman (with his "parton" model) argued that the deep-inelastic scattering, with its scaling laws, argued for nucleon substructure with building blocks of fractional charge. The controversy was so deep that, clearly, the Nobel committee must have wanted it to simmer down before the confirmation of quarks in the nucleon was recognized. Fortunately the trio of discoverers lived long enough to savour the accolades.

Dick Taylor has continued to live a full life in particle physics, working at SLAC, HERA (in Hamburg, Germany) and CERN. His cheerful brusqueness has not diminished and for Canadian physics he remains an invaluable elder statesman.

Erich Vogt, Professor Emeritus
University of British Columbia

JOHN TUZO WILSON, 1908 - 1993

I remember, very clearly, the first time that I began to appreciate the stature of my thesis supervisor. It was in Hart House Theatre at the University of Toronto when the Royal Society of Canada presented him with the Willet G. Miller Medal -- awarded to recipients who "were in their prime - not too old to continue such original work". We learned then that Tuzo, who was born in Ottawa, Ontario on October 24, 1908, had graduated from Physics and Geology at the University of Toronto in 1930, winning a Massey Fellowship, the Coleman Gold Medal in Geology, and the Governor General's Medal. Two years later he had received an M.A. from Cambridge and, in 1936, a Ph.D. from Princeton.

Tuzo Wilson receiving the Albatross Award of the American Miscellaneous Society, in Hart House, University of Toronto. Standing with Wilson in the picture are Art Maxwell and Teddy Bullard and an unknown albatross. For Tuzo the continents moved.

Following three years with the Geological Survey of Canada, he was commissioned in the 1st Tunnelling Company of the Royal Canadian Engineers, then became Director of Operational Research at the National Defence Headquarters. During the winter of 1945-46, he was Deputy Director of Expedition Musk Ox in the Canadian Arctic, and later flew as a Canadian observer on the first USAF flight over the North Pole.

He began his next career in 1946, as Professor of Physics at the University of Toronto, where he held an appointment until his death in 1993. His scientific accomplishments were immense. He had an enviable ability to absorb and synthesize information from his readings and from his travels. He was always at the forefront of the earth sciences. He was a major contributor to the understanding that the Canadian shield can be divided into geological provinces according to their structure and age. He is remembered for his early ideas about island arcs and the fracture of a brittle crust, and for his later ideas about continental drift and plate tectonics. His name is forever linked with such diverse concepts as transform faults, hot spots and mantle plumes, and the myriad of earth processes that are expressed in the geological character of the earth. These and other accomplishments led to Fellowship in the Royal Society in 1968 and the award, in 1978, of the Vetlesan gold medal, considered to be the earth sciences' equivalent of the Nobel prize.

A few years later, he became one of the first North Americans to travel to China when that became possible (typically going by the Trans Siberian Railway) and many will remember his book "One Chinese Moon" that was based on the visit.

In the Spring of 1967, it was announced that he was to become the new Principal of Erindale College. This recognition of his Alma Mater was very important to him at that particular time in his career. In 1974 he became Director of the Ontario Science Centre, of which he was justly proud. He held this position until 1985. His curiosity took him everywhere and into many disciplines.

He was elected President of the American Geophysical Union, before someone discovered that this post was not available to non-Americans. The gracious solution of the AGU was to revise the offending terms in their constitution. But most importantly, we remember him because we liked him so much.

R. Don Russell
University of British Columbia

A BRIEF HISTORY OF THE CANADIAN ASSOCIATION OF PHYSICISTS / L'ASSOCIATION CANADIENNE DES PHYSICIENS ET DES PHYSICIENNES

by Donald D. Betts

At the end of World War II a small group of industrial physicists decided to form the Canadian Association of Professional Physicists (CAPP). By July 1945 a group of 68 physicists in industry, government laboratories and universities agreed to join the embryonic organization under the President, F.E. Coombs of Research Enterprises Ltd. A few months later a temporary constitution was made, the Bulletin (now *Physics in Canada / La Physique au Canada*) with an editor was being published as a quarterly, and, early in 1946, an Executive Committee of the Association was established. Prof. J.O. Wilhelm, Univ. of Toronto, was President from 1946 -47; the next year's President, Dr. W.P. Dobson, was an industrial physicist, and, in 1948-49, Prof. G.A. Woonton, University of Western Ontario, was President. The CAPP membership then consisted of 122 full and 12 student members.

> Canadian physicists should be proud of our Association and support it with at least their membership. It appears that twice as many physicists working in Canada could join as have joined, and if most of them would join they would greatly strengthen the CAP/ACP.

An Annual Congress was started in 1946 at the University of Toronto, then 1947 at the University of Western Ontario, 1948 at the National Research Council, 1949 at the Université Laval, and so on until now with no gaps. In 1947, a revised constitution was made official with the new name, Canadian Association of Physicists (CAP). CAP was then a scientific society, not a professional association in spite of several of the founders. In 1950 the Bulletin became *Physics in Canada*, and it began to be subscribed to by many libraries as well as by the members. By 1955 the membership was some 500, and the childhood of CAP was outgrown!

In 1955, for the first time, the Annual Congress of the CAP was joined, in the University of Toronto, with the Meeting of the American Physical Society. At this Congress the nuclear physicists discussed the establishment of a high energy laboratory in Canada. In 1956 the CAP Medal for Achievement in Physics was introduced, and Prof. J.A. Gray of Queen's University received the first medal. Like a teenager, the CAP's Congress henceforth joined the Learned Societies' annual meetings at various Canadian universities each year, although no other scientific society did so. In 1955, the Medical Physics Division was established, and, in 1956, the Theoretical Physics Division (TPD).

In 1956 McGill Prof. P.R. Wallace, as Chair of the CAP Theoretical Physics Division, found that the Canadian Mathematical Congress (CMC) was to have a three-week seminar at the University of Alberta, Edmonton, in August 1957. One of the lecturers would be the famous theoretical physicist, Prof. E.P. Wigner. Thus it was arranged that the TPD would join the CMC seminar in Edmonton followed by a week in Banff, adding several theoretical physics lecturers including the very distinguished Profs. J. Bardeen, J.D. Jackson, P. Morrison and J. Schwinger. A second successful CMC and TPD summer seminar took place at the Université de Montréal in1961. Shortly thereafter such summer seminars occurred at least every year. These seminars were generously supported financially, and

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otherwise, by the universities, NRC, AECL, and some companies.

Throughout the sixties, and a bit earlier, the CAP office was housed in the Physics Department of McMaster University, and the staff consisted of one part-time secretary there, although the CAP Secretary, Prof. L.E.H. Trainor, served for several years at the University of Toronto. Nevertheless, E.W. Vogt, the *Physics in Canada* editor, stated that, starting in January 1967, *Physics in Canada* would be published bimonthly. In his address at the CAP Congress in Calgary, 1968, outgoing President H.E. Petch told us the CAP Executive had taken the important step of establishing a National Office in Ottawa, and he explained why. For example, the CAP had to respond in detail to Canada's Science Secretariat's newly published report, Physics in Canada: Survey and Outlook (the Rose Report). The recent expansion to seven Divisions also increased the CAP office load. A bit later in 1968 the CAP Office was established at 151 Slater Street, Ottawa with a full time Executive Secretary, Jean-Louis Meunier, and two secretaries. Furthermore, the CAP Congress was no longer associated with the Learned Societies' annual meetings. Our Association had reached adulthood!

Now our Association could celebrate its 25th birthday in style at the 1970 Congress at the University of Manitoba in Winnipeg. Its membership had climbed steadily to 1655. The American Physical Society and La Sociedad Mexicana de Physica joined our Congress. Of the 25 Past Presidents, 23 were still alive and 21 came to our Winnipeg birthday! The Herzberg Medal, the second annually-awarded CAP medal, was established for the occasion to recognize excellent Canadian physicists under 39 years of age.
R.R. Haering received the first Herzberg Medal at the 1970 Congress.

The 1972 Congress was held at the University of Alberta. Because Edmonton is relatively near the Orient, the CAP Executive (G.G. Cloutier, C.C. Costain, A.T. Stewart, H.L. Welsh, E.W. Vogt) decided that we should invite a few leading physicists from the Peoples Republic of China, and our Local Committee agreed. Indeed, four distinguished Chinese physicists came happily to our Congress in their blue " Mao uniforms", and they much enjoyed it scientifically and socially. Some years later one of the four, my friend and colleague Prof. Hao-Bai Lin, told me that the CAP's invitation was the first from any Western country to Chinese scientists of any discipline to attend a conference abroad. Accordingly, the Canadian physicists involved became and remain national heroes in China, as I have discovered when I have been there.

In 1971, the hard-working J.-L. Meunier was replaced by Mona Jento as Executive Secretary. She gave outstanding service to our Association for two decades. In 1991 Mona resigned and was replaced by Francine Brûlé, now Francine Ford, who is also doing very well for the CAP/ACP, including serving as Managing Editor of our periodical, *Physics in Canada / La Physique au Canada*. It is a principal source of CAP/ACP historical data. For example, the President's Address by A.E. Douglas at the 1976 Congress urged that our Association spend more of its effort in a political role. He showed that Federal support of R & D to each of industry, government labs and universities had declined considerably since 1969. In particular, the universities' share of GNP had steadily diminished until, in1976, it was two-thirds of what was provided to the universities in 1969. Douglas strongly recommended that the CAP join other Canadian scientific societies in lobbying the government for a bigger R&D share of the GNP. Gradually, this activity has taken place, and now the politicians are listening seriously.

The CAP Office, now at the University of Ottawa, has given me the numbers of members of our Association for approximately every five years, as follows in the table:

1945	1950	1956	1960	1965	1970	1975
154	210	720	1133	1507	1844	1878

1980	1985	1990	1995	1999
1878	1677	1523	1575	1566

We should be concerned that we have not recovered from a 20% decline in membership in the 80's, despite the great amount of work for the Association by members of the Executives and various committees over the past two decades. It appears that twice as many physicists working in Canada could join as have joined, and if most of them would join they would greatly strengthen the CAP/ACP.

Now the CAP has thirteen Divisions, including Atmospheric and Space Physics, Atomic and Molecular Physics, Canadian Geophysical Union, Condensed and Materials Physics, Industrial and Applied Physics, Medical and Biological Physics, Nuclear Physics, Optics and Photonics, Particle Physics, Physics Education, Plasma Physics, Surface Science, and Theoretical Physics. These Divisions contribute greatly to the organization and liveliness of the Annual Congresses.

One feature of the CAP in the 1990's has been the increase in the number of its medals and prizes, although some of them are not awarded each year. Association medals and recent first recipients now are: the CAP Medal for Achievement in Physics, the Herzberg Medal, the CAP Medal for Excellence in Teaching Undergraduate Physics (J.M. Pitre - 1995), the Peter Kirkby Memorial Medal (D.D. Betts - 1996), and four medals or prizes that were established through the efforts of various Divisions, including the Brockhouse Medal (W. Hardy - 1999). We do not, however, have more medals and prizes than are deserved.

In recent years our Association's lobbying of the Federal Government has become more and more vigorous and effective. For instance, P.S. Vincett, anindustrial physicist, stated in 1995, at the beginning of his term as CAP president, that the most important task for his presidency would be, with the help of many others, to establish the CAP as a truly effective voice for science, one which would speak to governments clearly and effectively on behalf of physics and science as a whole. Such a valiant and demanding effort has been, and is being, made. Among other efforts, the CAP, in partnership with the Chemical Society of Canada and the Canadian Federation of Biological Societies, is now lobbying the Federal Government well on behalf of science in Canada. One recent result is the government's plan to finance 2000 new university Chairs for Research Excellence over the next three years. The CAP lobbying is now focussed on continued support for basic research, including the indirect costs associated therewith, sufficient financing of government laboratories, TRIUMF, and a new Canadian Neutron Facility.

I would have liked to have written a longer and better history of CAP/ACP, but I must thank my friends Francine Ford and Erich Vogt for their help, which enabled me to write this article as well as I have. Further information on the CAP can be found in the article on the "Emergence of Physics Graduate Work" by M.A. Preston and H.E. Howard-Lock, as well as the article on "The Evolution of CAP/ACP Activities", by F.M. Ford, in this issue.

Canadian physicists should be proud of our Association and support it with at least their membership.

THE EVOLUTION OF CAP/ACP ACTIVITIES

by Francine M. Ford

I was asked by Dr. Vogt, guest editor for this issue, to write an article on the evolution of CAP activities. The intent was to have an article which complemented the brief history of the CAP written by CAP member and former CAP President Dr. D.D. Betts (in this issue), but written from the perspective of the Executive Director rather than that of a member. Having researched some background information for Dr. Bett's article, I found myself becoming increasingly enthused about the role the CAP has played over the years, and how it has often met the difficult challenge of modifying or expanding its activities to respond to the current environment. I have attempted to present the flavour of the CAP's evolution by tracking some of the more obvious indicators of change over the years, with a focus on the time frame with which I am personally familiar -- September 1991 to the present. I have also included some tables and supplementary information which complement the history prepared by Dr. Betts. There are likely many exciting developments that have not been included; their omission is simply a reflection of my short tenure rather than an indication of their lack of significance in the evolution of the Association. For the sake of brevity, I use CAP rather than CAP/ACP.

The CAP/ACP owes a great debt of gratitude to the volunteers who have contributed, in no small measure, to the success, stature, and viability of the Association. It is only through the efforts of these dedicated individuals that the CAP has survived and flourished during its 55-year existence and, we hope, will continue well into the next century.

CAP BECOMES CAP/ACP

The first indication of change and evolution of any association is found in its name. For the CAP, the first of such changes occurred in 1947, when the Association officially changed its name from the Canadian Association of Professional Physicists to the Canadian Association of Physicists, thereby recognizing the broader representation of all physicists in Canada, whether from industry, government labs, or academia. In June 1969, a special general meeting of the members of the CAP was held at the University of Waterloo for the purpose of considering a resolution passed by the CAP Council in February "for the change of the name of the Association from 'Canadian Association of Physicists' to 'Canadian Association of Physicists/Association canadienne des physiciens'". The Supplementary Letters Patent authorizing the name change were dated July 30, 1969. As a further step in evolution, members were asked to authorize a further name change during the 1994 AGM at the University of Regina - from 'Canadian Association of Physicists / Association canadienne des physiciens' to 'Canadian Association of Physicists / Association canadienne des physiciens et physiciennes', clearly to recognize the contribution our women physicists were making in the Canadian physics community. At that time, there was some debate whether we should adopt a simpler name such as the Canadian Physical Society; however, most Council members felt that the CAP acronym and logo were well established and the CAP would not benefit from changing either. Supplementary Letters Patent reflecting this name change were issued on September 26, 1994.

These changes seem to have an interesting relationship to the membership of the Executive during those periods. For instance, the first name change was adopted in 1947, at a time when the CAP had its first non-industrial physicist on the Executive

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(G.A. Woonton from the University of Western Ontario, who would have been Vice-President Elect in 1946). During the period of the second name change, in 1969, M.P. Bachynski (then at RCA Limited in Quebec) was President and Jean-Louis Meunier was Executive Secretary. The amendment put in place to officially recognize the role of women in physics coincided with the term of office of the CAP's first woman President, A.C. McMillan of the Atmospheric Environment Service. The influence of the Executive and Council members on the direction that the Association takes is clear. Fortunately, the CAP has been blessed with a very impressive roster of presidents (see Table 1) who have had no small measure of influence in making the CAP what it is today.

CAP DIVISIONS

The evolution of names and activities extends also to the various Divisions of the CAP. Divisions were first introduced in 1955, with the establishment of the Medical Physics Division, followed in 1956 by the Theoretical Physics Division. As various sub-disciplines developed a substantial enough representation within the Association, CAP's Council would approve the establishment of a further subject Division. Each Division developed their own constitution and objectives and obtained funding through individual members of the CAP opting to join and pay dues to the various divisions. During the course of their existence, some Divisions, such as DASP, DOP, and DCMMP, have undergone name changes to reflect changes in the activities of their members. In the case of the Division of Medical and Biological Physics (DMBP), this Division became inactive for a period of approximately ten years immediately following the decision of many of its members to break away and form the Canadian Organization of Medical Physicists (COMP). DMBP was officially reactivated in October 1999, at the request of the

CAP PRESIDENTS / PRÉSIDENTS DE L'ACP

45-46	F.E. COOMBS Research Enterprises Limited	64-65	P. LORRAIN Université de Montréal	83-84	B.P. STOICHEFF University of Toronto
46-47	J.O. WILHELM Ontario Research Commission	65-66	R.E. BELL McGill University	84-85	G.C. HANNA Atomic Energy of Canada Limited
47-48	W.P. DOBSON Ontario Hydro	66-67	J.M. ROBSON University of Ottawa	85-86	A.I. CARSWELL York University
48-49	G.A. WOONTON University of Western Ontario	67-68	H.E. PETCH University of Waterloo	86-87	J.S.C. McKEE University of Manitoba
49-50	D.C. ROSE National Research Council	68-69	M.P. BACHYNSKI RCA Limited	87-88	P.A. EGELSTAFF University of Guelph
50-51	J.S. MARSHALL McGill University	69-70	D.D. BETTS University of Alberta	88-89	L.G. CARON Université de Sherbrooke
51-52	A.D. MISENER University of Western Ontario	70-71	E.W. VOGT University of British Columbia	89-90	A.A. OFFENBERGER University of Alberta
52-53	G.C. LAURENCE National Research Council	71-72	G.G. CLOUTIER Institut de recherche de l'Hydro Qué.	90-91	R.L. ARMSTRONG University of Toronto
53-54	G.M. SHRUM University of British Columbia	72-73	A.T. STEWART Queen's University	91-92	R.M. LEES University of New Brunswick
54-55	L. KERWIN Université Laval	73-74	H.L. WELSH University of Toronto	92-93	J.C.D. MILTON Atomic Energy of Canada Limited
55-56	B.W. SARGENT Queen's University	74-75	A.H. MORRISH University of Manitoba	93-94	A.C. McMILLAN Atmospheric Environment Service
56-57	G. HERZBERG National Research Council	75-76	A.E. DOUGLAS National Research Council	94-95	R.A. LESSARD Université Laval
57-58	R.H. HAY Aluminum Company of Canada	76-77	R.J.A. LEVESQUE Université de Montréal	95-96	P.S. VINCETT FairCopy Services
58-59	B.W. CURRIE University of Saskatchewan	77-78	H.E. JOHNS Ontario Cancer Institute	96-97	B.E. ROBERTSON University of Regina
59-60	L.G. ELLIOTT Atomic Energy of Canada Limited	78-79	R.R. HAERING University of British Columbia	97-98	E.C. SVENSSON National Research Council(CRNL)
60-61	H.E. DUCKWORTH McMaster University	79-80	P.A. FORSYTH University of Western Ontario	98-99	M.O. STEINITZ St. Francis Xavier University
61-62	E.R. POUNDER McGill University	80-81	C.C. COSTAIN National Research Council	99-00	M. D'IORIO National Research Council
62-63	G.M. VOLKOFF University of British Columbia	81-82	P. MARMET Université Laval	00-01	G.W.F. DRAKE University of Windsor
63-64	L. KATZ University of Saskatchewan	82-83	A.R. CRAWFORD Anatek Electronics Limited		

TABLE 1 **CAP Presidents since the Association was founded in 1945.**

members of the Division. The CAP nevertheless maintains a close relationship with COMP, including a joint membership arrangement and the exchange of speakers at each other's annual congress.

In addition to the specific activities undertaken by the Divisions at the direction of the their Executive and membership, the Chairs of each of these Divisions are members of the CAP Council as well as of the Program Committee that develops the technical program for each CAP Congress. The participating Division Chairs establish a full program of invited and contributed talks each year. Several years ago, DCMMP solidified its support of the CAP Congress by deciding to move its annual Symposium from the Fall to the Sunday immediately preceding the CAP Congress, at the same location. This arrangement has been very successful, both in drawing more DCMMP members to the Congress, and in drawing some non-DCMMP members to the Symposium.

CAP CONGRESS

The CAP held its first Annual Congress in 1946 and it has remained an annual event ever since (see Table 2). The CAP Congresses are a great venue for physicists to meet and to remain abreast of the current research interests in the various subdisciplines of physics. They also offer the CAP an opportunity to honour and recognize important developments and events within the Canadian physics community. Over the past few years, in particular, the CAP has been fortunate to have been able to include recent Nobel Prize recipients amongst its plenary speakers. In 1991 (just before my arrival), the CAP Conference, which bore the slogan 'Physics is Phun' featured a "Taylorfest" in honour of Dr. Richard Taylor's recent Nobel Prize. In 1995, the CAP hosted a joint 'Canadian-American-Mexican' (CAP/APS/SMF) congress in honour of its 50th anniversary.

MEDALS AND AWARDS

The CAP medals detailed in Dr. Betts' article provide an opportunity for the CAP to recognize Canada's outstanding achievers within different subdisciplines as well as overall career achievement. The winners of the medals are invited to give a plenary talk at the CAP Congress during the year of their award. The medals are then presented to the recipients during the Congress banquet. An impressive list of Canadian physicists has been honoured over the years as recipients of these medals (see Table 3).

The expansion of the medals from the lifetime achievement award (introduced in 1956) to the current slate of eight medals is another measure of the

ANNUAL CONGRESS / CONGRÈS ANNUEL

1946	University of Toronto	1966	Université de Sherbrooke	1985	University of New Brunswick
1947	University of Western Ontario	1967	University of Toronto (CAP/APS/SMF)	1986	University of Alberta
1948	National Research Council	1968	University of Calgary	1987	University of Toronto
1949	Université Laval	1969	University of Waterloo	1988	Université de Montréal (CAP/APS)
1950	McMaster University	1970	University of Manitoba (CAP/APS/SMF)	1989	University of Guelph
1951	McGill U. and U. de Montréal	1971	Carleton University	1990	Memorial University of Newfoundland
1952	Université Laval	1972	University of Alberta	1991	University of Manitoba
1953	University of Western Ontario	1973	Université de Montréal	1992	University of Windsor
1954	University of Manitoba	1974	Memorial University of Newfoundland	1993	Simon Fraser University
1955	University of Toronto (CAP/APS)	1975	York University	1994	University of Regina
1956	Université de Montréal	1976	Université Laval (CAP/APS/SMF)	1995	Université Laval
1957	University of Ottawa	1977	University of Saskatchewan	1996	University of Ottawa
1958	McMaster University	1978	University of Western Ontario	1997	University of Calgary
1959	University of Saskatchewan	1979	University of British Columbia	1998	University of Waterloo
1960	Queen's University	1980	McMaster University	1999	University of New Brunswick
1961	Sir George Williams University	1981	Dalhousie University	2000	York University
1962	McMaster University	1982	Queen's U. and Royal Military College, Kingston	2001	University of Victoria
1963	Université Laval	1983	University of Victoria (CAP/CASCA)	2002	Laval University
1964	Dalhousie University	1984	Université de Sherbrooke		
1965	University of British Columbia				

TABLE 2 The locations of the CAP Annual Congress since 1946.

evolution of the CAP. In particular, since 1995, the CAP has established joint medals with three outside organizations: the Centre de recherches mathématique (prize in theoretical and mathematical physics), the Canadian Organization of Medical Physicists (the Peter Kirkby Memorial Medal), and the Institut national d'optique (medal for achievement in applied photonics). We have also entered into reciprocal agreements with numerous physical societies around the world: the American Physical Society, the Institute of Physics, and the physical societies in Brazil, Mexico, Israel, and Germany. The CAP is becoming recognized by industry as well as internationally as the national body representing Canadian physicists.

MEDALLISTS / LAURÉATS

CAP MEDAL FOR ACHIEVEMENT IN PHYSICS / MEDAILLE DE L'ACP POUR CONTRIBUTION EXCEPTIONNELLE À LA PHYSIQUE

1956	J.A. GRAY	Queen's University
1957	G. HERZBERG	National Research Council
1958	J.S. FOSTER	McGill University
1959	B.W. SARGENT	Queen's University
1960	D.K.C. MACDONALD	National Research Council
1961	H.I. WELSH	University of Toronto
1962	B.W. CURRIE	Univ. of Saskatchewan
1963	G.A. WOONTON	McGill University
1964	D.A. KEYS	Atomic Energy of Canada Ltd
1964	H.E. DUCKWORTH	McMaster University
1965	H.E. JOHNS	University of Toronto
1966	G.C. LAURENCE	Atomic Energy Control Board
1967	B.N. BROCKHOUSE	McMaster University
1968	R.E. BELL	McGill University
1969	L. KERWIN	Université Laval
1970	A.E. DOUGLAS	National Research Council
1970	W.B. LEWIS (special award)	Atomic Energy of Canada Ltd
1971	A.E. LITHERLAND	University of Toronto
1972	E.P. HINCKS	Carleton U. and N.R.C.
1973	M. BLOOM	Univ. of British Columbia
1974	B.P. STOICHEFF	University of Toronto
1975	J.A. JACOBS	University of Alberta
1976	J. VAN KRANENDONK	University of Toronto
1977	A.H. MORRISH	University of Manitoba
1978	J.M. ROBSON	McGill University
1979	J.P. CARBOTTE	McMaster University
1980	B. MARGOLIS	McGill University
1981	W. ISRAEL	University of Alberta
1982	R.R. HAERING	Univ. of British Columbia
1983	P.A. EGELSTAFF	University of Guelph
1984	M.P. BACHYNSKI	M.P.B. Technologies Inc.
1985	C.C. COSTAIN	National Research Council
1986	A. ARROTT	Simon Fraser University
1987	G.T. EWAN	Queen's University
1988	E.W. VOGT	TRIUMF
1989	P.A. REDHEAD	National Research Council
1990	R.L. ARMSTRONG	University of Toronto
1991	G. KARL	University of Guelph
1992	A.T. STEWART	Queen's University
1993	W.N. HARDY	Univ. of British Columbia
1994	G.W.F. DRAKE	University of Windsor
1995	W.G. UNRUH	Univ. of British Columbia
1996	P. CORKUM	National Research Council
1997	D.W.L. SPRUNG	McMaster University
1998	E.R. KANASEWICH	University of Alberta
1999	J.W. McCONKEY	University of Windsor

HERZBERG MEDAL / MÉDAILLE HERZBERG

1970	R.R. HAERING	Simon Fraser University
1971	P. MARMET	Université Laval
1972	D.W.L. SPRUNG	McMaster University
1973	R.L. ARMSTRONG	University of Toronto
1974	J.P. CARBOTTE	McMaster University
1975	A.J. ALCOCK	National Research Council
1976	J.C. HARDY	Atomic Energy of Canada Ltd
1977	M.B. WALKER	University of Toronto
1978	W.N. HARDY	Univ. of British Columbia
1979	G.W.F. DRAKE	University of Windsor
1980	G.I. STEGEMAN	University of Toronto
1981	B. NICKEL	University of Guelph
1982	A.R.W. McKELLAR	National Research Council
1983	W.G. UNRUH	Univ. of British Columbia
1984	N. ISGUR	University of Toronto
1985	S. RUDAZ	University of Minnesota
1986	A.M. TREMBLAY	Université de Sherbrooke
1987	A.H. MacDONALD	National Research Council
1988	F. WESEMAEL	Université de Montréal
1989	T. TIEDJE	Univ. of British Columbia
1990	I. AFFLECK	Univ. of British Columbia
1991	D. MacFARLANE	McGill University
1992	R. KIEFL	Univ. of British Columbia
1993	N. KAISER	University of Toronto
1994	J.F. YOUNG	Univ. of British Columbia
1995	S. JOHN	University of Toronto
1996	J. DAHN	Simon Fraser University
1997	D. BONN	Univ. of British Columbia
1998	L. TAILLEFER	McGill University
1999	R.C. MYERS	McGill University

CAP MEDAL FOR OUTSTANDING ACHIEVEMENT IN INDUSTRIAL AND APPLIED PHYSICS / MÉDAILLE DE L'ACP POUR DES RÉALISATIONS EXCEPTIONNELLES EN PHYSIQUE INDUSTRIELLE ET APPLIQUÉE

1991	P. WEBB	General Electric Canada Inc
1993	J.J.A. BEAULIEU	Defence Research Est. Valcartier
1995	M. BACHYNSKI	MPB Technologies Inc
1997	J. DOBROWOLSKI	National Research Council
1999	L. WHITEHEAD	University of British Columbia

TABLE 3 (Part One) List of recipients of the first three Medals established by the CAP, starting in 1956.

MEDALLISTS / LAURÉATS (continued)

CAP/CRM PRIZE IN THEORETICAL AND MATHEMATICAL PHYSICS
PRIX ACP-CRM DE PHYSIQUE THÉORIQUE ET MATHÉMATIQUE

1995 W. ISRAEL
University of Alberta
1996 W.G. UNRUH
University of British Columbia
1997 I. AFFLECK
University of British Columbia
1998 R. BOND
CITA/University of Toronto
1999 D.J. ROWE
University of Toronto

CAP MEDAL FOR EXCELLENCE IN TEACHING UNDERGRADUATE PHYSICS
MEDAILLE DE L'ACP POUR L'EXCELLENCE EN ENSEIGNEMENT DE LA PHYSIQUE AU PREMIER CYCLE

1995 J. PITRE
University of Toronto
1996 A.J. SLAVIN
Trent University
1997 E.L. McFARLAND
University of Guelph
1998 S.P. GOLDMAN
University of Western Ontario
1999 C. KALMAN
Concordia University

CAP/COMP PETER KIRKBY MEDAL FOR OUTSTANDING SERVICE TO PHYSICS IN CANADA
MÉDAILLE COMMÉMORATIVE PETER KIRKBY DE L'ACP/OCPM POUR SERVICES EXCÉPTIONNELLES À LA PHYSIQUE AU CANADA

1996 D.D. BETTS
Dalhousie University
1998 J.S.C. McKEE
University of Manitoba

CAP/INO MEDAL FOR OUTSTANDING ACHIEVEMENT IN APPLIED PHOTONICS
MÉDAILLE ACP/INO POUR DES RÉALISATIONS EXCÉPTIONNELLES EN PHOTONIQUE APPLIQUÉE

1998 K.O. HILL
Communications Research Centre
2000 R. NORMANDIN
National Research Council

CAP/DCMMP BROCKHOUSE MEDAL FOR OUTSTANDING ACHIEVEMENT IN CONDENSED MATTER AND MATERIALS PHYSICS
MÉDAILLE BROCKHOUSE DE L'ACP/DCMP POUR DES RÉALISATIONS EXCÉPTIONNELLES EN PHYSIQUE DE LA MATIÈRE CONDENSÉE ET MATÉRIAUX

1999 W. HARDY
University of British Columbia

TABLE 3 (Part Two) The recipients of the five CAP Medals established since 1995.

In addition to the Medals, the CAP offers a few Prizes and Awards geared to students. Two of these awards are sponsored by Corporate Members, including the annual GSI/Lumonics Award (a $300 cash prize and Certificate for each of the top three student presentations at the competition during the CAP's annual congress), and the annual Newport Instruments Canada Award in Optical Sciences (a $2,500 award for a research project in optical sciences). Under the auspices of the Educational Trust Fund, the CAP's charitable fund, the CAP holds a University Prize Examination (the Lloyd G. Elliott prize exam; see the vignette on Dr. Elliott in this issue), a High School Prize Examination, and a Lecture Tour series geared to undergraduate students. The ETF also sponsors the Canadian Undergraduate Physics Conference, the Physics Olympiad, and the Canada-Wide Science Fair. The revenue for this Fund comes from the voluntary contributions of CAP members and the fees of Corporate Members. At this time, the CAP has twenty-two Corporate members (see Fig. 4).

Atlantic Nuclear Services Ltd.
Atmospheric Environment Service
Atomic Energy of Canada Ltd.
Faircopy Services Inc.
Gennum Corporation
Glassman High Voltage Inc.
GSI/Lumonics
Harvard Apparatus Canada
Institut national d'optique
JDS Uniphase Inc.
Kurt J. Lesker Canada Inc.
Leybold Canada Inc.
MPB Technologies Inc.
Mathis Instruments Ltd.
Newport Instruments Canada Corp.
Nortel Technology
OCI Vacuum Microengineering Inc.
Ontario Hydro Tech.; Research Div.
Optech Incorporated
Spectra Research Corporation
TRIUMF
Varian Canada Limited

TABLE 4 CAP's Corporate Members as at December 31, 1999.

PHYSICS IN CANADA

Another great indicator of change has been the evolution of the CAP's Bulletin from a quarterly newsletter-style publication to the glossy, two-colour Journal style of today. Although '*Physics in Canada*' may have been produced in the early years of the Association, I believe that this publication was limited to the annual congress program. It appears that the first journal-style issue of *Physics in Canada* was produced in 1950 under the editorship of P.R. Wallace, with J.J. Brown and E.R. Pounder as members of the Editorial Board. This 44 page publication included ten pages of advertising and extra copies of the issue were sold for fifty cents each. It was at this time that *Physics in Canada* began to be subscribed to by many libraries, as well as by the individual members (some years later, it was decided that *Physics in Canada* would be provided to members as part of their annual dues, although subscriptions from non-members and institutions were still solicited). The Bulletin continued as a separate, annual publication until 1951. In 1952, the two publications were amalgamated and began appearing, on a quarterly basis, as "*Physics in Canada: The Bulletin of the Canadian Association of Physicists*", in a 8 1/4" x 6 3/4" format, with K.L.S. Gunn of McGill University as Editor. Since then, *Physics in Canada* (PiC) has undergone a number of changes in editors (see Table 5) as well as styles. In 1968, the publication was expanded from four issues (Spring, Summer, Autumn, Winter) to six (January, March, Congress, July, September, November). PiC moved into a 8 ½" x 11" format in 1969 but perhaps the most noticeable change came in July 1998 when it was published, for the first time, in a two-colour format.

Although the Editorial Board had, from time to time throughout PiC's history, published special issues, it was in 1992, under the editorship of J.S.C. McKee, that the 'theme issue' was adopted as a regular feature, after the March 1992 issue on Sudbury Neutrino Observatory was so well received. The decision, in 1994, to expand the theme issues to two per year (March and September) was clearly well-founded, as evidenced by the current commitments from guest editors that extend to September 2003. Like the CAP, *Physics in Canada* continues to evolve in response to the changing environment which it strives to represent.

P.R. Wallace	1950-51	D.E. Brodie	1969-72
K.L.S. Gunn	1952-59	R.L. Clarke	1973-76
P.A. Forsyth	1960	E.R. Fortin	1977-80
D.M. Hunton	1961-62	J. Rolfe	1980-88
A.V. Jones	1963-65	G. Dolling	1988-89
E.W. Vogt	1966-68	J.S.C. McKee	1990-

TABLE 5 Editors of *Physics in Canada*

ART OF PHYSICS

In addition to his influence on the evolution of *Physics in Canada* since 1991, J.S.C. McKee was the driving force for the launch, in July 1992, of the CAP's Art of Physics competition. This competition, which was initially sponsored by Kodak Canada and is now under the sponsorship of Shenanigan's Inc., has provided a number of very striking covers for *Physics in Canada*. An Art of Physics exhibition featuring the winning entries and honourable mentions from each competition is available for loan to any group wishing to display it.

SCIENCE POLICY / LOBBYING

Another area in which the CAP has evolved, and is now very much involved, is that of lobbying for continued funding for physics. In his article, Dr. Betts mentions how A.E. Douglas, at the 1976 Congress, urged our Association to spend more of its effort in a political role and that, gradually, this activity took place. While this is true, the most significant advances in this realm have occurred since 1995, as a result of the commitment of P.S. Vincett, then President of the CAP, to the importance of making and then presenting our case to those with political influence. This convict-ion set the stage for major changes within the structure and activities of the CAP office and Council. In 1996, the role of the Executive Director, F.M. Ford, was broadened to specifically include responsibilities in this area, under the title of Science Policy Officer. The most important activity of the Science Policy Officer is her involvement as a member of the Steering Commit-tee of the Canadian Consortium for Research (CCR) and as a participant in the lobbying meetings coordi-nated throughout the year. The CCR, comprising over 20 scientific organizations, develops a submission each year for the House of Commons Standing Committees on Finance and Industry, which details what the community feels are the priority areas of concern in research at that time. These presentations are follow-ed by a targeted lobbying effort in November and December of each year; meetings are arranged with politicians and senior bureaucrats who have any responsibility for research. In addition, the CAP, in partnership with the Canadian Society for Chemistry and the Canadian Federation of Biological Societies, conducts an annual tri-society lobbying effort on behalf of science in Canada, which complements the one coordinated by the CCR. This is an ongoing activity which is now firmly entrenched in the roles and responsibilities of the Executive Director and the members of the Executive, who participate as lobbyists in the meetings each year.

In 1997, the CAP hired a part-time Science Policy Consultant, Dr. Don McDiarmid who had recently retired from the National Research Council, to allow the CAP to extend its science policy activities by participating in additional groups, such as the Partnership Group for Science and Engineering and to assist in the CAP lobbying activities. PAGSE has developed as a body which offers advice to politicians and senior bureaucrats as a representative voice of the Canadian science and engineering research community. In addition to direct input, it organizes meetings at which these people can hear from distinguished researchers. At the parliamentary breakfast meetings (Bacon and Eggheads), the target audience hears about outstanding research work and how it might contribute to the Canadian economy and culture. The annual dinner meeting, held across the street from parliament, begins following question period and ends at 9pm. Dinner is included. Here the emphasis is on how the Canadian S & T system can be made to func-tion better in the national interest. PAGSE has had a significant impact among people of influence.

PROFESSIONALISM

Another equally important activity, which was advanced considerably during P.S. Vincett's term as president, is that related to professionalism. This issue had been consistently kept on the agenda of Council meetings by one of the CAP's most dedicated members, Peter Kirkby. Peter was a tireless champion for the physics profession and had engaged, as early as 1984, in 'battles' with the engineering profession to ensure that the engineers, when introducing amendments to their provincial legislation, did not inadvertently broaden their definition of practice to the extent that it would include the practice of the natural scientists, and physicists in particular. Many years later, through his efforts, and those of Ann McMillan and Paul Vincett who were both members of the CAP Executive during this important period, a group called the 'Natural Science Societies of Canada' was established. Its sole purpose was to interact with the Canadian Council of Professional Engineers, the national body which includes each of the provincial associations as its members, to contribute to the development of an exemption clause for natural scientists which each provincial engineering association would be encouraged to adopt. After numerous meetings and negotiations, agreement was reached on suitable wording for an exclusion clause to be included with a new definition of the practice of engineering. Unfortunately, as the CCPE is not in the position to enforce the adoption of the exclusion clause, the CAP, through its Director of Professional Affairs and some provincial volunteers, must remain vigilant to promote the adoption of the negotiated NSSC/CCPE exemption clause in provincial legislation. In recognition of the importance of his efforts in this area, after over a decade of service on Council, P. Kirkby was appointed the first Director of Professional Affairs in 1994. Sadly, Peter was killed in an accident in early 1995. Monitoring the activities of the engineers across the country is not an easy task and the CAP has been very fortunate to have had, first P. Kirkby and now D. McDiarmid, in the role of Director of Professional Affairs.

P.Phys. / phys.

As an extension of this professionalism issue, the CAP looked many times at the merits of pursuing either a right of title or a right of practice. Since the right of practice requires a provincial Act, and the provinces are known not to be interested in introducing new legislation of this kind (even if the CAP had enough members on a provincial basis to undertake such an overwhelming and expensive task), this option was quickly abandoned. The right of title, if provincially obtained, would also involve a lengthy political process that the CAP did and does not have the resources to mount. This option was not pursued. During the 1994 CAP Congress in Regina, a representative of the Institute of Physics suggested an alternative that appeared to the CAP Executive to be achievable; that the CAP could seek a federal trademark on the titles P.Phys and phys. and appropriately license its members to use them, just as the engineering associations do with P.Eng. Thus was the P.Phys./phys. trade-mark initiative born (see *Physics in Canada*, vol. **53**, 3, 1997). Even this 'simplified' certification process proved to be extremely time-consuming and complicated to initiate. Nonetheless, the efforts of the Trademark Committee, comprised of Paul Vincett, Don McDiarmid, Bob Barber, Mick Lord, and Francine Ford, resulted in the launch of the professional certifi-cation application process at the 1999 CAP Congress in Fredericton, New Brunswick, with the awarding of the first P.Phys. license to Dr. Bertram Brockhouse, one of Canada's Nobel Laureates. The presentation to Dr. Brockhouse included the awarding of both a Certificate and a T-shirt which bore the new professional designation logo designed by Martin Gagnon, a CAP member in industry in Quebec (see Physics in Canada, Vol. **55**, 4, 1999). Since June 1999, the CAP Office has received and processed a number of applications for the designation. As with any new initiative, there were some complications with the process which have now been resolved. The result: the CAP has awarded a number of licenses to truly deserving applicants and will be formally announcing its first group of P.Phys./phys. licensees in the 2000 Congress issue of Physics in Canada.

MEMBERSHIP

Over the years, the CAP's income has grown from just under $1,600 in 1952 to over $200,000 in 1999. The CAP has never received any government funding and relies primarily on the fees from individual and institutional (physics departments) memberships, as well as a surplus from the CAP Congress, for the bulk of its operating funds. For many years the CAP has had the benefit of the support of Physics Departments across Canada through the institutional membership program. In 1995 this program was expanded to include CEGEPs/Colleges. Last year, the CAP had **44** institutional members (see Table 6). Since its inception, CAP membership has fluctuated, with the high period from 1975-1980 (see article by D. Betts in this issue). From its humble beginnings, membership has been expanded from full and student members to include a wide-range of additional categories, such as affiliates, high school teachers, foreign members, and joint members with the Chemical Institute of Canada and the Canadian Organization of Medical Physicists. In 1990, after a number of years of operating deficits, the CAP introduced a category of 'sustaining member' in an effort to help the Association fund its activities within a balanced budget. Many members opted to make this voluntary contribution in addition to their regular membership fee. Today, there are more than forty sustaining members (see Table 7).

Acadia University	Royal Military College	University of Ottawa
Bishop's University	Saint Mary's University	Univ. du Québec à Montréal
Brandon University	Simon Fraser University	Univ. du Québec à Trois-Rivières
Brock University	St. Francis Xavier Univ.	Univ. of Prince Edward Island
Carleton University	Trent University	University of Regina
Cégep de Chicoutimi	University of Alberta	University of Saskatchewan (and Eng. Phys.)
Collège Montmorency	Univ. of British Columbia	University of Toronto
Concordia University	University of Calgary	University of Victoria
Dalhousie University	University of Guelph	University of Waterloo
École Polytechnique	University of Lethbridge	Univ. of Western Ontario
Lakehead University	University of Manitoba	University of Windsor
Laurentian University	Université de Moncton	University of Winnipeg
McGill University	Université de Montréal	Wilfrid Laurier University
McMaster University	Université de Sherbrooke	York University
Memorial Univ. of Nfld.	Université Laval	
Mount Allison Univ.	Univ. of New Brunswick	
Queen's University	Univ. of Northern B.C.	

TABLE 6 The CAP's Institutional Members as at December 31, 1999

A. John Alcock	Ron M. Lees
J. Brian Atkinson	Roger Lessard
C. Bruce Bigham	J.S.C. (Jasper) McKee
Bertram N. Brockhouse	Jean-Louis Meunier
Allan I. Carswell	J.C. Douglas Milton
Robert L. Clarke	Allan A. Offenberger
R. Fraser Code	Roger Phillips
Walter G. Davies	Satti Paddi Reddy
Christian Demers	Robert G.H.Robertson
Marie D'Iorio	John M. Robson
Gerald Dolling	Michael O. Steinitz
Gordon W.F. Drake	Alec T. Stewart
David J.I. Fry	G.M. Stinson
William M. Gray	Boris P. Stoicheff
Elmer H. Hara	Eric C. Svensson
Akira Hirose	Louis Taillefer
Betty Howard	John G.V. Taylor
Roger Howard	Michael Thewalt
Allan E. Jacobs	Jacques Trudel
Martin W. Johns	Henry M. Van Driel
J. Larkin Kerwin	Paul S. Vincett
James D. King	Erich Vogt
Peter R. Kry	

TABLE 7 CAP's sustaining members as at February 17, 2000

One final indicator of change must be the status of the CAP Office, which started out as a filing cabinet within the physics department at McMaster University. When the CAP established a national office in 1968, located at 151 Slater Street in Ottawa, it leased space from the Association of Universities and Colleges of Canada. For the next approximately thirty years, the CAP office remained on Slater Street (albeit in two different suites over the years). At some point in this period, the CAP entered into a long-term lease with the realty company under the auspices of the Canadian Scientific and Engineering Learned Societies, which included other scientific bodies such as the Agricultural Institute of Canada, the Chemical Institute of Canada, Canadian Student Pugwash, and the Canadian Home Economics Association. When the lease at 151 Slater expired in May 1996, the CAP Office took up residence within the Physics Department at the University of Ottawa, providing both a substantial savings in rent and an opportunity to establish closer links with the academic physicists. Coincidentally, this move to the University of Ottawa occurred just one month before the Physics Department there hosted the 1996 CAP Congress. Their support during that very busy time was appreciated.

Since the establishment of its national office, the CAP has had only three Executive Secretaries: Jean-Louis Meunier (1968-70), Mona Jento (1971-91), and Francine Brûlé (now Ford) from September 1991 to the current time. In 1993, the title of the Executive Secretary was changed to Executive Director to reflect the increased responsibility of that position.

As a reflection of the ever-expanding activities of the CAP, and perhaps of the limited resources the Association has with which to manage them all, the current Executive Director also holds the titles of Science Policy Officer and Managing Editor of *Physics in Canada.* Over the years, F.M. Ford has been assisted by Judy McCool, Ginette Allard, Annick Blanc, Carmen Harvey, Tony Bove, and a number of other short-term staff members. At this time, the CAP office staff includes the Executive Director (Francine Ford), a full-time Administrative Assistant (Carmen Harvey) and a part-time Special Projects Assistant (Pauline Loyer). In 1998, with the help of graduate students at the University of Ottawa, the CAP made its presence known on the Web under the URL http://www.cap.ca. In 1999, a new look was introduced for the CAP's website and, for the first time, the CAP offered electronic renewals and membership applications. It is clear that the availability of modern technology such as electronic mail and the website have had a significant impact on the operations of the Association, including the modifications to the By-laws introduced last year that now allow the electronic distribution of regular mailings such as the slate of nominations for Council.

Many long-term members will note that the CAP Council has changed over the years, from its initial composition of Executive and Executive Secretary, to a Council that now includes the Executive, the Executive Director, the Chairs of the various Divisions, representatives of ten different regions, Directors for the different categories of members and various specific interests of the CAP, the Editors of Physics in Canada and the Canadian Journal of Physics, some councillors-at-large, and the Chair of the Science Policy Committee. After creating the position of Director of Professional Affairs, as discussed earlier in this article, it was decided that this individual should be a member of the Executive Committee of the CAP. Over the course of the next few years, as an additional reflection of the evolution of CAP activities, the Executive Committee was further expanded to include the Director of Academic Affairs (who chairs the CAP/NSERC Liaison Committee), and the Director of International Affairs (who monitors international activities and attend the APS Council meetings when the CAP President is unable to do so).

At this time, the Council is an impressive 51 members strong. Apart from the Executive Director, each of these Council members is an unpaid volunteer, who donates varying amounts of time and energy to ensuring that the CAP adequately represents the interests of the physics community in a broad spectrum of activities. Since 1945, over 780 physicists have volunteered their time in different capacities within Council, with another twelve scheduled to be added to the list when the new Council takes over in June, for 2000-2001. While this number is, in itself, impressive, it does not take into account the considerable number of additional physicists who have volunteered their time as the coordinators of the various exams, the members of the selection committees for the medals and awards, the members of the Local Organizing Committees for the Annual Congresses, the members of the various Committees of the CAP and those acting as CAP representatives on other Committees, as well as the members who offer their services to review and suggest changes to brochures and documents, or undertake some minor translations from time to time.

From the position of administrator, rather than that of a member, I have the unique opportunity to witness firsthand the dedication of many of the volunteers. I am very much aware of the number of hours that members of the Executive, in particular, donate to the CAP, as well as the seriousness with which they undertake their role. In my short history with the CAP, numerous changes and additions to the CAP's programs have been introduced. There are still a number of worthwhile projects on the back burners waiting to be implemented. Most of these changes are in response to suggestions put forward by the CAP's members, through Council and at the Annual General meeting.

The CAP owes a great debt of gratitude to each of these individuals who has contributed, in no small measure, to the success, stature, and viability of the Association. It is only through the efforts of dedicated volunteers that the CAP has survived and flourished during its 55-year existence.

ACKNOWLEDGEMENTS

I would like to thank C. Harvey for her help in researching the information for some of the tables, as well as to thank D.R. McDiarmid, M.O. Steinitz, and E. Vogt for their valuable editorial comments on the first draft of my article. I would also like to acknowledge Peter Kirkby whose dedication to this Association instilled in me an appreciation of the value of the CAP, which continues to this day.

RUTHERFORD AND HIS LEGACY TO CANADA

by John M. Robson

Though it is undeniable that several European and American universities have significantly affected Canadian physics, it is probably equally undeniable that the one individual who has most influenced this development is Ernest Rutherford. The direct effect of his stay at McGill and the subsequent impetus it gave to physics research at other Canadian universities and laboratories, coupled with the heritage of the many students who were touched by his personality and style, led to Canada being at the forefront of nuclear physics for a significant period during this century.

Rutherford's work at McGill and the later influence of his colleagues and students led to Canada being at the forefront of physics research for several decades of this century.

During his eight and a half years at McGill, Rutherford identified the basic properties of radioactivity. These included the exponential decay and growth, the nature of the emanations from radium and thorium (Rn 222 and Rn 220), their active deposits, and, with the collaboration of Frederick Soddy, a colleague in the McGill Chemistry Department, the transformation theory of radioactivity. Though they now seem quite natural, these were truly revolutionary concepts at the time. They were followed by the first proof that alpha rays were heavy charged particles and by the tentative suggestion that they were ionised helium atoms. Then, after several experiments on the successive decay products of radium, he proposed a decay series which was very close to that accepted today. Furthermore, in collaboration with Howard Barnes, a colleague from the Physics Department, he showed that the energy associated with a radioactive disintegration was orders of magnitude greater than could be expected from atomic or molecular changes. Though part of all this work was done in collaboration with colleagues, research students, and visitors, Rutherford was the idea man and the leader. His reputation soon attracted many to his laboratory at McGill and several of them, including A.S. Eve and Otto Hahn, made important contributions on their own, though no doubt inspired and influenced by him. While at McGill he published 69 scientific papers and two editions of his definitive book *Radio-activity* [1].

Quite apart from these astonishing contributions as a physicist, all of which are documented elsewhere in greater detail [2-5], Rutherford changed dramatically the image and role of the "Professor" from the austere and unapproachable master to one who took a very deep and personal interest in the lives as well as the work of his coworkers and students - one who was always approachable and who exerted encouragement and praise as often as possible, and who always gave credit where credit was due.

John Cox, the Head of the Physics Department at McGill during Rutherford's stay, had immediately recognised what a catch he had, and it is a great credit to him that he gave him much more time for research than a junior professor usually gets. The Department was already quite well known due to the fame of his predecessor, H.L. Callendar, but it was Rutherford who gave it an international reputation, the shadow of which has continued to this day. The influence on his friend, J.C. McLennan, helped to secure, for Toronto, a Physics Laboratory as good as that at McGill [2] and his prestige soon

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affected other Canadian universities. H.L. Bronson, who worked with him at McGill, later became Professor at Dalhousie. A fitting tribute to Rutherford was made by William Macdonald, the tobacco merchant who gave millions for various purposes to McGill; he said that all his expenditures were fully justified by Rutherford's results alone.

Rutherford at Cavendish

The list of Rutherford's colleagues and students from Manchester and Cambridge who later worked at Canadian Universities and research institutions is long and distinguished. The McGill Physics Department was dominated until the late 50s by professors who either had a Cambridge Ph.D. or post doctoral experience. Some readers may remember A. Norman Shaw, Louis King, W. Watson, David Keys and Ferdi Terroux, amongst others. Terroux, in a lasting tribute, created the Rutherford Museum where students and visitors can now see the original equipment used by Rutherford and his colleagues and students at McGill. Several, including W. Watson, went to Toronto, J.A. Gray and B.W. Sargent to Queen's, R. Boyle to Alberta, R.K. McClung to Manitoba, and G. Laurence to the NRC laboratories, but it was at Chalk River that his legacy really had a dramatic influence. First John Cockcroft, and then Ben Lewis, had learned from Rutherford. They realized and insisted that strong, well supported research programs in both the pure and the applied sciences were essential in the developing laboratory. Both had inherited Rutherford's love of research and took great personal interest in the work underway, especially in the physics area; I recall well how Cockcroft would come around the labs with his little black notebook in which he would write notes as we described the latest progress in our experiments.

Rutherford's determination to provide for his 'boys' equipment and materials which were the most advanced possible enabled them to keep ahead of his 'competitors'. This rubbed off onto his colleagues and students and had a profound influence in helping Canada to leap ahead in the 50's and 60's. Cockcroft and Lewis exploited it in persuading the Canadian government to fund the NRX, NRU reactors, and the series of Van de Graff accelerators which catapulted Canadian physics into the forefront in the wonderful days of the 1950's and 60's . The follow-up by others with TRIUMF and the TASCC facilities continued this tradition later. It is a sad commentary on the present state of scientific support that TASCC was subsequently closed and that some other facilities such as ING and KAON were not pursued.

Cockcroft laid the plans for the NRX reactor, perhaps the most far sighted scientific investment ever made in Canada. The lab was fortunate in having so many Cambridge graduates who had been Rutherford's students or colleagues: George Laurence, Bernard Kinsey, Don Hurst, Hugh Carmichael, Arthur Ward, Les Cook, as well as the next director, W. Ben Lewis. Some, such as Laurence and Ward, made major contributions to the development of the CANDU program [6] and others, such as Kinsey, quickly developed major research programs and encouraged and helped others to do likewise; they all played significant roles in the successful nuclear programs in Canada. But Lewis' drive and determination were the main influence in making Chalk River one of the most productive laboratories in the world during the 30 year period following the start of the NRX reactor in 1947. Both Cockcroft and Lewis had inherited Rutherford's appreciation that facilities and opportunities were far more important than salaries in attracting bright young scientists to remain in or come to Canada in those hay days of Chalk River's glory. The enthusiasm and vitality in the labs, especially in the experimental and theoretical physics research groups, were quite exhilarating, and several of us were driven by it to far greater accomplishments than we might have ever hoped to achieve elsewhere.

It is difficult to overestimate the influence of Lewis on this and later development of Canadian physics; the realization that significant research could be done in Canada soon spread from Chalk River to Canadian universities. The parallel enthusiasm and accomplishments at the NRC labs in Ottawa doubly enhanced this spreading of confidence to the universities. Though Rutherford's direct legacy was less there than at Chalk River, it was nevertheless present in the outlook on research of many of its renowned scientists. Rutherford encouraged many visitors to spend a few months in his laboratory observing and learning his techniques and style of research. In this vein, one of the more far sighted and fruitful programs instituted at Chalk River and NRC was the invitation to science professors at Canadian universities to spend a few months during their summer vacation period with one or two of their graduate students there. Under this program, they not only had the opportunity to use the available state-of-the-art facilities, but they were exposed to the excitement and enthusiasm which pervaded the labs at that time. They carried this back to their universities, and the quality of research and teaching was subtly, but significantly, enhanced.

Rutherford was seldom concerned with the practical applications of his nuclear research, but he did have a lasting interest in the influence and benefits of radiation in medicine. However, the main applications of his work were to come later. Though involved with research funding through the Royal Society, he was spared the dramatic dependence of research on governments. But nowadays, as the funding of research has become significant, government granting agencies are becoming increasingly concerned, usually with the possible economic feedback. To justify the expenditures to their electorates they are veering towards a link between grants and short term results. Though this is partially understandable, it overlooks the real reason that a country must support fundamental research, especially long term research. This is the need to develop and maintain a tradition of teaching and research which will create a viable and active scientific infrastructure.

A scientific infrastructure is a complex thing! It involves scientists, engineers, technicians and a few competent administrators in well-equipped facilities who can take quick advantage of scientific and technological developments which may occur anywhere. Such groups might be in industry, government laboratories, university cooperatives, or private think tanks. But they must be there for a country such as Canada to take advantage of the immense opportunities presented by the present technological revolution. And it all comes back to the need for a strong and viable fundamental research climate which will produce the manpower for this infrastructure. Immigration may help, and obviously has done so in the past, but it is not the real answer. As Rutherford might have said: you have to have the "boys" and give them facilities and keep at them.

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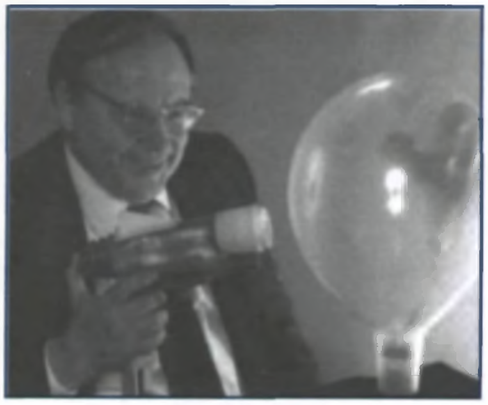
ARTHUR LEONARD SCHAWLOW, 1921 - 1999



A.L. Schawlow

The many contributions to science of Arthur Leonard Schawlow as a teacher, creative physicist and science writer, have won for him a renowned national and international reputation, highlighted by the award of a Nobel Prize in Physics in 1981, and the National Medal of Science in 1991. Two prestigious Arthur L. Schawlow Awards, given annually, honour him as one of the laser pioneers: a Prize of the American Physical Society for contributions to laser science, and a Medal of the Institute of America for laser applications. On a more personal note has been the adulation of his students, co-workers, and the many people whom he had touched with his friendship and joy and wonder of science, experiences recounted in the volume "Laser, Spectroscopy and New Ideas: A Tribute to Arthur L. Schawlow" published by his students on his 65th birthday.

Schawlow was born in Mt. Vernon, New York, in 1921, but his family moved to Toronto when he was three years old, and he took his primary, secondary, and university education there. He obtained a scholarship to enroll in the demanding program of Mathematics and Physics at the University of Toronto and so began his career in science. He continued with graduate studies and obtained a Ph.D. degree in atomic physics in 1949, under the supervision of Malcolm F. Crawford. His research in hyperfine structure using atomic beam spectroscopy was carried out with co-workers Fred Kelly and Mack Gray and led to one of the first determinations of nuclear size. They designed and built almost all of their equipment, one part being a Fabry-Perot interferometer which later turned out to be Schawlow's basic contribution to the laser, namely the two parallel end-mirrors which form the resonator. Schawlow also enjoyed Dixieland jazz; he played the clarinet, helped to organize the Delta Jazz Band, and had an enviable collection of jazz records.

Schawlow carried out most of his scientific research in the U.S.A. - at Columbia University, the Bell Telephone Laboratories, and Stanford University. In 1949 he received a postdoctoral fellowship to work at Columbia University and there began his long and fruitful association with Charles H. Townes, a pioneer of microwave spectroscopy. Schawlow started with research on the diatomic molecule OH using microwave spectroscopy and, having difficulty in finding its spectrum, coined the memorable line "a diatomic molecule is a system with one atom too many". His early research contributed to the measurement of nuclear moments and properties. He also co-authored, with Townes, the book titled "Microwave Spectroscopy", published in 1955.

In 1951 Schawlow married Aurelia, Charles Townes' youngest sister, a fine musician and vocalist, and they raised a family of a son and two daughters. That year he joined Bell Labs at Murray Hill, and started research in superconductivity and spectroscopy. He collaborated with Townes on the possibility of extending the range of the maser into the visible region and published the famous paper of 1958 "Infrared and Optical Masers" establishing the principles of the laser. Within two years the first working devices were announced, launching the laser era, and spawning a flourishing new field of "Quantum Optics", and a huge industry, "Photonics and Electro-Optics". Schawlow was one of the most imaginative contributors to the use of lasers in science, communications, engineering, and medicine.

With his appointment as Professor of Physics at Stanford University in 1961, Schawlow became a major influence in the lives of many young scientists. Students enjoyed his fatherly advice given with his usual charm and sense of humour: "To do successful research, you don't need to know everything, - you just need to know of one thing that isn't known"; and "Anything worth doing is worth doing twice - once quick and dirty, and the second time the best way you can." They also loved his amusing demonstrations of popping one balloon inside another with a laser beam, and making an edible laser of Jell-O.

The Schawlow Lab became one of the outstanding contributors in laser spectroscopy, producing new ideas and techniques, many of which became standards in the field. Of his many remarkable contributions in science, Schawlow chose as his most important papers the determination of nuclear size with his colleagues at Toronto, the laser idea with Townes, and the slowing down of atoms and molecules with laser beams published with Theodor Hânsch at Stanford.

Boris Stoicheff
University of Toronto

THE LIFE OF SIR JOHN CUNNINGHAM MCLENNAN PH.D., F.R.S., O.B.E., K.B.E. 1867 - 1935

by Robert Craig Brown

John Cunningham McLennan was the son of David McLennan, a Scots miller born in Aberdeenshire in 1836, and Barbara Cunningham of Glasgow whom David had married in 1864. In October 1865, David had emigrated to Canada and, eight months later, Barbara and her newborn child, Janet, joined him in Ingersoll, a small village between Woodstock and London in Southwestern Ontario, where David was a grain merchant. John was born in Ingersoll on October 14, 1867. John spent his early pre-school years there before the family moved westward to Exeter, and later to Blyth, following the fortunes of David's grain business. In 1880, the family moved again to Clinton so that Janet and John could attend Clinton High School. By then John had a brother, David, and two more sisters, Barbara and Jean. Then, in December 1882, the McLennans moved to Stratford. John passed his Matriculation at the Stratford Collegiate Institute the following summer. Another sister, Mary Louise, was born that year and, in September 1884, John's youngest brother, William Edward, was born.[1]

John wanted to go to university. But, with the onset of depressed times and falling wheat prices in 1883-4, his father could not afford the expense. More than that, to help support the large family, John had to go to work.

John wanted to go to university. But, with the onset of depressed times and falling wheat prices in 1883-4, his father could not afford the expense. More than that, to help support the large family, John had to go to work. He chose school teaching and, over the next few years, he taught in a number of Perth County schools. On Fridays he returned home for his regular Friday evening private tutorial in mathematics with Dr. A.H. McDougall, the mathematics master at Stratford Collegiate. David McLennan nearly lost everything in the grim year of 1884 but managed to recover enough by 1887 to acquire a spacious house on Williams Avenue that became the family home. In the Fall of 1888 John enrolled in University College, University of Toronto, to study in the university's Mathematics and Physics Honours Program. He was twenty-one and older and more mature than most of his fellow undergraduates. John studied under the Professor of Physics and President of the University, W. James Louden, and graduated with first class honours at the head of his class in June, 1892.[2]

Louden appointed him Assistant Demonstrator in Physics that summer. Two years later he was given a permanent appointment in the Department and the following year, with encouragement from Louden, McLennan made his first trip to Britain and Europe. He met Sir Oliver Lodge at London University and Lodge gave him letters of introduction to several of the important physics laboratories on the continent. He returned to Toronto convinced that a future in physics would depend on experimental research. With Louden's support, that Fall the Physics Department Calendar announced that "special arrangements" could be made by graduate students "for pursuing original investigations in the laboratory"[3] The following September McLennan, finding it "quite impossible to carry on my laboratory

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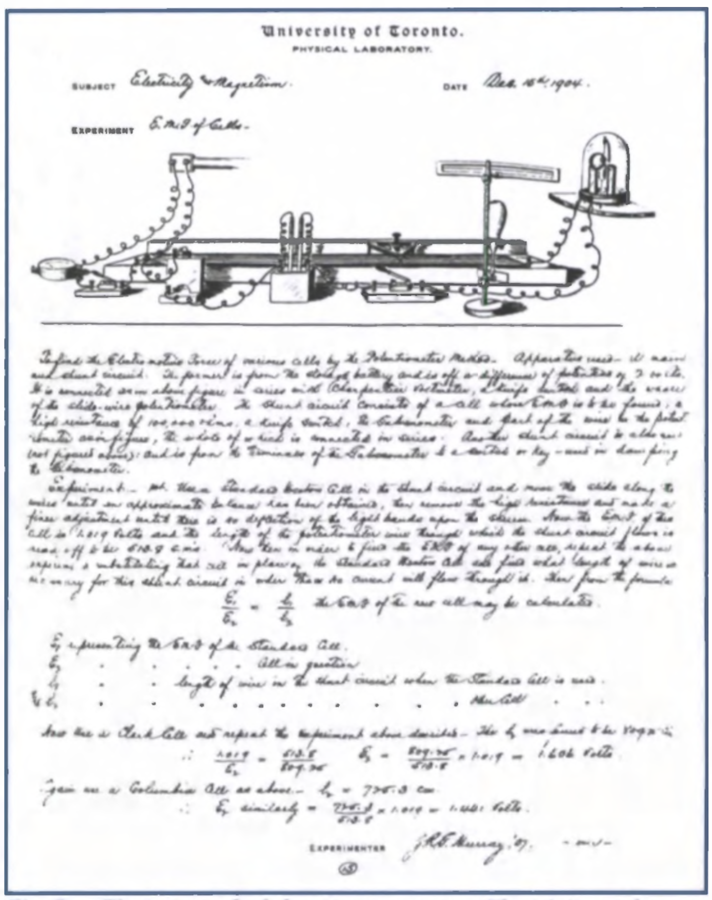
work with desirable efficiency", asked Louden for separate laboratory space in Physics, then housed in University College, to carry out his "special investigations" in electricity and magnetism.[4]

In 1898-99 McLennan returned to Britain to work under the direction of J.J. Thomson at the Cavendish Laboratory at Cambridge University. Fellow students that summer included Paul Langevin, Ernest Rutherford, who was just about to leave to take up his appointment at McGill, R.J. Strutt, J.S.E. Townsend and C.T.R. Wilson.[5] McLennan immersed himself in the most recent literature on gas conductivity, then, late in the summer, spent a week in Paris ordering equipment for the Toronto laboratory before going on to Germany for several weeks to study German. By October he was back at Cavendish and beginning his experimental work. In February he was having difficulties with his project and, in April, he reported to Louden that "for three months it was just try this and try that and always fail" but, at last, he seemed to have found "a method which promises some success". In July, 1899, he was done, in Berlin writing up his results, and reporting to Louden that Thomson judged his experiment "a splendid success."[6] McLennan returned to Toronto with a promotion to Demonstrator. His first paper, "Electrical Conductivity in Gases Traversed by Cathode Rays",

Fig. 1 The Post-Graduates at the Cavendish Laboratory in 1898-99: Left to right: Back Row: G.H. Bryan, R.S. Willows, unidentified. Middle Row Standing: J.W. Walker, A.A. Robb, H.S. Allen, J.C. McLennan, J.S. Townsend, J.H. Vincent, unidentified. Front Row Seated: C.T.R. Wilson, J. Talbot, John Zedeny, R.G. Klempfert, Sir J.J. Thomson, G.A. Shakespeare, H.A. Wilson, J. Butler Burke.

based on his Cavendish experiment, was published in the Transactions of the Royal Society in 1900.[7] That same year McLennan, who had enrolled in the new doctoral program in the Department at Toronto while at Cavendish, was awarded the first Ph.D. in physics at the University of Toronto.

The first decade of the new century was a time of momentous change for the Toronto Physics Department and for McLennan. In 1902 he was promoted to Associate Professor and was joined in the Department by Eli Franklin Burton, a recent graduate who was already assisting McLennan in his research as Assistant Demonstrator. In 1904 McLennan was formally appointed Director of the physics laboratory. That same year the Ontario Government, which had been providing funding for the Department since 1901, agreed to fund a new physics building.[8] McLennan, assisted by Burton, threw himself into the work of planning, as far as funds would allow, a physics laboratory modeled on the Cavendish Laboratory at Cambridge.[9] Then, quite suddenly, in



University of Toronto.
PHYSICAL LABORATORY.

SUBJECT Electricity & Magnetism DATE Dec 15th 1904

EXPERIMENT E.M.F of Cells

EXPERIMENTER J.R.G. Murray '07

Fig. 2 First page of a laboratory report on Electricity and Magnetism by first year student J.R.G. Murray, Class of 1907, December 15, 1904, at the Department of Physics, University of Toronto.

1906, Louden retired from the Presidency and the Department. In 1907, the new president, Robert Falconer, appointed McLennan Head of the Department and the new building (now the Sandford Fleming Building of the Faculty of Applied Science and Engineering) opened. McLennan's dream of heading a major physics laboratory was beginning to be realized. Graduate students started to enrol and, in 1910, the Department awarded its third Ph.D. That same year the Carnegie Foundation surveyed the "academic and industrial efficiency" of a selected number of North American physics departments. Only Toronto and Columbia passed without criticism and the report observed that, at Toronto, "the scientific results of the work done in this laboratory were of a superior character."[10]

By then McLennan had become a commanding presence in the University. He was head of a major department and internationally recognized laboratory. He was a member of the Royal Society of Canada. He was a founder and leader of the Alumni Association and, in 1903, had joined his mentor Louden on a cross-country tour to found local University of Toronto Alumni groups and raise funds for the building of Convocation Hall which opened a year later. He pursued his goals with aggressive and ceaseless determination. Sir William Mulock, Chancellor of the university recalled, many years later, that McLennan was known for being "positive and straightforward in the enunciation of his views". Some colleagues, less charitably, regarded him as "the stormy petrel of committees".[11] Falconer, a regular recipient of entreaties from McLennan, patiently replied to one in 1908 that, though "eagerness is commendable" in a head of department, "it may be necessary for me at times to seem reluctant, simply because I have to adjust relations according to the necessities of such a large and rapidly growing institution."[12]

Outside the university McLennan had developed strong relationships with colleagues in the small but growing number of physicists in Canada, especially with Ernest Rutherford, with whom he exchanged ideas on their mutual interest in radioactivity, with Howard T. Barnes, Rutherford's successor at McGill, and with A.L. Clark at Queen's.[13] In 1904 he had been called to Ottawa to give expert testimony, advocating the adoption of the metric system of weights and measures, to the Standing Committee on Agriculture and Colonization of the House of Commons. In Toronto he was a prominent figure in the Royal Canadian Institute where he vigorously promoted the cause of industrial research.

McLennan had two main research interests in these years, the natural radioactivity of substances and the electrical conductivity of the atmosphere. Between 1900 and 1910 McLennan published seventeen papers, the majority of them on his investigations of radioactivity in metals, gases, and oils. Several were in the Transactions of the Royal Society of Canada; others in the British journals Philosophical Magazine and Physical Review. A particularly important paper, published in the Physical Review in 1903, in collaboration with Burton, announced the discovery of penetrating radiation passing through the atmosphere.[14] Burton soon developed his own research interest in colloidal solutions, but also became McLennan's right hand man, his "first assistant" for whom he had "profound respect and admiration for his ability as a teacher, an organizer of laboratory classes, and as an investigator."[15] Having gotten to know McLennan very well, shortly after McLennan's death, Burton summed up McLennan as a researcher. "Vivid imagination and his indomitable energy in carrying his programme forward" were his strong points, Burton noted. "His forte was not, in essence, originality, which is so remarkable in the work of J.J. Thomson and Rutherford, but, when he once got on the scent of an investigation, no one could show more trained imagination or single-mindedness in carrying it forward."[16]

Much of McLennan's research was stimulated by annual summer trips to Britain, which began in the early 1900's. There, and on the continent, McLennan paid regular visits to fellow researchers, continually seeking for new areas of research which he could take back to Toronto for his own investigations and, in the last years of the decade, those of a growing number of graduate students. Gradually his interests shifted to the emerging field of analysis of spectra. In 1911 he devoted his Presidential Address to Section III of the Royal Society of Canada to a report on the most recent advances in spectroscopy research.[17] By 1914 he was publishing papers of his own in the field.

Throughout these years McLennan dedicated his life almost exclusively to his work. Days were occupied, morning and afternoon, with lectures and laboratory work for a steadily growing number of students and administering the Department which Lorne Gilchrist and H.A. McTaggert had joined in mid-decade. Evenings found McLennan at his bench, engaged in his research. He had many acquaintances, increasing numbers of students, and a small but cohesive group of colleagues. But his relationships with others were formal apart from a strong friendship with Professor J.C. Fields in Mathematics. That changed in 1910 when he married Elsie Ramsay, the eldest daughter of William Ramsay, the owner of a large estate, Bowland, in Scotland. William Ramsay had come to Canada in 1854 and prospered as a merchant in Toronto. He became the largest shareholder of the Imperial Bank and Vice President of the Toronto, Grey and Bruce Railway, and then, in 1882, retired to Bowland. Thereafter Ramsay made frequent visits to Toronto. It was on one of these visits in the 1900's that McLennan met Elsie. In September, 1910, with Fields as best man, John and Elsie were married at Bowland and quickly returned to Toronto. Elsie McLennan became McLennan's beloved companion, the attractive and engaging hostess of an annual party for staff and students of the department each winter, a prominent figure in Toronto society, and an enthusiastic supporter of the Toronto Symphony and the Women's Auxiliary of the Canadian Institute for the Blind.[18]

John and Elsie McLennan were in Scotland when war was declared in August, 1914. They returned to Toronto in September, just as the First Canadian Division of the Canadian Expeditionary Force was leaving for training in England. In Toronto the city was alive with patriotism and expressions of support for the British Empire. Hundreds of volunteers crowded into the headquarters of the city's militia regiments seeking to enlist. The City of Toronto promised to pay the full wages for six months for city employees who signed up, and to insure the life of every citizen who served in the CEF. The newspapers were filled with justifications of participation in the war – a just war – by public figures and noted clerics. Volunteer organizations raised funds for Belgian Relief and a host of other causes. At the University President Falconer was fighting to defend three of his staff of German origin, two members of the German Department and the Professor of Oriental Languages, against demands that they be fired.[19]

McLennan, just short of his forty-seventh birthday, was too old and unqualified to sign up (in the early days of the war recruiting officers looked for volunteers who had had some military experience). Two of his younger colleagues, Gilchrist and McTaggart, were not and, early in 1915, both left the Department to serve as x-ray specialists in the Canadian Army Medical Corps. That left all the teaching and laboratory supervision of the large department to McLennan, Burton and John Satterly, a D.Sc. from the University of London who had joined the department in 1912. Early in the 1914 Fall term, McLennan received a letter from Sir Oliver Lodge, Principal of the University of Birmingham, asking why he had not applied for the Chair of Physics at Birmingham which had been vacant since the death of J.H. Poynting the preceding March. McLennan cabled his application on 5 November. Shortly after, the Toronto Daily Star, the Stratford Daily Beacon, and other papers announced that McLennan had an "attractive" and "very flattering" offer of the Chair at Birmingham. The Alumni Association, of which McLennan was a founder and officer, responded with an urgent resolution dispatched to the President, the Premier, and the Chairman of the Board of Governors proclaiming the possible loss of McLennan a "calamity" and pledging "to leave no stone unturned to secure his services in perpetuity to Alma Mater." Two weeks later another hastily called meeting of the Alumni Association heard testimonials on McLennan's behalf from a number of distinguished citizens including the Honourable Lyman P. Duff, Justice of the Supreme Court of Canada. President Falconer told the crowd that, though the finances of the University "were not yet in satisfactory shape", he hoped that "shortly better provision would be made for Professor McLennan's important Department." McLennan then told the meeting that his chief concern was that 'Physics should have its rightful place in the institution" and that he had "not yet decided what course he would take."[20] But news from Lodge took the decision out of McLennan's hands. Because of the war and the commandeering of Birmingham's laboratories for the war effort, no appointment would be made.[21] McLennan returned to his students and his research.

Then, in July 1915, while in Britain, McLennan was invited to join the Advisory Council of the new Department of Scientific and Industrial Research (DSIR). It, and the Bureau of Inventions and Research, established at the same time as responses to the Munitions Crisis of that year, were attempts by the British Government to organize the best civilian scientific advice available to industry and to the Admiralty.[22] McLennan's British colleagues knew of his strong advocacy, through the Royal Canadian Institute, of establishing linkages between industry and scientific research in Canadian universities, and of his participation, in May 1915, in a meeting of university leaders with Sir George Foster, Canada's Minister of Trade and Commerce, to discuss formation of a Commerce Commission to establish relationships between Canadian manufacturers, university scientists and scientific societies, the Royal Society and the Royal Canadian Institute.[23] The DSIR, with its special mandate to link industry and science in the British war effort, fit exactly with McLennan's interests. It was his first opportunity to serve the war effort.

Another soon followed. At the Front, British observation balloons filled with hydrogen were frequently set on fire by enemy incendiary bullets with considerable loss of life. Sir Richard Threlfall and Sir Ernest Rutherford persuaded the Board of Inventions and Research, in 1915, that helium would be a good substitute for hydrogen if an adequate supply could be found for British airships and observation balloons. In December, the Board asked McLennan to do a survey of helium resources in the Empire to determine if helium extracted from natural gas could be commercially produced in sufficient quantity for war-time use.[24] McLennan began collecting samples of gas from wells in southwestern Ontario for analysis at the Physics Department. There Burton, Satterly, and Professor H.F. Dawes of McMaster University (then located on Bloor Street adjacent to the University of Toronto) analyzed the gas after teaching hours. They found that the Ontario gas contained .33% helium. In April of 1916 McLennan went to Alberta to collect samples from a well in the Bow Island Field in central Alberta and from the pipeline carrying gas from the field to Calgary. It contained .36% helium and proved to be the richest source in the Empire.[25] In the Fall of 1917 McLennan received authorization to establish an extraction plant on the outskirts of Hamilton, Ontario, using gas supplied by the National Gas Company and equipment donated by L'Air Liquide of Toronto. By then McLennan was at work on other projects in England. He got John Patterson, an engineer from the University of Toronto, who was a senior officer of the Canadian Meteorological Service, to join the research team and operate the plant. In due course the team succeeded in extracting small quantities of helium but, by the Fall of 1918 the supply of gas from Ontario wells was declining and the project moved its extraction apparatus to Calgary to use gas from the Bow Island field. Between October 1919 and April 1920, the Calgary plant managed to produce 60,000 cubic feet of helium which was shipped to McLennan and the Admiralty in England. By then the idea of using helium from Empire gas wells in British airships had been abandoned. Though large quantities of helium from United States wells had become available after the American entry into the war, the airplane had replaced airships for most military purposes and helium proved to be considerably more costly than hydrogen.[26]

In the summer of 1917, while working with the Admiralty during his annual visit to Britain, McLennan was among the first group of Imperial persons to be awarded membership in the Order of the British Empire.[27] He was also asked to stay on and continue his work in anti-submarine warfare research. Germany's unrestricted submarine warfare campaign against allied shipping was at its height and the British were desperately searching for devices to

Fig. 3 John and Elsie McLennan leaving Buckingham Palace, August 25, 1917, after the O.B.E. was conferred on McLennan by King George V.

combat the enemy submarines. President Falconer, an enthusiastic Imperialist and supporter of the war effort, told McLennan that the Board of Governors approved a leave of absence for the duration and that the University would pay his salary while he worked in Britain.[28] He had two main projects for the BIR. He was helping the development of an "indicator loop", an underwater magnetic coil or loop which, when laid on the floor of the sea, could detect the passage of ships and indicate it by galvonometric recording. When linked to a cluster of mines which could be fired from shore, the "loop" system could destroy an enemy ship passing through the system. McLennan's other project was to develop workable magnetic and contact fuses for undersea mines. At the time British mines were notoriously unreliable: many broke from their moorings in all but the calmest waters and most failed to explode when struck by an enemy ship, while others had fuses so unstable that they exploded in moderately rough seas.[29] His main laboratory was in South Kensington and he had also set up a smaller laboratory in King's College to continue his research on helium.

There were few skilled hands to help as nearly every capable scientist in Britain was already engaged in war work. He turned to Sir Edward Kemp, Minister for the Overseas Forces of Canada, for help, pleading that he needed "scientific men" and that "I hardly know where to look for them".[30] Eventually a sizeable group of former students was released from the CEF and others came from Toronto to work for him. Three of these former students were Robert Cooley, who came from an Overseas Training Company in Toronto, Albert Roger Self, who was released from the Corps of Signals, and Horace Holmes, "one of the most brilliant students I ever had", who was released from the 12th Field Ambulance of the CAMC. All three worked in Cambridge at a factory making magnetic mines, and in Portsmouth taking measurements of the magnetic effects of ships. Many years later they recorded their memory of the times. McLennan was "kindly but very aggressive", Holmes recalled. Self found his old professor "very demanding" but "we managed". By mid-1918 the indicator loops had been developed and were being deployed. And more reliable contact fuses began to be produced. But students remembered that magnetic fuses "never came to a proper success. They never got past the problem of these things firing when the weather got rotten and shook them.[31]

After the Armistice, at the end of 1918, the Director of Experiments and Research for the Admiralty, Charles Merz, reported that small loop systems with mines were "now in service" and much larger loops used only to detect passing ships had given "useful results in practice". Firing systems for magnetic mines were presently "being tested in rough water" and he recommended that the work be continued. McLennan, the report added, was also working on a magnetic firing device for torpedoes and tests of the device were about to begin.[32]

In December, 1918, a major change in the research work at the Admiralty was approved. The BIR was replaced by a Scientific Research and Experiment Department headed by McLennan. He would also be director of an Admiralty Central Research Institution and Scientific Advisor to the Admiralty.[33] McLennan told President Falconer that the new central research institution was estimated to cost £1.3 million and that its establishment and staffing would be "a task great enough for any one man". Funding for the central research institution was "problematical" and without it "I would not care to stay on here, as I have hoped all my life I would have more opportunity for research than I have hitherto had". He added that, "if the burden of lecturing could be lessened in Toronto and I could have more time for research that is the life that I should prefer to follow." He had told the Admiralty that he had to have a definite decision by April 30.[34]

McLennan wanted the job very much. "It is all so big, away beyond anything I ever dreamed of, that it makes me almost tremble when I see the responsibility of it," he wrote.[35] The April deadline passed. In June he told Robert Boyle, a Rutherford student who was Head of Physics at the University of Alberta and who, with Paul Langevin in Paris, had developed, at the end of the war, the first experimental ASDIC (SONAR) devices to detect submarines, that he thought he would be remaining in England. Still there was no decision on funding for the central research institute. In mid-September McLennan told Rutherford that he was leaving for Canada and taking some of the helium with him. He was also sending some helium to Cambridge and hoped that Rutherford, Thomson, Rayleigh and Sir Willam Pope would use it. But McLennan still had hope. If the situation changed at the Admiralty in the next few months, "I will come back to England."[36]

It was not to be. John McLennan's war was over. Back in Toronto, after the University had given him a "grand reception", he worked to transfer some equipment from the Admiralty to his laboratory, began plans to liquify hydrogen and helium in the laboratory and to establish a cryogenic laboratory in the Physics Department.[37]

In the Spring of 1919, on a brief visit to Canada while the fate of his post as Scientific Advisor to the Admiralty was still undecided, McLennan joined several other scientists and a representative of the Canadian Manufacturers Association before a Select Committee of the House of Commons to advocate the creation of a national research institute for Canada. He and most of the others were the original members of the Honorary Advisory Council on Scientific and Industrial Research, the predecessor to the National Research Council, which had been created in 1916. He strongly supported the establishment of a national research institute and was a leader in the effort to secure funds from the Government of Canada for the Advisory Council to award fellowships and bursaries to outstanding graduate students in the pure and applied sciences. By 1919 the student grants program and a smaller program of grants in aid of research to universities had begun and increased funding was anticipated. In 1918 the Advisory Council, under the leadership of Professor A.B. Macallum, formerly Professor of Biochemistry at the University of Toronto, recommended the establishment of a central research institute. Sir Robert Borden's Government, deeply engaged in the war effort, was not interested. But, in January 1919, a committee of Cabinet had approved the recommendation and sent it to the Select Committee for further consideration.[38]

The primary function of Canada's universities, McLennan told the Committee, was "to educate and train men and women." Industrial research to aid "the creation of national wealth" he added, "is a pure business proposition directed in a certain way without regard to education" and "the establishment of a Central [Research] Institution as the nucleus of a new system ... will permeate and develop the whole country, by utilizing the services of the men and women whom we have trained."[39] McLennan reminded the Committee of the contributions Canadian scientists like Boyle of Alberta, Eve of McGill and himself and others at Toronto had made to the war effort. He feared that more Canadian scientists would follow those who already were "steadily leaving this country". To counter that trend, to improve the productivity and efficiency of Canadian industry, he urged the establishment of a "Central Research Institute as a beginning in working out a scheme for the scientific development of industry in this country."[40] The Committee reported, in July, that "Scientific Research in Canada requires and deserves generous encouragement and support from the Dominion Government" but added that further consideration be given to the institute proposal.[41] In 1921 a Bill to create a national research institution passed the House of Commons but was defeated by the Senate. It was not until 1928, under the leadership of Henry Marshall Tory, that the National Research Council got approval for a national laboratory based in Ottawa.

Macallum, having launched the Advisory Council, resigned as Chair to accept a Professorship at McGill. A long wrangle over a successor followed and McLennan received strong support from Hume Croyn, the MP from Toronto who had headed the 1919 Special Committee, and Lloyd Harris, a prominent businessman who had represented Canada at Washington during the later stages of the war. He did not have Macallum's blessing, Macallum favoured A.S. Mackenzie, a physicist from Dalhousie nor that of fellow Advisory Council member R.F. Ruttan from Montreal, who regarded McLennan as "extremely energetic and is experienced" but "lacks tact and would doubtless make a great many enemies". Arthur Meighen, the Prime Minister, who had known of McLennan since his student days at Toronto at the end of the 1890's, "could think of no one his superior" as a scientist, but was concerned that "temperamentally he is disposed to animosity."[42] Between 1921 and 1923 three others served short terms as Chairman before Tory was appointed in 1923. McLennan remained on the Council and was one of its most active members throughout the years.

In the 1920's the student scholarship program and the grants in aid of research were the cornerstone of the work of the Advisory Council/National Research Council. McLennan was among the most assiduous supporters of funding for his students and for research projects in the Physics Laboratory. And the most successful. Yves Gingras, the historian of physics in Canada, noted that McLennan got half of all the bursaries (studentships and fellowships) granted in physics as well as $25,000 in grants in aid of his projects between 1918 and 1932, the year he left

Toronto. McLennan had the most students and supervised more than twenty of the twenty-seven doctorates in physics awarded in Canada in that period.[43] Gordon Shrum, one of those students who received both fellowship and post-doctoral awards, recalled McLennan telling him that "We don't want support for scientific research just to keep scientists busy: we want scientists to be looked upon by the public as people who can do things for them that they can't do themselves."[44]

Elizabeth Allin, another of McLennan's students, and a long-time faculty member who wrote a fine brief history of the Department after retirement, recalled student life in the laboratory at the time. Each morning McLennan, the workshop foreman, T.S. Plaskett, the glass blower, R.H. Chappell, and, frequently, a junior member of the faculty, visited the work station of each graduate student. "What's new?" McLennan would ask. "It was unwise to have nothing to discuss since this was regarded as evidence of lack of endeavour." Students were expected to be in the laboratory every weekday during the academic year, working on their projects, doing demonstration duties, or attending lectures. Every other Thursday at 4:00pm, faculty graduate students, and senior undergraduates were expected to attend the departmental seminar which invariably began with a talk by McLennan. At the end Elsie McLennan appeared to pour tea. On alternate Thursdays the 4:00pm hour was given over to a meeting of the Mathematics and Physics Society. Those graduate students not supported by the National Research Council held Assistant Demonstratorships with an annual stipend of $750. In the summer months, students prepared their work for publication, attended summer school elsewhere, or worked to help support themselves.[45]

For McLennan, who was fifty-two when he returned to Toronto in 1919, this was the most productive period of his career. Between 1919 and 1932 he published more than one hundred and fifty papers, well more than half of them with his graduate students.[46] Shrum was especially important for McLennan's work in cryogenics and spectroscopy. He had been an undergraduate in physics until he enlisted in the Artillery of the CEF in 1916. He fought at Vimy, was wounded at Passchendaele, returned to the Front to fight in the battles of the "last 100 days", and was awarded the Military Medal.[47] Shrum returned to Toronto in the Fall of 1920 and McLennan immediately set him in charge of building the equipment to liquify helium. After many trials, it was accomplished at the beginning of 1923. It had been done only once before, in 1908, by the Dutch physicist Kamerlingh-Onnes, who provided advice to McLennan after the war. Very quickly thereafter Shrum could produce the liquid helium almost on demand. McLennan, overjoyed by this technological achievement in his laboratory, arranged an evening lecture in the laboratory for the University's Board of Governors. Just as he was concluding a report on his research, McLennan was informed that the gas had been liquified. McLennan stopped and ushered the Governors into the laboratory to see the gas. The headline in the Globe the next day read: "Stand In Wonder As Local Wizard Liquefies Helium."[48]

Later that year Shrum completed his doctoral studies with a thesis on the hydrogen spectrum. Shrum spent another year in Toronto as a post-doctoral fellow working with McLennan and then took a position in the Corning Glass Company in New York State. He returned in the Spring of 1925. Vegard, a Norwegian physicist, had recently announced that he had discovered that the source of the auroral green line was nitrogen in the atmosphere. Neither Shrum nor McLennan were convinced, and Shrum set to work to find the auroral green line. He did, and demonstrated that its source was oxygen, not nitrogen. The discovery, later confirmed by other scientists, was very important at the time. McLennan announced it in Nature on 14 March, 1925, with himself as the sole author. Shrum was incensed. "You know, I'll share everything with you," he told McLennan, "but I hate to give you my good luck completely." A second piece in Nature on 25 April was co-authored, as was a major paper on the origin of the auroral green line in the Proceedings of the Royal Society (London) later in the year.[49] It was the high point of McLennan's research career. He was awarded the Royal Society's Gold Medal in 1927 and delivered the Bakerian Lecture before the Royal Society in London, on "The Aurora and Its Spectrum" in 1928.

By now nearly all of McLennan's papers were published in collaboration with his students. In 1928 all but two were with students, including two with H.J.C. Ireton, who would be a long-time member of the department. Elizabeth Allin joined the list in 1929 with one paper and two more in 1930. Over the three year period fifty seven papers appeared.[50] In June, 1930, President Falconer wrote to tell him that the

Board of Governors had approved his appointment as Dean of the Graduate School. "I only hope," McLennan replied from England, "that in the short time that I can hold the post I may be able to give you some effective help in developing graduate work in the University."[51]

Fig. 4 Lord Rutherford and Sir John C. McLennan at the British Association Meeting, Norwich, England, September 7, 1935, a month before McLennan's sudden death.

McLennan did not enjoy the appointment. He was anxious to improve the "social life" of graduate students, more especially women graduate students, and to reorganize the work of the School. But his main goal was to centralize the oversight of research at the University in the Graduate School and rename the faculty as the School of Graduate Studies and Research. The other faculties and departments would have none of it and fought, successfully, to preserve their entrenched autonomy from the supervision of the powerful, outspoken former Head of the Physics Department. As his friend and colleague, A.S. Eve at McGill, delicately put it in McLennan's obituary a few years later, the "academic freedom and the liberty of departmental control could not lightly be sacrificed."[52] The following Spring, with Elsie's health deteriorating, and frustrated by his failure to bring research at the University of Toronto under the mandate of the School of Graduate Studies, McLennan gave notice to Falconer of his determination to resign from the Deanship and the University at the end of June, 1932. He reminded the President that "for forty years I have given my all to the University of Toronto" and rehearsed all the contributions he had made. He was worried about his pension and hoped that the Board of Governors would "treat me considerately." "For practically the whole of that time," he added, " I have had to maintain the home at Stratford and to keep from three to four members of my family. As a consequence I have never been able to save anything and the only money I have now is what I hold in trust for Mrs. McLennan."[53] McLennan returned in the Fall and was granted leave with full pay for the Spring term in 1932 prior to his formal resignation. He did not sever his connection with the department; arrangements were made for him to be an Annual Visiting Professor.

McLennan and Elsie moved to England and built a fine home, "Ramsay Lodge", with a laboratory for his work, in Surrey. McLennan immediately became involved as an expert advisor, with Lord Rayleigh and others, to report to the Royal College of Physicians of London and the Royal College of Surgeons of England on the scientific basis for mass radium beam therapy treatment for cancer. In mid-December the advisors reported that treatment of cancer by massive doses of radiation was of medical value and recommended Britain acquire the required units of radium and treatment apparatus to carry out research on the treatment process. Then disaster struck. On 20 March, 1933, just months after the McLennan's had moved into Ramsay Lodge, Elsie died. McLennan was absolutely devastated. She had been his devoted companion for twenty-three years and perhaps the only close friend he had. For the rest of his life McLennan was a desperately lonely man.[54]

In June McLennan became Chairman of the Executive Committee of the radium research group. He persuaded Union Minière du Haut Katanga to donate ten units of radium to the work and set up a laboratory at the Radium Institute with funding from the Medical Research Council and the Department of Scientific and Industrial Research and other organizations. With seven associates to assist him, research treatments of cancer by radium therapy began early in 1934. McLennan never saw it to completion. Nor did he have much time to enjoy the honour he cherished most, the announcement in the 1935 Honours List of Knighthood in the Order of the British Empire, for his long, distinguished service to the Empire. In October, 1935, he went to Paris for meetings of the International Bureau of Weights and Measures. On the ninth he took the boat train to Calais. Shortly after leaving Paris, John Cunningham McLennan, scientist and Knight of the Realm, was stricken and died, suddenly and alone, in his compartment.[55]

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53. *Ibid.*, Box 127, McLennan to Falconer, 15 June, 1931.
54. UTA, McLennan Family Papers, Box 1, file 5, Geoffrey Pearce to Janet McLennan, 5 February, 1936 with enclosed report on McLennan's work on radium beam therapy; Janet Cumming McLennan Papers, Scrapbook, p. 108; Eve, "Sir John Cunningham McLennan", p. 518, *op. cit.*
55. *Ibid.*

The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest are particularly welcome.

Le comité de rédaction invite les lecteurs à soumettre des articles qui interesseraient et seraient compris par tout physicien, ou physicienne, et étudiant ou étudiante en physique. Les articles de synthèse et d'intérêt général sont en particulier bienvenus.

HARRY LAMBERT WELSH, 1910 - 1984

Harry L. Welsh

Harry Lambert Welsh began a long association with the University of Toronto with his enrollment in undergraduate physics in 1926. Later, as a professor in the Department of Physics, he brought fame to his Alma Mater with his pioneering studies in Molecular Spectroscopy and Intermolecular Forces. He played a major role in the development of the Department in the 60's, with the establishment of research groups in Theoretical, Atmospheric, and High Energy Physics, and by instituting more democratic procedures in the administration of the department and its programs. Over a period of four decades he stimulated sixty-five Ph.D. students who had the privilege and pleasure to carry out research under his supervision. These scientists have made, and are continuing to make, important contributions to research in a variety of ways in universities, industry, and government institutions across Canada and in other countries.

Welsh was born on March 23, 1910 on a farm north-east of Toronto. He attended a one-room primary school, showed little enthusiasm for farming, and much preferred study and reading books from a small travelling library, which he credited for sparking a lifelong interest in science. Welsh inherited a passionate love of music from his father, particularly in piano playing, and pursued it at a professional level throughout his life. He completed his high school education at age sixteen, and took up the challenging honours course of Mathematics and Physics at the University of Toronto. Welsh's intention was to specialize in mathematics, but he was soon persuaded to switch to physics by the masterful lectures of John Satterly, which were always accompanied by vivid demonstrations. Fellow students in the honours program included Tuzo Wilson and Byron Griffiths, who later became professors at the University of Toronto.

In addition to his studies in physics, Welsh registered in the Faculty of Music. His daily schedule included physics in the mornings, usually by self-study which he much preferred to lectures, followed by music theory and piano practice every afternoon. In third and fourth years he came under the influence of the dynamic John C. McLennan, F.R.S., Head of the Physics Department, who thought that Welsh spent far too much time on the piano, and asked him one day "When are you going to give up that damned music?"

Welsh completed his Bachelor of Arts degree in 1930 and, after a year of graduate work, decided to continue his graduate studies in Göttingen with James Franck whose personality and work had so impressed him during Franck's visit to Toronto. There he found the physics courses to be exceptionally good, but the big event was the weekly Colloquium, with lively discussions amongst Born, Cario, Eucken, Heitler, Kuhn, Nordheim, Pohl, Sponer, and Teller of the Institutes, and the many distinguished visitors. With the assumption of power by the Nazis in 1933, followed by the devastation of the great Institutes of Physics and Mathematics in Göttingen, Welsh left Germany and completed his Ph.D. degree in Toronto in 1936. After a six-month stint with industry, he returned to the university as a demonstrator and collaborated with Malcolm Crawford, then leader of the spectroscopy laboratory, in research on Raman spectra of liquids. At the outbreak of World War II, Welsh participated in the service courses given to Army, Navy and Air Force personnel, and then spent two years in Ottawa working on anti-submarine operations and convoy protection with the Royal Canadian Navy. He married Marguerite Ostrander, a school teacher of languages with special interest in French.

Welsh resumed his post at the University of Toronto, was appointed Professor in 1954 and served as Chairman of the Department from 1962 to 1968. This was the period of the most rapid growth of the Physics Department: along with the expansion of existing research groups, new fields of research were established, and the faculty was increased to about 60, to supervise 150 graduate students and teach over 3,000 undergraduates enrolled in physics. The long planning for a new building for physics and astronomy came to fruition on the opening of the McLennan Physical Laboratories in September 1967.

Welsh's interest in molecular physics and spectroscopy focussed on intermolecular forces. For these investigations, his choice was molecular hydrogen, the simplest molecule for experimentation in the gaseous, liquid, and solid states. His excellent intuition for doing the right experiment was the hallmark of his distinguished research career. He is best known for the discovery (in 1949, with Malcolm Crawford and their student Jack Locke) of pressure-induced absorption of homonuclear molecules, for his original contributions to our knowledge of solid hydrogen, and the development of high-resolution Raman spectroscopy of gases. Finally, it may be said that, while he appreciated the importance of precise measurements, Welsh undoubtedly derived the greatest joy from the search for, and observation and elucidation of, new phenomena.

The H.L. Welsh Lectures, presented annually by the world's leading scientists, were inaugurated in 1975 as a celebration of the respect with which the physics community across Canada and molecular spectroscopists internationally held Harry Welsh for his friendship, sincerity and integrity, and for his outstanding scientific accomplishments.

Boris Stoicheff
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RASETTI À LAVAL

par Jean Le Tourneux

"J'avais été épaté par ce type qui était venu faire une conférence sur l'effet Raman dans les cristaux (à l'ETH de Zurich)... Il était parmi les meilleurs que j'avais vus, éblouissant de vraie clarté tranquille." C'est en ces termes [1] que le chimiste québécois Cyrias Ouellet évoquait le souvenir que lui avait laissé le physicien italien Franco Rasetti, et ce souvenir se trouve vraisemblablement à l'origine de l'un des épisodes les plus fascinants de l'histoire de la physique au Canada: la venue à Québec de cet éminent physicien, doublé d'un extraordinaire naturaliste, l'un des hommes de science les plus universels de ce siècle.

> "Quebec was a quiet place to live in, and Canada a land abounding in trilobites."
>
> Laura Fermi [2]

Faut-il évoquer une fois de plus ce lieu commun? Le Québec francophone n'était entré qu'avec réticence dans le monde des sciences et de la technologie. L'Université Laval n'y était venue qu'en 1919 en créant son École supérieure de chimie, et pour trouver des professeurs, francophones, elle avait dû se tourner vers l'étranger, la Suisse le plus souvent. Dans l'esprit de ses fondateurs l'École serait le noyau d'une future Faculté des Sciences, et quand l'édifice de l'École des Mines est inauguré, en 1938, Laval se voit en mesure d'enseigner l'essentiel du spectre des sciences appliquées.

Les sciences pures continuent pourtant d'accuser un retard certain. La physique, en particulier, ne fait l'objet que d'un enseignement de service, confié tout naturellement à Cyrias Ouellet, puisque ses recherches portent sur la chimie physique. Formé en partie à Cambridge, où il avait fréquenté Occhialini et Blackett, ce chimiste connaît trop bien le monde de la physique pour ne pas se rendre compte du caractère peu satisfaisant de cette situation. Il rêve pour Laval d'un département de physique de première force et réussit à faire partager ce rêve à l'administration de l'Université. Mais où trouver le scientifique d'envergure qui acceptera de venir fonder ce département? Dans un tel désert? Chacun tente d'exploiter les contacts qu'il a dans les endroits où il a travaillé. Monseigneur Alexandre Vachon, doyen de la Faculté des sciences, fait plusieurs démarches en France, mais sans succès. Comme le rappelle Paul Koenig [3]. "On cherchait désespérément un directeur au niveau des espérances et même des rêves."

À la fin de 1938, Ouellet apprend qu'Enrico Fermi ne rentrera pas en Italie après être allé chercher son Prix Nobel à Stockholm, et qu'il émigrera directement aux États-Unis. Ce départ signifie l'éclatement complet du Groupe de Rome: Segrè est déjà à Berkeley et Amaldi cherche, lui aussi, un poste dans une université américaine. Et dans un éclair d'imagination, Ouellet entrevoit la possibilité que dans ces conditions Rasetti, l'ami et le bras droit de Fermi, accepte une offre de Laval. Le fait que ce Rasetti est incroyant et descend d'une famille de carbonari ne pose aucun problème aux yeux des autorités ecclésiastiques, sans doute plus sensibles au fait qu'il appartient à l'Académie Pontificale des Sciences! Elles demandent donc à Cyrias Ouellet d'aller rencontrer Rasetti en Italie au début de l'été 1939 pour lui communiquer l'offre de Laval, et, surtout, pour organiser sa sortie d'Italie et son entrée au Canada, ce qui est loin d'être trivial dans le contexte politique de l'époque. L'historienne des sciences Danielle Ouellet, qui prépare une biographie de Rasetti en collaboration avec René Bureau, a raconté les péripéties de cette mission rocambolesque [1] : l'envoyé de Laval qui, pour détourner les soupçons des autorités italiennes, prétend aller visiter une tante religieuse à Rome, l'étonnement de Rasetti qui, croyant voir arriver un prélat d'un âge respectable, se retrouve devant un homme encore jeune qui s'adresse à lui en italien

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(Ouellet avait échangé des cours d'anglais contre des cours d'italien avec Occhialini!), Rasetti entraînant son visiteur dans les rues de Rome pour discuter loin des oreilles indiscrètes! Moins pittoresques, les difficultés liées à l'immigration canadienne n'en furent pas moins réelles. Rasetti fut enfin en mesure d'accepter l'offre de Laval. Tout au long de son voyage, il fut protégé par la diplomatie vaticane et c'est elle qui se portera garante de lui pendant toute la guerre [3] Après un crochet par New York pour revoir Fermi à Columbia, il s'amène à Québec à la fin de l'été.

Laval a enfin trouvé son physicien. Mais qui est-ce au juste?

AMI ET COLLABORATEUR DE FERMI

Né à Pozzuolo en Ombrie le 10 août 1901, Franco Rasetti se considère comme un descendant d'Etrusques et en conçoit une grande fierté. Laura Fermi [2] et Emilio Segrè [4] nous ont laissé de lui un portrait pénétrant. "Rasetti ... was not a usual person; his main interest was directed to that part of the world which is not made of human beings. He was a born naturalist." [2] En effet, dès son adolescence il publie des articles d'entomologie, en collaboration avec son père, un féru de botanique et d'entomologie, professeur dans une école d'agriculture. Malgré sa passion pour la biologie, Rasetti s'inscrit en génie à l'Université de Pise, où il rencontre Fermi qui le convainc de quitter le génie pour la physique. Il s'engage dans cette discipline parce qu'il éprouve du mal à la maîtriser: il veut se prouver qu'il peut en surmonter les difficultés. Les sommets l'attirent. Très jeune il était devenu un alpiniste accompli, et il entraîne Fermi en montagne. On est frappé par l'importance de l'alpinisme dans les stratégies de recrutement qui ont conduit à la formation du groupe de Fermi [5] : Segrè rencontre Rasetti dans les montagnes de l'Italie centrale, Amaldi Fermi dans les Dolomites. Il y a deux classes de physiciens italiens, me faisait récemment remarquer l'un d'entre eux: les alpinistes et les spéléologues. Faut-il voir en Rasetti l'ancêtre des premiers?

Très vite, Fermi et Rasetti deviennent inséparables. Rasetti embrigade son ami dans la "Société anti-voisins"qu'il a fondée à seule fin de casser les pieds aux gens. Un jour, les deux compères risquent d'être expulsés de l'Université de façon définitive pour avoir fait exploser pendant un cours une bombe puante de leur fabrication. Seuls leurs résultats académiques exceptionnels leur permettent de trouver grâce devant le conseil disciplinaire spécial constitué pour les juger.

Il n'y a que trois étudiants en physique à Pise en 1920. On leur donne les clefs des laboratoires et de la bibliothèque, et une liberté totale. L'état piteux des laboratoires explique sans doute l'habitude que prirent Fermi et Rasetti de tout fabriquer de leurs propres mains. Complètement autodidacte, Fermi s'affirme bientôt comme l'autorité locale en physique. Dès ce moment, les deux amis commencent à s'influencer mutuellement, et ils continueront de le faire quand ils se retrouveront à Florence et ensuite à Rome. Segrè en témoigne : "Rasetti's exceptional native ability and versatility made him a precious companion to Fermi ... The overall influence was reciprocal; if Fermi taught theoretical physics to Rasetti, Rasetti taught Fermi many other things ranging from modern English literature to biology, and at the same time Rasetti's exceptional grasp of experimental physics allowed him to do significant modern experiments with very modest means." [4]

Au milieu des années 20, l'Institut de physique de la via Panisperna à Rome était dirigé par le Sénateur Corbino. Ce physicien politicien, sicilien brillant et généreux, rêvait de redonner à la physique italienne l'éclat qu'elle avait perdu depuis les jours glorieux de Volta et d'Avogadro. Voyant en Fermi la personne capable de transformer ce rêve en réalité, il créa pour lui en 1926 une chaire de physique théorique. À l'instigation de Fermi, il fait également venir Rasetti pour développer la physique expérimentale. Ensemble, ils recruteront la pléiade de jeunes scientifiques connue comme le Groupe de Rome, Segrè, Amaldi, Majorana et Pontecorvo, "le groupe absolument parfait", dira Occhialini. Souvent, on les désignait familièrement comme "les gars (*ragazzi*) de Corbino". La personnalité originale de Rasetti laisse une empreinte profonde sur eux. Selon Segrè, "Rasetti's influence on Fermi and the whole group was great, even outside physics. He read books (fiction and popular science), he traveled to remote places, he collected insects, he ate special foods, and so on. By subtly extolling his own readings or activities he spurred imitation. We called him the "revered master" (venerato maestro) in a joking way which had more than a grain of truth in it." [4]

En 1928-29, dans le laboratoire de Millikan au CALTECH, Rasetti entreprend des travaux de pionnier sur l'effet Raman, qui vient tout juste d'être découvert. Ces travaux lui valent rapidement une réputation internationale et il y verra sa plus importante contribution à la physique. D'une façon ironique, c'est au moment où Corbino crée pour lui une chaire de spectroscopie que le groupe décide de passer de la spectroscopie à la physique nucléaire, une transition qui était loin d'aller de soi puisque personne dans le groupe n'avait la moindre expérience de cette physique. Rasetti, pour sa part, alla chez Lise Meitner à Berlin, pour y apprendre l'art de fabriquer chambres de Wilson, compteurs Geiger-Muller et sources de neutrons. Cinq ans s'écoulent entre la prise de cette décision et l'année 1934, où les découvertes se précipitent: celle de la radioactivité artificielle induite par les neutrons et celle de l'efficacité accrue des neutrons lents, découvertes qui vaudront le Prix Nobel à Fermi et l'Accademia dei Lincei à Rasetti. Homme d'affaires averti, Corbino pressent qu'elles pourraient avoir d'importantes applications pratiques, et il suggère aux membres du groupe de prendre un brevet. Le brevet protégeait un procédé de production d'éléments radioactifs par bombardement de neutrons, ainsi que l'amplification de l'effet obtenu en ralentissant ceux-ci. Bien entendu, personne ne soupçonnait alors que ce serait là la clef de l'énergie nucléaire: Hahn et Strassmann découvrirent la fission à quelques jours du moment où Fermi reçut son prix Nobel, et celui-ci n'en apprit la nouvelle qu'une fois rendu aux États-Unis [4,6]. Mais comme les neutrons lents jouent un rôle essentiel dans les réacteurs nucléaires, le brevet était pertinent à la production d'énergie nucléaire. Aux termes d'une bataille juridique longue et compliquée, les inventeurs reçurent en 1950 une "compensation juste" de 400 000 $, ce qui laissa à chacun d'eux 24 000 $, une fois les frais d'avocats décomptés [4,6].

En 1935, le Groupe de Rome commence à se disperser. Rasetti va passer plusieurs mois à l'Université Columbia, Segrè accepte un poste à Palerme et Pontecorvo part pour Paris. La dispersion sera complète en 1939.

LAVAL, LES ROCHEUSES ET LES ALPES

Aussitôt arrivé à Laval, Rasetti se met à l'oeuvre. Il élabore le programme d'un cours de physique complet en quatre ans. L'Université lui engage trois assistants, dont deux, Christian Lapointe et Harold Feeney, feront un doctorat sous sa direction. Grâce à sa réputation de spectroscopiste il obtient de la Fondation Carnegie un magnifique réseau optique. Se souvient-il de ses années à Pise quand il va chercher dans les laboratoires du Séminaire de Québec le matériel didactique expérimental dont il a besoin?

Pourtant, comme le dit très justement Paul Koenig, "Le Département de physique de Laval n'est pas né d'un "programme de cours", mais d'un feu d'artifice de publications par son créateur Franco Rasetti, pour qui un universitaire n'est pas un professeur qui s'adonne à la recherche, mais un chercheur dont l'expérience et la culture sont déjà un enseignement pour quiconque a la vocation, le feu sacré" [3]. En effet, la performance de Rasetti en recherche est proprement stupéfiante, quand on considère qu'il était parti de zéro! Mettant à profit son aptitude à faire beaucoup avec peu, il monte de ses propres mains dispositifs expérimentaux et circuits électroniques. Non seulement parce que cet équipement ne se trouve pas sur le marché (Paul Koenig et lui ont fabriqué d'innombrables compteurs Geiger-Muller pour des universités et des laboratoires gouvernementaux), mais encore par esprit d'économie. "Don't throw away the gold!", criait-il joyeusement à Feeney. Le résultat de ce tourbillon d'activité: 7 publications dans *Physical Review* de 1940 à 1942. On y trouve un résultat de caractère historique : étudiant la désintégration du "mésotron", c'est-à-dire du muon, il en mesura pour la première fois le temps de vie au repos. Le coût total des 12 premières publications du Département de physique n'a vraisemblablement pas dépassé les 2 000 $!

Pendant son séjour à Laval, Rasetti donne enfin libre cours à sa passion pour la géologie. Juste en face de Québec, sur les hauteurs de Lévis, se trouve un remarquable gisement de trilobites du Cambrien, et les Rocheuses en abritent un gisement unique au monde, celui des Burgess Shales du Mont Stephen. Ce fut pour Rasetti l'occasion de renouer avec ses habitudes de jeunesse en conciliant camaraderie, randonnées, alpinisme et préoccupations scientifiques. Quand il partait en excursion, c'était souvent en compagnie de la "chain gang" chargée de casser des cailloux pour en extraire les précieux spécimens. Il la recrutait parmi ses étudiants. S'y joignait souvent René Bureau, du Département de géologie, qui, devenu un ami fidèle de Rasetti, accumula pendant un demi-siècle la précieuse documentation à l'origine du projet actuel de biographie. " Souvent", raconte Paul Koenig, "au cours de la semaine, il allait "aux bugs" (comme j'appelais ses trilobites). Mais jamais il ne s'absentait du département (nous non plus) sans qu'il y eut en marche une expérience devant conduire à une publication. "Les compteurs travaillent pour nous", disait-il." Autre souvenir mémorable : un jour, descendant du sommet glacé du Mont Victoria, Koenig et Rasetti vont se reposer dans un chalet de montagne. "Il s'y trouvait un groupe d'une demi-douzaine de haut-gradés de l'Armée canadienne, cousus de décorations, en haute tenue militaire, qui, amusés au récit de notre randonnée, nous offrirent avec grande amabilité le thé à l'anglaise. L'amusant était qu'en pleine guerre contre l'Italie et l'Allemagne, un Rasetti et un Koenig fussent accueillis par le "top brass" de l'Armée canadienne! Nous aurions eu moins de chance si nous étions tombés sur des policiers!" [3]

Franco Rasetti à la recherche de trilobites dans les Burgess Shales, juste au-dessus de Kicking Horse Pass, B.C. (juillet 1941).

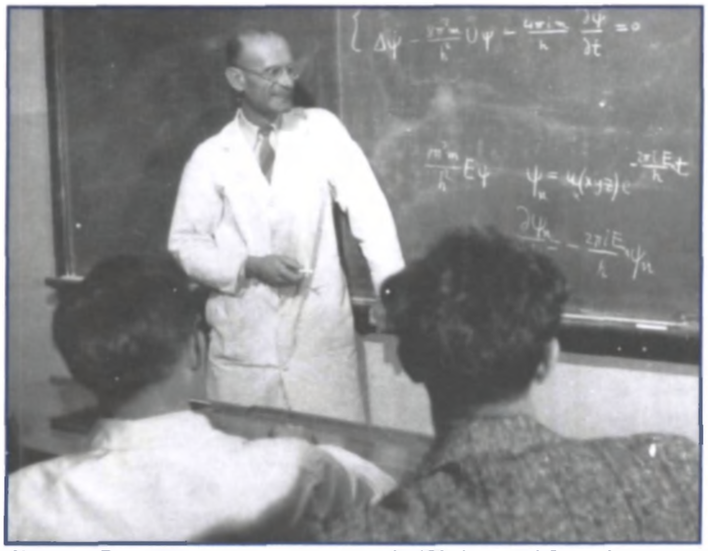
Rasetti identifia plusieurs nouveaux genres et espèces de trilobites, et il accomplit un travail de Titan pour clarifier la nomenclature et dissiper la confusion qui régnait dans le domaine. En fait, il devint en l'espace de quelques années un paléontologue de réputation internationale, et aujourd'hui, dans le domaine du Cambrien il n'y a probablement pas un géologue au monde qui ne connaisse Rasetti. Il suffit, pour avoir une idée de l'empreinte qu'il a laissée sur le domaine, de consulter sur Internet la table des matières de *Palaeontographica Canadiana*, No 6 (1989). En 1956, la National Academy of Sciences de Washington lui décerne la médaille Walcott en récompense de ses travaux sur le Cambrien.

Rasetti à Laval a laissé le souvenir d'un être exubérant de joie. Il aimait l'Université et, par-dessus tout, il appréciait de pouvoir faire de la physique et de la paléontologie en toute liberté, indépendamment de toute contrainte administrative et bureaucratique. Je me suis souvent demandé comment, avec son profil psychologique, il aurait fonctionné dans le contexte actuel. Pourtant, tout heureux qu'il y ait été, il quitta Laval en 1947 pour aller occuper un poste à la Johns Hopkins University. On explique d'ordinaire son départ par le désir d'être moins isolé scientifiquement qu'à Québec et d'avoir plus de fonds pour la recherche. Ces facteurs ont certainement joué, mais, Dieu merci, la réalité fut plus intéressante: vivait alors à Baltimore celle qui deviendra quelques années plus tard la compagne de sa vie!

En quittant Québec, Rasetti lègue au Département de géologie de Laval des centaines de trilobites, montés, décrits et identifiés. Quand il prend sa retraite de Johns Hopkins en 1966, il doit vendre sa magnifique collection personnelle pour vivre. Il l'offre à l'Université Laval, qui ne peut trouver l'argent pour l'acheter. Finalement, le British Museum en fait l'acquisition pour la somme dérisoire de 25 000 $.

Le Johns Hopkins Magazine salua le départ de Rasetti par un article de Nelson Thelma intitulé *A Man for all Sciences*. Et pourtant, sa contribution majeure à une autre science, la botanique, restait à venir. En effet, ce n'est qu'en 1980 qu'il publie son ouvrage encyclopédique *I fiori delle Alpi* à l'Accademia Nazionale dei Lincei. Giuseppe Montalenti écrivait dans la préface : "Franco Rasetti, depuis ses jeunes années, est un naturaliste passionné, et il l'est resté: on pourrait dire que les sciences naturelles sont sa vraie passion, alors que la physique, en un certain sens, est son hobby...". Cet ouvrage est maintenant considéré comme un classique. En 1996, à l'âge de 95 ans, il en publiait une deuxième édition, complètement revue et mise à jour! Dans la nouvelle préface, Giorgio Salvini saluait en lui le grand "humaniste", "un cas unique de savoir universel en ce siècle de spécialisation". L'année précédente, le président Oscar Luigi Scalfaro avait reconnu ses mérites scientifiques en le nommant Grand Chevalier de la Croix de la République.

Soucieux d'assurer la survie du département qu'il venait de fonder, Rasetti, avant de quitter Laval, se trouva un successeur en la personne d'Enrico Persico, l'ami d'enfance de Fermi, celui-là même qui l'accompagnait dans ses excursions au marché aux puces de Campo dei Fiori, quand il partait à la recherche de livres de physique et de mathématiques. Persico avait été, après Fermi, le deuxième professeur de physique théorique en Italie. Il ne resta que quelques années à Québec.



Franco Rasetti pendant un cours à l'Université Laval, en présence de deux étudiants, Claude Geoffrion et Albéric Boivin (octobre 1947).

Quand je demande à Paul Koenig quel fut l'apport de Rasetti au Département de physique de Laval, il s'exclame: "Nous lui devons tout! Nous sommes tous ses enfants!" Pourtant, quand on y regarde de plus près, il est difficile d'établir une filiation explicite entre le Maître et les avenues de recherche qui se sont développées à Laval. Rasetti dirigea peu de thèses de doctorat. À part celles de Lapointe et de Feeney, qui ne restèrent pas au Département, il dirigea celle de Koenig sur les rayons cosmiques et le début de celle de Larkin Kerwin, qui fut terminée sous la direction de Persico. Ce petit nombre s'explique sans doute par le fait qu'il n'y avait pas de candidats sur place aux études supérieures: c'est en 1944 seulement qu'on verra la première promotion en physique à Laval. Feeney venait de McGill, Koenig et Kerwin du MIT, et Rasetti n'avait pas de temps à perdre avec des étudiants formés en chimie! Par ailleurs, les trois principaux secteurs de recherche à Laval furent créés après le départ de Rasetti. Le développement de la physique atomique fut l'oeuvre de Larkin Kerwin, et Albéric Boivin assura celui de l'optique après que le physicien français Georges-Albert Boutry soit venu installer un laboratoire d'optique au cours d'un séjour d'une année; finalement, Claude Geoffrion développera la physique nucléaire.

L'influence de Rasetti à Laval fut beaucoup plus subtile que celle qui aurait découlé de la formation d'un (ou de plusieurs) groupe(s) de recherche, et Koenig a sans doute raison d'écrire : "En un sens, l'apport de Rasetti à Laval est celui de l'homme, et il dépasse de beaucoup les traces laissées sous forme de publications, d'équipement et d'enseignement." En effet, ce que Rasetti a laissé à Laval, c'est un exemple inoubliable que j'entendis constamment évoquer quand j'y fis mes études une dizaine d'années après son départ. Cet homme, qui avait rencontré plusieurs des plus grands physiciens du siècle, ouvrait à ses étudiants les portes de la physique vivante. Il leur donnait le spectacle d'un scientifique d'envergure internationale à l'oeuvre, et leur proposait des standards extrêmement élevés. Le même pouvoir de séduction que son intelligence aiguë et son immense culture avaient exercé sur le groupe de Rome les éblouissait. Son individualisme farouche et son indomptable vitalité leur offraient un antidote salutaire au conformisme plat de la vie québécoise des années 40. Et surtout, la plus précieuse des leçons pour les années à venir, il leur apprenait qu'avec de l'enthousiasme et du courage, on peut construire même quand on ne dispose que de modestes moyens.

Après le départ de Persico en 1950, les disciples de Rasetti se retrouvèrent sans Maître et allèrent demander secours à leur Doyen, Adrien Pouliot. Il leur répondit: "La boule est maintenant lancée. Vous n'avez plus qu'à continuer." Auraient-ils eu le courage de le faire sans l'exemple de Rasetti?

REMERCIEMENTS

Je n'aurais pu écrire cet article sans la collaboration généreuse et amicale de Paul Koenig. Je l'en remercie avec une profonde reconnaissance.

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DAVID KEITH C. MACDONALD, 1920 - 1963

Keith MacDonald came from Oxford to Canada in 1951, having been asked by the National Research Council (NRC) to establish a low temperature and solid state physics section at NRC's Ottawa laboratories. He did this with outstanding success, and in such a manner as to allow him to make an astonishingly wide and lasting impression on Canadian science and on the public's appreciation of science during the twelve years of life remaining to him.

Keith MacDonald

MacDonald was born in Scotland in 1920. During World War II he took a degree at Edinburgh University, worked on radar development as a member of the Royal Electrical and Mechanical Engineers, and joined the staff of the British Military College of Science. After the war he returned to Edinburgh University, receiving a Ph.D. in 1946 for his work on electrical noise. He then went to Oxford where his studies of the transport properties of metals gained him a D.Phil.

He arrived in Ottawa with experience as a researcher, a teacher, an organiser and a leader. Initially he was on his own, but with freedom to purchase equipment and to select or take on additional staff or Research Fellows of his own choosing. The result was a highly productive and cosmopolitan group that within a year began producing a steady flow of publications and presentations at conferences. MacDonald had taken an immediate liking to Canada, and would point out to fellow immigrants its numerous advantages, citing examples such as Canada's generous research budgets and its simple income tax forms that could be filled out in fifteen minutes - this was in 1952 - instead of their requiring, as had his UK ones, more than half a day.

An excellent teacher, he introduced Ottawa to the British tradition of Christmas science lectures for children, and used radio, film and television to present science topics to the general public. From 1955 to 1960 he was Honorary Chairman of the Physics Department of the University of Ottawa, and continued to give lectures there until near the end of his life. In 1958, a week's stay at the Montreal Neurological Institute undergoing medical tests put MacDonald in contact with various medical specialists. This resulted in his organizing a multi-disciplinary symposium on "self-regulation in living systems", the first of several similar symposia, each deliberately arranged to attract attendees from half a dozen differing scientific or engineering disciplines.

During the last six years of his life MacDonald suffered from a progressive atrophy of the muscles that, starting with the loss of control of a single finger, near the end left him able only to breathe and speak. He continued to work for virtually all of that time, his intellect being unimpaired. But his personality changed significantly; he became less dissatisfied with his own worth and more concerned for and considerate of other people.

In a short research career, MacDonald published about 130 papers and wrote five books. He became a fellow of the Royal Societies of Edinburgh, Canada and London. He was a complex and occasionally, until his last years, a difficult man, and an inspiration to all who knew him.

H. Preston-Thomas
Retired physicist, currently residing in Ottawa, Ontario

THE NATIONAL RESEARCH COUNCIL'S IMPACT ON CANADIAN PHYSICS

by Paul A. Redhead

In 1916 the Honorary Advisory Council on Scientific and Industrial Research was created by the Canadian government; this group was known by its short title of National Research Council. Of the eleven members of the first Council, eight were academics (one a physicist, J.C. McLennan), three were from industry, and one was a banker [1,2]. The difficulties in 1917 were summarized later by C.J. Mackenzie, "the NRC was instructed to coordinate and promote scientific and industrial research in Canada. The NRC soon found there was little or nothing to coordinate." [3] Only thirty-seven companies in Canada had research laboratories and most were staffed by one man. Fewer than a dozen Ph.D.s in pure science had ever been granted in Canada. It was estimated that there were only about 50 researchers in pure science in Canada.

> When first established in 1916, the NRC was instructed to coordinate and promote scientific and industrial research in Canada. The NRC soon found there was little or nothing to coordinate.

A program of grants to universities for the support of research was started in 1918, though it proved difficult to spend the $70,000 allocated; in 1918-1919 only $10,301.39 could be expended on five projects. One of these projects was in the area of applied physics, "an investigation on the action of ultra-violet rays in certain industrial applications" at L'École Polytechnique. By 1939 there were 26 research grants, about one-third being in physics.

Four NRC Studentships and three Fellowships were granted in 1918 at the universities of Toronto, McGill, Alberta, and Saskatchewan. NRC had recognized that the limited number of researchers in Canadian universities and industry was a major barrier to the development of an industrialized country and that an expansion of postgraduate training was required. The NRC scholarship programs were to prove an effective solution in the long run. The growth of the Awards program was slow because of the lack of adequate research facilities in Canadian universities and, as a result, many candidates asked to be allowed to apply to American universities. By 1926, however, 155 students had completed post graduate studies in science in Canada, with NRC support, and, of these, 123 were actively engaged in research in Canada. Several outstanding physicists were amongst this group, including Gordon Shrum and Don Rose. The Scholarship program grew from $5,500 in 1918 to $15,675 in 1937.

Prior to 1929 almost all Canadian physics was published in foreign journals. In 1929, NRC started the Canadian Journal of Research (CJR) which provided a place for the publication of the results of physics research in Canada; later the CJR was subdivided and the Canadian Journal of Physics (CJP) begun.

NRC began research in its own laboratories in 1925 in rented space in Ottawa; the new Sussex Drive laboratories of NRC were opened seven years later, in 1932. In 1928 the first full-time President was appointed: he was H.M Tory, a physicist from the University of Alberta. By 1929 there were 598 people working at NRC but only 105 of them were paid. In 1929 the NRC laboratories were reorganized into four Divisions, one of which was the Division of Physics and Engineering under its first Director, Robert W. Boyle, also from the University of Alberta. By 1931 the Division consisted of 8 professionals; as later events would prove they were a remarkable group - B.G. Ballard, G.S. Field, J.J. Green, G. Klein, G.C. Laurence, C.D. Niven, D.C. Rose, and

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K.F. Tupper. In 1936 the mechanical and aeronautical engineers were split off and the Division's title became the Division of Physics and Electrical Engineering; in 1947 the electrical and electronic engineers were separated so the title became the Division of Physics.

The activities of NRC during the thirties were severely restricted by the Depression. For example, the total budget of NRC dropped from $550,334 in 1930-1 to $379,499 in 1933-34. The Division of Physics expanded slowly until the outbreak of the war in 1939, by which time there was a staff of 26 physicists and electrical engineers and 37 technicians. The research prior to 1935 was almost entirely nonmilitary and of an applied nature related to industrial problems. The type of research is indicated by the names of the research sections -- Acoustics and Ultrasonics [George Field], Electrical Engineering [Guy Ballard], Electrical Measurements [A.J. Grant], Heat [Charles Niven], General Physics [Don Rose], Light [Leslie Howlett], Metrology [R.H. Field] which was transferred to NRC in 1931 from the Department of the Interior, Radio [John T. Henderson], Radiology [George Laurence]. Heat, Light, Sound, and Electricity were the backbone of physics text books in the 1930's, so the sectional arrangements were conventional. The General Physics section, which consisted of Don Rose only, was the place for those important problems that did not fit neatly into the usual pigeonholes. Much of the work of the Physics Division was designed to meet the requirements contained in the NRC act: "The investigation and determination of the standards and methods of measurements, including length, volume, weight, mass, capacity, time, heat, light, electricity, magnetism ... physical constants ...The standardization and certification of ... scientific and technical apparatus and instruments for government service." This role was very similar to that of the National Physical Laboratory of the UK. A detailed description of the work of the Division of Physics from 1929 to 1952 can be found in W.E.K. Middleton's history of the Division [4].

In 1935, Prime Minister R.B. Bennett was feuding with Tory, who had been appointed President of NRC by Mackenzie King; he replaced Tory with Major-General A.G.L. McNaughton, the Chief of the General Staff. McNaughton was sympathetic to the Conservative party but was a handicap to the Bennett government because of the turmoil he had caused by his management of relief camps during the Depression. " If you think, Andy," Bennett declared, "that I am going to face an election with you as Chief of the General Staff, you'd better think again. From now on I address you as President of the National Research Council" [5]

McNaughton did not drastically alter the course of research at NRC but he did increase the efforts devoted to urgent projects needed to improve Canada's military position. This slowly increasing military-related R/D from 1935 to 1939 led to the dramatic expansion of the applied scientific and engineering effort in World War II. During the four years of McNaughton's term as President, the budget of NRC was increased by 80%, although this was still miserly. In 1939 NRC had a paid staff of 300 and a budget of 1 M$.

In the autumn of 1937 McNaughton began to discuss with the Department of National Defence the possibilities of detecting aircraft by radio methods. In the spring of 1939 the British government decided to inform the Dominions, in strict secrecy, of the progress made in the UK in developing radar. J.T. Henderson, head of the Radio Section of the Division of Physics, was chosen as the scientific representative of Canada at the meetings in the UK to demonstrate radar in March 1939. Henderson had worked on the development of the cathode-ray direction finder since 1936, making him particularly suited to this liaison task. On his return to Canada in June 1939 he wrote a detailed report on the state of radar development in the UK. The Canadian Chiefs of Staff were impressed with the possibilities of radar but the requests for additional finances were ignored by the government. The Radio Section was to become the Radio Branch and during the war became larger than the rest of the Physics Division.

Five days after September 10th 1939, when Canada declared war on Germany, the NRC Council appointed C.J. Mackenzie as acting President of NRC, in the absence of McNaughton who assumed the position of Officer Commanding the First Canadian Division.

PHYSICISTS AT WAR: 1939-1945

The history of NRC's activities during the war have been described by Eggleston [6]. The wartime activities of the Division of Physics [4,7] and its Radio Branch [8,9] have been reported in some detail; space will only permit brief mention of the major projects in physics. It has been said that the first world war was a chemist's war and the second world war was a physicist's war; it is certainly true that in the second world war physicists in Canada were central to wartime R/D and that NRC took the lead.

Throughout the war Mackenzie (as acting President) was a punctilious letter-writer in keeping McNaughton informed of NRC activities; these letters give an insight into the wartime activities of NRC [10].

The Radio Section at the start of the war was grossly underfunded and understaffed to tackle the development of radar. In September 1939 the staff consisted of J.T. Henderson, D.W.R. McKinley, F.H. Sanders and H.R. Smyth, and eight technicians; by March 1940 the number had grown to twenty-two. Little financial help came from the government until the fall of France in 1940. In August and September the Tizard Commission [11] came to Canada and the United States, resulting in one of the most important scientific developments of the war. The Commission, named for its chairman Sir Henry Tizard, brought to the Canadian and the U.S. governments the most important British secrets of military science including the cavity magnetron and the proximity fuze amongst much else. One effect of the Tizard Commission was to persuade the governments of Canada and the U.S. to mount massive programs to develop radar, and particularly microwave radar. Colonel (later Brigadier) F.C. Wallace of the Tizard Commission remained behind in Canada and, in due course, was put in charge of the Radio Branch. Resources now became available to NRC, in the first instance from a group of patriotic business men who moved faster than a lethargic government, to expand radar development and other military R/D. The Radio Branch expanded rapidly reaching a total staff of about 300 by war's end. Radar equipment was developed for the three Canadian services and the British government; a plant to manufacture radar and optical equipment, called Research Enterprises Ltd., was set up in Toronto.

Another project related to radar was the development of the proximity fuze (an electronic fuze for shells operated by radio waves reflected from the target) which was brought to Canada by the Tizard Commission. The project was operated by the University of Toronto and was funded by NRC and the university. The project started in September 1939 and, in April 1943, the engineering staff was reassigned to work with groups in the U.K. and U.S. All proximity fuzes were manufactured in the U.S.

In March of 1940 George C. Laurence started construction of a nuclear pile in the Sussex Street laboratories of NRC, in great secrecy, using half a ton of uranium oxide and ten tons of calcined coke (used for making graphite) [12]. Although the pile was unsuccessful because the materials were not sufficiently pure, it allowed Laurence to become familiar with the nuclear programs in the U.S. and U.K. In September 1942 the Canadian and U.K. governments agreed to a joint nuclear laboratory in Montreal administered by the NRC. The first director was H.H. Halban who had been in charge of slow neutron research at Cambridge University; he arrived in late 1942 and the first group of British scientists arrived in January 1943. Staff was recruited from several Canadian universities to provide the core of the Canadian group at Montreal. The combined staff grew to 340 by the end of the year and was housed in the new buildings at the University of Montreal. In early 1944 an agreement with the U.S. government for a joint program of research between the University of Chicago and the Montreal project was signed. The moderator of the planned pile was to be heavy water which was being produced in a plant at Trail, B.C. A site for the project was rapidly constructed at Chalk River, Ontario, and John Cockroft was appointed Director in Charge. On September 5th, 1945 the first nuclear reactor in Canada (ZEEP) went operational at Chalk River. When the laboratories and town (Deep River) neared completion, the management was taken over completely by NRC. David Keys of McGill was appointed Vice President and W.B. Lewis was appointed Director of Research, replacing Cockcroft who returned to England to head the atomic energy project there.

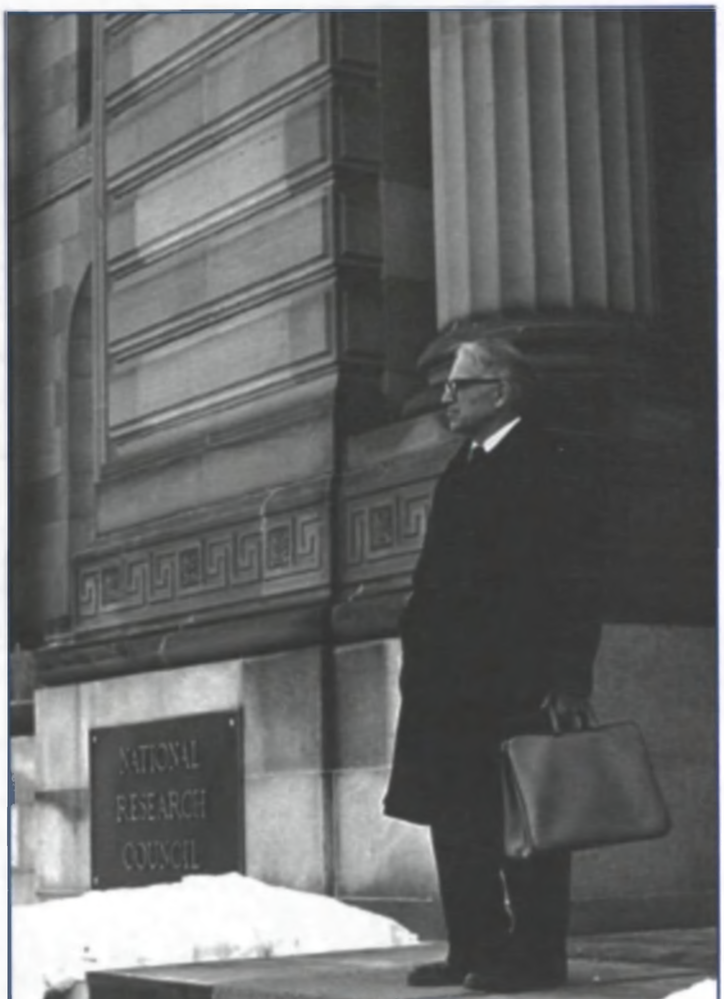
The Optics section designed and helped to staff the optical component factory at Research Enterprises Ltd. which was set up in 1940 to provide Canada with an optics industry to manufacture optical glass and instruments for military purposes. The section established a small optical workshop in the Ottawa laboratories to train optical mechanics and to construct experimental optical equipment. By 1944 the staff of the section had grown to 44.

The rest of the Division was involved in many other projects in applied physics for the war effort, these included work on ASDIC and problems of defense against acoustic torpedoes, the degaussing of ships, and studies of the properties of ice in connection with the Habbakuk [13] project, amongst a multitude of smaller projects for the Canadian services and the British government.

The work on radar, nuclear energy, optics, and other applied physics projects during the war had a profound impact on the establishment of the Canadian high-technology industry after the war, by training a cadre of experts and by involving several universities in research in applied physics. Perhaps the biggest impact was on national confidence by demonstrating that Canada, with an economy based mainly on natural resources before the war, was capable of developing a high technology industry and research infrastructure. The effect on NRC was to establish its role as the national laboratory for Canada, the provider of funds for research in universities and industry, and an advisor to government on science. It also generated a growing confidence within NRC of its own ability and international stature.

GROWTH AFTER THE WAR: 1945-1975

During this period the principal objectives of NRC were to promote research at Canadian universities, to build up research capabilities in Canadian industry, and to raise the calibre of research at its own laboratories to world class. The activities of NRC during the war provided a new credibility for NRC, and science in general, in the eyes of the government. This resulted in increased government funding and led to a period of scientific self-government with a minimum of governmental interference (later called by some the Golden Age). From 1962 onwards, NRC's power to control overall science policies decreased as a result of the Glassco Commission's inquiry into the organization of research and development activities in the federal government [14] and culminated in the Lamontagne reports at the end of the decade [15]. These reports were highly critical of NRC and resulted in much closer control by the government of science policies and funding. The politicization of basic science that occurred in the 1960's has been studied in detail by Louise Dandurand [16].



The picture of Herzberg standing on the NRC steps, gazing out confidently should be burnished in the memory of every Canadian physicist. It represents what was finest about our past century.

In 1966 the newly created Science Secretariat proposed "a comprehensive review of physics research in Canada and ... assessing future needs." [17] The Canadian Association of Physicists appointed a steering committee to undertake the study, which was chaired by D.C. Rose who had just retired from the Physics Division at NRC. This report had a considerable influence on the subsequent debates on the financial and procedural choices to be made in physics research.

Reorganizing After the War

At the end of the war many members of the Physics Division left for positions in universities and industry and most of the Americans, who had joined NRC before the U.S.A. was in the war, returned to the U.S.A. During 1946 the staff of the Radio Branch decreased to 210 and the rest of the Division of Physics to 97. In 1947 the Radio Branch was separated from the Physics Division to form a new Division of Radio and Electrical Engineering.

With the arrival of Gerhard Herzberg in the Physics Division in 1948, physics at the NRC was given new impetus, one that would have an impact well beyond the NRC laboratories. Herzberg became Director of the Division in 1949, on the retirement of Boyle, and he set out to create a world class laboratory that would attract the best scientists from Canada and abroad. By the 1950's the Physics Division consisted of groups in several fields whose research ranged from basic to very applied. In all cases, Herzberg's emphasis was on excellence in research, and on creating an environment that was conducive to creative research.

Grants, Graduate Scholarships, and University Interactions

In 1949 NRC started the Post-doctorate Fellowship Program which selected recent graduates to work for a few years (typically two) in the NRC laboratories. Over the years many bright young Post-doctoral fellows were attracted to the Physics Division, both from Canada and abroad. Not only did this keep new blood flowing through the NRC laboratories but it also created a pool of highly qualified young physicists, many of whom were hired by Canadian universities. Later the PDF program was extended to include fellowships held at Canadian and foreign universities. This program proved to be extremely successful, not only for physics but for Canadian science generally.

As well as PDFs, university professors were also encouraged to spend time in the NRC laboratories, either during the summer months or on sabbatical leave. While in Ottawa the scientists had use of the NRC facilities and often developed long term collaborative programs with NRC scientists. Many undergraduate physics students also spent their summers at the NRC .

During the 1950's there was important research being done in the physics departments of Canadian universities, and it was part of the NRC mandate to encourage and support this work. The Grants and Scholarships program was largely responsible for the rapid increase in physics research at Canadian universities during the 1950's and 60's. In the twenty year period from 1946 to 1966 the grants and scholarship budget grew from about 0.28 M$ to 34 M$. Proposals for research support were usually submitted by individual scientists, and grants were awarded on the basis of recommendations from peer review committees.

The staff of the Physics Division played a direct role in establishing programs, both in teaching and research, at Canadian universities. In 1954 D.K.C. MacDonald, while full time on the staff of the NRC, was Chairman of the fledgling Physics Department at the University of Ottawa and built up the department over the next five years. In a similar vein, E.P. Hincks, in 1965, took a partial leave of absence from the NRC to head the Physics Department at Carleton University, while at the same time remaining head of the NRC Particle Physics Group. Before returning full time to the NRC in 1975, Hincks set up a new program at the university to study the physics of particle detection. Within a few years particle detection systems, developed as a result of this work, were in operation at major laboratories in North America and Europe.

Other staff of the Physics Division were also involved in organizing and supporting research programs with the university community. For instance, a collaborative program involving a cosmic ray station on Sulphur Mountain in Alberta was established with the University of Calgary. In another case, funding was obtained for satellite (ISIS) instruments, developed at the University of Calgary and York University, which produced the first images of the aurora from space.

During the presidency of E.W.R. Steacie[18] the expenditures by NRC on grants and scholarships increased by a factor of 7.7 from 1954-5 to 1962-3. As an example of Steacie's commitment to developing university research capabilities, rather than that of the NRC laboratories, we note the budget increase in 1958-59 of 70 % for university support compared to an increase of 7.8% for the NRC laboratories. In the last decade of NRC's control of grants and scholarships to universities, the budget was doubled from 45.5 M$ in 1967-68 to 92.8 M$ in 1976-77. Steacie's support of university research did not cause him to neglect the support of industry, as has been alleged by some, for it was Steacie who established the Industrial Research Assistance Program (IRAP), which is arguably the most successful industrial research support program partly because of its administrative simplicity.

Major Physics Facilities

A significant NRC contribution to physics in Canada has been the promotion of government support for major facilities that can be used by scientists throughout Canada (and other countries). Once approved, the NRC has assumed, in some cases, the responsibility for the provision, operation, or funding of these facilities. In other cases the NRC enters into agreements with other agencies, universities and governments, and is responsible for partial funding and jointly controls the overall operations of the facilities.

Astrophysics at NRC began in 1946 in the Radio and Electrical Engineering Division (REED) when A.E. Covington converted war-time radar equipment to undertake microwave observations of the sun. In 1970 the astronomical activities of the Department of Energy, Mines and Resources (EMR) were transferred to NRC and the Astrophysics Branch, under the direction of J.L. Locke, was created within REED. The Branch was responsible for three major astronomical facilities; a) the Dominion Astrophysical Observatory near Victoria B.C., which had been founded in 1918 with a 1.85 m telescope; b) the Algonquin Radio Observatory in Algonquin Park, Ontario with a 46 m reflector capable of operating at wavelengths as short as 8 mm; and c) the Dominion Radio Astrophysical Observatory near Penticton B.C., with two large arrays at 10 and 20 MHz and a 25.6 m paraboloid. The Branch also included the Upper Atmosphere Research Section started in 1955 under Peter Millman, which was concerned with aurora and meteoritics.

In 1957 D.C. Rose took on the chairmanship of the Canadian Organizing Committee for the International Geophysical Year (IGY) at a time when there was considerable confusion as to how Canada should participate. Rose brought together scientists from government, universities, and industry to carry out a research program which focused on the Canadian north, including certain features of the Auroral Zone and the North Magnetic Pole. This program made a major contribution to the IGY, the only countries to make greater contributions were the United States and the USSR. Rose also initiated space research at the NRC and built up an active group in the Physics Division. From this base he organized a number of projects involving government and university laboratories and Canadian industry. Eventually, the NRC took over (from the U.S. Army) the operation of the Churchill Rocket Range and a broad program developed using rockets and balloons to investigate the upper atmosphere and the near-earth space environment. This program not only created new opportunities for scientists, both in university and government laboratories, but it also had industrial benefits in terms of support for the development of the successful family of Black Brant rockets by Bristol Aerospace of Winnipeg, and the spawning of several companies.

During the 1960's and 70's there was a growing interest in space research in many countries. In Canada, the rocket program, and particularly the Alouette-ISIS satellite program, had stimulated considerable interest. In response to this interest the NRC in 1965 established the Space Research Facilities Branch to operate the Churchill rocket range. In addition to the launch operation, the Branch provided engineering support to scientists, mostly from universities, who participated in the program.

NRC's Physics Offspring

Over the years the NRC has given birth (not always easily) to a number of new organizations which have continued, and expanded, programs started by NRC. In 1946 it was decided to separate military and civilian research by establishing the Defence Research Board to take over most of the defence research that was being done at the NRC. Much of this work was physics related and had been started at the NRC during the war.

In 1952, Atomic Energy of Canada Ltd. was formed to take over the operation of the NRC nuclear energy program. The president of NRC, C.J. Mackenzie, was appointed the first President of AECL and he was replaced at NRC by E.W.R. Steacie.

In 1974 the government decided that the responsibility for providing a program of Grants and Scholarships to universities should be separated from NRC; the program was continued by NRC until the new agency, the Natural Sciences and Engineering Research Council (NSERC), was established in 1978.

Physics in NRC's Laboratories

We now consider a few highlights of physics research in the NRC laboratories, during the period 1945-75, chosen to demonstrate the wide range of research in physics at NRC.

Acoustics

The areas of study included ultrasonic absorption and hypersonic light scattering in liquids, radiation pressure, elastic waves in solids, sound-generating mechanisms in machinery, hearing protector design, the acoustics of circumaural earphones, and the design of acoustical instruments. Work on the absolute measurements of sound pressure formed the basis for Canada's primary acoustical standard. Research on the physics of the outer ear and sound propagation in the atmosphere was started. NRC's first anechoic chamber was designed and constructed in the mid 1950's.

Basic Standards

The Division of Physics expanded its work on developing the basic standards of measurements until, by 1959, it had established these standards in all the usual areas with a quality comparable to those at other major national standards laboratories. In 1970 the Time Service of Canada was transferred from EMR to NRC's Division of Physics. By 1958 the world's first continuously operating cesium clock was in operation as the primary time standard for Canada. NRC was one of the five major laboratories measuring perturbations and absolute wavelength values of the spectroscopic radiations that led to the redefinition of the International Metre in 1960, in terms of a transition in Kr^{86}. NRC was the only laboratory equipped to make all the three isotopic sources (Kr^{86}, Hg^{198} and Cd^{114}) being considered, and provided such lamps to the other four laboratories. NRC designed and built the first interference comparator for the routine measurement of standard metre bars in terms of wavelengths; the only time the US national metre standard was allowed out of the country was to be measured in this instrument. The iodine stabilized laser, still widely used as the de facto primary standard of length and wavelengths, originated at NRC in 1969.

Lasers and Plasmas

In June 1962 S.A. Ramsden joined the Physics Division and set up what was later called the Laser and Plasma Physics Section to work on high intensity lasers and the application of lasers to the production and investigation of dense plasmas. Following the development of the transverse-discharge, atmospheric pressure (TEA) carbon dioxide laser at DREV in 1970, a large CO_2 laser system was assembled and laser plasma interaction experiments were carried out with 10.6 µm radiation at intensities in the 10^{14} - 10^{15} W/cm^2 range.

Particle Physics

The world's first Microtron, a type of electron accelerator, was built at NRC in 1947-48 based on the proposal made independently by V.J. Veksler and E.M. McMillan in 1945. The Microtron could produce 8 orbits with a final electron energy of about 5 MeV and a current of 1 µA; it was eventually transferred to the University of Western Ontario.

From the 1950's, NRC played a substantial role in helping to build up particle physics in Canada. A number of particle physics projects were launched, including major initiatives such as TRIUMF, the OPAL experiment at CERN, and the Sudbury Neutrino Observatory. The key figure in triggering these developments in the 1960's and 1970's was Ted Hincks. He set up and guided the high energy physics program at Carleton University, was an early supporter of TRIUMF, brokered and identified NRC funding for Canadian participation at FermiLab, and had an important role in founding the Institute for Particle Physics, the collegial body that oversees the field in Canada.

In the 1960's and 1970's the work of the NRC High-Energy Physics (HEP) group was in the field of muonic atoms. They were the first group to use solid state counters to study this and, as a result, had a number of firsts: observation of muonic atom hyperfine structure in heavy elements, observation of nuclear polarization by muonic atoms, and a precision measurement of the vacuum polarization potential.

Radio Astronomy

Long baseline interferometry was first demonstrated in 1967 when a radio interferometer was set up amongst the radio telescopes at Algonquin Park, Penticton, Prince Albert, and Jodrell Bank in England.

Solid State Physics

In 1952 D.K.C. MacDonald arrived in the Physics Division and set up the Low Temperature and Solid State Physics Section, which was to attract a number of outstanding scientists and was to have a profound influence on solid state physics in Canadian universities and eventually in Canadian industry.

The results of low-temperature studies of thermoelectric power and anomalous resistivities in metals and alloys, begun by MacDonald and his colleagues (prior to his untimely death in 1963), led to an interest in Fermi Surface (FS) studies by the de Haas-van Alphen (dHvA) effect in the early 1960's. Newly available superconducting solenoids, and the development at NRC of very high precision absolute and differential measuring techniques (an improvement of more than 3 orders of magnitude) allowed, over the next two decades, for sufficiently precise measurement of FS dimensions that the effects of alloying and of hydrostatic pressure could be studied in detail. Valuable insight was gained into the effect of transition metal (magnetic) impurities in the noble metals, and it even became possible to test some of the fundamental predictions of dHvA theory.

Similar advances were made in studies of deformation processes in metals, in particular on fatigue failure and the relationships between dislocations and work-hardening. Other areas of study included specific heats, thermal and electrical conductivity, superconductivity, optical properties of solids, magnetic susceptibility, and Hall effect.

Spectroscopy

The spectroscopy section of the Physics Division was initiated with the arrival of G. Herzberg in 1948. The first four permanent staff members to join the section were Alex Douglas, Donald Ramsay, Hin Lew, and Cec Costain. They were respectively responsible for the construction of spectrographs and spectrometers for the visible, ultraviolet and infrared; a flash photolysis apparatus for studying the spectra of free radicals; an atomic beam laboratory; and a microwave spectroscopy laboratory. By the early 1950's the laboratory was equipped for studying problems in atomic and molecular spectroscopy from the microwave to the ultraviolet.

The section always had a large component of Post Doctoral Fellows and visiting scientists from many different countries around the world. The laboratory soon achieved the reputation of being the Mecca for spectroscopists and was visited by the most senior workers in the field. Among the early successes of the group was the realization that molecules frequently change shape on excitation to higher electronic states, e.g. linear to bent, and the discovery of the spectra of some simple free radicals such as NH_2 and HCO.

In 1971 Gerhard Herzberg was awarded the Nobel Prize in Chemistry "for his contributions to the knowledge of electronic structure and geometry of molecules, particularly free radicals."[19] The citation also noted that "Dr. Gerhard Herzberg is generally considered to be the world's foremost molecular spectroscopist and his large institute in Ottawa is the undisputed center for such research. It is quite exceptional, in the field of science, that a single individual, however distinguished, in this way can be the leader of a whole area of research of general importance. A noted English chemist has also said that the only institutions that have previously played such a role were the Cavendish Laboratory in Cambridge and Bohr's institute in Copenhagen."

Several universities in Canada and other countries have spectroscopy groups staffed by persons who served their apprenticeship in Ottawa. Of the members of the group, five have been awarded Nobel prizes and eight have been made Fellows of the Royal Society of London.

Surface Physics

Modern surface physics started in the 1950's with the development of ultrahigh vacuum techniques which allowed the preparation and maintenance of atomically clean surfaces for times long enough to conduct meaningful experiments. Much of this work on ultrahigh vacuum was pioneered at NRC. Surface physics studies were started in the late 1950's, including work on thermal desorption spectroscopy, electron stimulated desorption, physical adsorption, and ionic entrapment in solids.

THE LAST QUARTER CENTURY: 1975-1999

The shift of NRC's financial support from its laboratories to university and industrial research accelerated in the 1960's ; in 1958 the NRC laboratory operations took 65% of the budget, and extramural support (industry and universities) took 20%; by 1967 the corresponding figures were 35% and 55%. By the 1970's scientific research in Canadian universities had reached world standards with the help of NRC's, programs of Grants and Scholarships so that NRCs initial objective had been reached. When NSERC assumed the major role of supporting university research in 1978, NRC's prime role became the support of R/D to advance Canada's industry. As a result, the proportion of basic research in NRC laboratories decreased from 25% in 1977-8 to 15% in 1980-1.

During the last quarter of the century NRC has made many improvements in support programs for industrial R/D and arranged reorganizations of the NRC laboratories intended to facilitate the transfer of technology to industry. In 1975 the PILP program (Program for Industry-Laboratory Projects) was started to fund the exploitation by industry of marketable products conceived and developed in NRC laboratories.

In 1987 the Canadian Space Agency was set up to bring together a number of programs that existed in NRC and other government departments. Three programs initiated by the NRC now form an important part of the activities of the Space Agency; these are the Space Science Program, the Astronaut Program, and the Space Station Program. L. Kerwin, then President of NRC, became the first President of the new Space Agency.

Major Physics Facilities

In the period 1975-99 the NRC maintained its responsibilities to promote and support major physics facilities for use mainly by university researchers, in several cases with other agencies or governments providing partial funding.

When the original proposal for the construction of a synchrotron light source in Canada was turned down, the NRC provided the finances for the construction of a Canadian beam-line on the synchrotron light source at the University of Wisconsin (1979) to be operated by the University of Western Ontario; in 1988 a second beam-line was added. A second proposal for a Canadian synchrotron light source at the University of Saskatchewan was approved for funding by the federal and provincial governments and other agencies in March 1999.

The TRIUMF accelerator at the University of British Columbia was originally funded by the federal government through the Atomic Energy Control Board. In 1976 the responsibility for the supervision of the federal government's interests in TRIUMF was transferred to NRC. By 1977 the proton beam at TRIUMF was greater that 100 μA at 500 MeV. The controversial proposal for the Kaon Factory addition to TRIUMF was discussed for several years and finally failed to get federal government financing in 1994.

In 1976 the NRC obtained new funding for support of a space science program and the Canada Centre for Space Science was established under the directorship of Ian B. McDiarmid. The Centre's mandate was to develop a broadly based program involving university and government scientists and Canadian industry. Since Canada had no launch capability, collaborative research programs were negotiated with space agencies of other countries. Space instruments were developed in scientist's laboratories and final test flight units were built and tested in industry. Instruments were flown on many foreign satellites and Canadian scientists became internationally recognized, particularly in the fields of imaging from space and analysis of charge particle populations in space.

NRC represented Canada in negotiations with France and the government of Hawaii to construct the Canada-France-Hawaii Telescope at the top of Mauna Kea on the island of Hawaii. The 3.6 m diameter mirror was ground and polished at the optical workshop of the Dominion Astrophysical Observatory near Victoria. The telescope was in operation by 1979. In 1987 an agreement was reached by NRC for Canada to take a 25% share in the construction on Mauna Kea of the James Clerk Maxwell radio telescope, jointly with the British and Netherlands governments. This 15 m radio telescope, is capable of observations in the 4 to 0.3 mm wavelength range. NRC is representing Canada with a 15% stake in the Gemini Project, in collaboration with NSERC and WESTAR, which is constructing twin 8 m telescopes, usable in the optical and infrared, on Mauna Kea, Hawaii and on Cerro Pachon, Chile. The NRC laboratories are undertaking a substantial part of the Gemini Project, in instrumentation and software development. First light on the telescope on Mauna Kea was achieved in 1998.

NRC and the University of Calgary are planning a Square Kilometre Array (SKA) radio telescope. About 30-40 parabolas would reflect the incoming radio waves from space onto a 5 m receiving antenna suspended from a balloon. It is hoped to build a $5 million prototype early in the new century.

In 1978 NRC was assigned responsibility for co-ordinating fusion energy research; this led to the funding of the Tokomak de Varennes, jointly with Hydro-Québec, in 1981.

The initial planning for the National Optics Institute was undertaken by the staff of the Physics Division, and the Institute was established in Ste. Foy in 1986.

NRC exercised a strong catalysing role in starting the Sudbury Neutrino Observatory, particularly in bringing together the large collaboration required, preparing the original proposal, and ensuring support by the federal government. NRC laboratories were involved in measuring the attenuation of light in heavy water, in measuring the optical properties of acrylic, developing inductively-coupled plasma mass-spectrometry techniques to measure femtogram amounts of thorium and uranium in heavy water, and development of a TPC detector for low-level radon counting. NRC has made budget outlays totaling about $20 million to the SNO project, starting with funds for the exploratory drift in the Creighton mine in 1986. Neutrinos were first observed in May 1999.

In 1999 the NRC and AECL made a joint proposal to government for the construction of a Canadian Neutron Facility intended to provide an advanced materials research capability for use by Canadian universities and industry and to be used as a test facility for improved reactor design. If funded, the facility is expected to come on line in 2005.

Physics in NRC's Laboratories

In spite of severe budget cuts, reductions in staff, and several reorganizations, the quality of physics research at the NRC laboratories has remained high. Between 1984 and 1991 the NRC budget decreased by 100 M$ (in 1984 dollars) and the total staff decreased by 18%. A drastic reorganization of NRC occurred in 1990 which was intended to improve the laboratories' ability to assist Canadian industry and to concentrate basic research activities; more than 200 employees took voluntary layoff.

A major reorganization of the divisional structure of the laboratories occurred in 1990 when it was decided that the traditional title of 'Division' for a major laboratory grouping at NRC was no longer appropriate and the title 'Institute' substituted. Disciplinary titles such as Physics or Chemistry were also eliminated as being too academic. The Division of Physics was subdivided into the Institute of Microstructural Sciences (solid state physics and technology) and the Institute of National Measurement Standards (basic measurement standards), the basic physics activities were transferred to the Herzberg Institute of Astrophysics and the new Steacie Institute of Molecular Sciences. About 300 staff members (person years) were eliminated from NRC and the funds thus released were applied to the operating and capital budget. In 1995 it was announced that the NRC budget would be further reduced by 76.2 M$ over 3 years.

In 1995 the activities of the Herzberg Institute of Astrophysics based in Ottawa, other than spectroscopy, were moved to the site of the Dominion Astrophysical Observatory near Victoria. A few highlights of physics research in the NRC laboratories in the period 1975 to 1999 are noted below.

Acoustics

Today, as a result of close collaboration with the Acoustics Section, the high-fidelity loudspeaker industry has grown and Canadian-made loudspeakers are recognized as being amongst the best in the world, with Canadian manufacturers occupying an important share of the North American market. In 1989, NRC established the Canadian Audio Research Consortium (CARC), with members from the industry, to explore the audio technology required to continue building competitive loudspeakers well into the next decade.

Astrophysics

Research in optical astronomy, radio astronomy, space physics, upper atmosphere research, and laboratory astrophysics was transferred in 1974 to the newly created Herzberg Institute of Astrophysics (HIA), named in honour of Gerhard Herzberg. The HIA was also made responsible for the Algonquin Radio Observatory (NRC support for ARO ended in 1987), the Dominion Radio Astrophysical Observatory in Penticton, and the Dominion Astrophysical Observatory in Victoria. Observing time with the DAO and DRAO telescopes, the James Clerk Maxwell Telescope and, soon, the Gemini telescopes are available to all astronomers; time is allocated by Time Allocation Committees. In some cases it is not necessary for the visiting astronomer to be present; observations can be taken by staff astronomers. In 1986 the Canadian Astronomy Data Centre was established at DAO to create special software for astronomical data archives.

The principal instrument of the DRAO is now the Synthesis Radio Telescope which consists of seven 9 m paraboloids on an east-west axis, 600 m long. It is currently used to survey the Galactic Plane at frequencies of 408 and 1420 MHz.

Optics

A research program on optical interference coatings resulted in the development of advanced techniques for the computation and production of optical filters and reflectors that have been of great value to Canadian companies and universities. A familiar example is the iridescent anti-counterfeiting device used on Canadian currency which was developed in the Physics Division; a modified form of this system is used for special inks on the currencies of fifty countries.

In the process of redefining the International Metre, by reference to a Cs clock and a conventional value for the velocity of light (c), a unique frequency comparison chain was built at NRC, in 1979, to lock optical radiation (Kr^{86}) to a microwave frequency standard. In 1983, this was used to provide one of three independent determinations of c, in terms of the old standard, that was required to define the present International Metre. In the same year inter-comparisons of time standards were made via satellite links amongst the NRC, the National Bureau of Standards in Boulder, Colorado, the US Naval Observatory in Washington, and the Bureau des Poids et Mesures in Paris. The first direct measurement of the frequency of visible radiation was made at NRC. Recently the frequency of visible radiation (at 674 nm), locked to a transition in a single trapped cesium ion, was measured to form the basis of a new time standard.

A program of research in photogrammetry, which arose naturally from the early work on aerial photography, placed Canada in the forefront of aerial mapping techniques and, in particular, produced the first digital analytic plotter, a development that revolutionized the process of map-making throughout the world.

An example of research in modern optical physics at NRC is that of the Femtosecond Research group which is concerned with electronic relaxation and energy flow in molecules using time resolved photoelectron and photoionization spectroscopy, and also with control of dynamic processes and material properties with optical phase. A highlight of this work is the development of a method of isotope separation using the quantum mechanical rephasing of nuclear wavepackets in diatomic molecules by femtosecond laser pulses.

During the 1980's, a collaboration between NRC and Lumonics Inc. resulted in the development of several large aperture, multi-atmosphere CO_2 laser amplifiers. This culminated in the development of a 1 terawatt laser system, which generated nanosecond duration infrared pulses with an energy of 1 kJ, and the focused output created intensities as high as 3.1015 W/cm^2. Another collaboration involved the Laser and Plasma Physics Section and the Lawrence Livermore National Laboratory (LLNL). A direct result was the construction of a 300 J Nd:glass laser system, based on components provided by LLNL from the de-commissioned SHIVA laser. Using the glass laser it was possible to create plasma conditions that provided significant gain from transitions in Ne-like Ge, and experiments in collaboration with researchers from the Université du Québec and the University of Toronto resulted in the demonstration of Canada's first XUV laser at 23 nm.

Particle Physics.

The High Energy Physics section of the Physics Division was moved to Carleton University in 1978 so as to be in closer contact with the university group working in the same field. In 1990 the staff and equipment of the HEP section were transferred from NRC to Carleton University.

In collaboration with researchers from TRIUMF and the universities of Carleton, Montreal, and Victoria, the first operating Time Projection Chamber (TPC) was developed to search for a rare muon decay mode. The OPAL detector project at CERN, started in the early 1980's and installed on the LEP collider, is now in its final phase of operation; there are about 250 collaborators from several countries. The OPAL detector measures results of e + e- collisions from the mass of the Z_0 particle (91 GeV) to 200 GeV in the centre of mass. The Canadian component of this collaboration was started by NRC and expanded to include TRIUMF and the universities of Alberta, Carleton, Montreal and Victoria. About 50 Canadian physicists are involved in OPAL. It is estimated that the total Canadian contribution during the construction phase was $15 million, divided between NRC and NSERC. Over 40 papers per year have been published by the collaboration including;
1) measurements to show that the number of neutrino species is restricted to three, 2) precision measurements of the Z_0 mass and width, allowing the mass of the top quark and the Higgs boson to be inferred, and 3) the Weinberg angle.

Solid State Physics

By 1975 there were noticeable changes in solid-state physics research from studies in crystalline solids to the study of thin films and quantum (layer) structures, many of these in semiconductors rather than metals. By the 1980's the trend was towards the support of the semiconductor industry. Basic research became concerned with the fundamental electronic and optical properties of systems of reduced dimensionality, and with the study of new phenomena, such as the quantum Hall effect, and photoluminescence in quantum wells and superlattices.

The Institute for Microstructural Sciences (IMS) established the first Molecular-Beam-Epitaxy facilities in Canada and was early on the scene in the fields of mesoscopics and nanoelectronics, setting up a project in the late 1980's. The program includes research into lithographic and growth techniques for making nanodevices, and experimental and theoretical studies of their novel properties such as the 'Coulomb blockade' single electron charging effect, which will probably form the basis of future electronics. The program has included the first spectroscopic investigations of few-electron lateral quantum dots (artificial atoms). The program has resulted in many international collaborations, including formal programs with European nanoelectronic centers (ECAMI and CERION) and with Taiwan.

Research on the optical properties of semiconductors was built up; in 1989 NRC established the Solid State Optoelectronics Consortium (SSOC) bringing together members from industry, universities and government to explore the emerging subject of optoelectronics. The SSOC collaboration has developed several new technologies, including 1.5 mm QW lasers, circular grating lasers, distributed feedback lasers, and an optical time domain reflectometer. Research on the physics of optical processes in quantum wells has laid the groundwork for rapid advances in an area of enormous current interest to the telecommunications industry. Recently it has led to basic research concerned with the fabrication and understanding of quantum dots. The first quantum dot laser with emission in the red was demonstrated at IMS in 1996 using self-assembled growth to control the semiconductor epitaxy on the atomic scale in all three dimensions. Such high-quality nanostructures are now obtained in a wide-range of wavelengths with good uniformity and reproducibility, and are engineered to produce devices with enhanced and/or unique properties.

Spectroscopy

In the last 25 years the introduction of laser spectroscopy, the extensive use of double- and multi-resonance methods, and the replacement of grating spectrographs with Fourier-transform interferometers has caused a considerable change in experimental methods. With these new tools, extensive work has been done on molecular ions (Oka and Amano), van der Waals and other non-rigid molecules (McKellar), and more recently on metal-containing molecules (Simard). In 1980 Oka discovered the infrared absorption spectrum of H_3^+ in the laboratory; this has since been identified in emission from the hydrogen-rich planets such as Jupiter and Saturn and in absorption in interstellar space. The search for H_3^+ had a serendipitous spin-off in the discovery of the emission spectrum of neutral H_3 by Herzberg in 1979; this molecule had stable Rydberg states but no ground state.The study of this and similar emission spectra of neutralized closed-shell molecules was a laboratory theme for many years; this included the rare gas hydrides, which started with the spectrum of ArH discovered by Johns in 1970, and the analysis of the spectrum of NH_4 by Watson in 1984.

Surface Physics

By the 1970's surface physics and surface chemistry had become almost indistinguishable and were renamed surface science. In 1984 the various groups involved in surface science and solid state physics in the Divisions of Physics, Chemistry, and Electrical Engineering were combined in what later became known as the Institute for Microstructural Sciences; the basic research in surface science continued but emphasis was placed on interactions with Canadian industry. Facilities were built up for molecular beam epitaxy, together with x-ray, electron, and ion lithography and instruments for several surface spectroscopies.

SUMMARY

For the last 84 years the National Research Council has supported the physics community in Canada and, since 1925, has maintained research in physics and astrophysics in its own laboratories. When NRC was founded in 1916 there was little physics research in Canada. From 1916 to 1939 the priorities were, 1) expanding physics research in Canadian universities through programs of grants and scholarships, and 2) establishing the NRC laboratories to conduct R/D related to industrial and governmental needs, the latter being severely restricted by lack of government support. During the war NRC took a leading position in the development of radar, nuclear energy, and other physics-related wartime R/D. The credibility gained by NRC's wartime activities resulted in increased government support after the war. The support of university research in physics was greatly expanded while physics at the NRC laboratories expanded slowly and more basic research was undertaken. NRC became the national standards laboratory for Canada by developing and maintaining the basic standards of physical measurements. In 1970 NRC took over all astrophysical research in government.

In the 1960's NRC came under attack, as did national laboratories in many other countries. The result was the transfer of the university granting function from NRC to NSERC, in 1978, and the shift of NRC's first priority to the support of industrial-related research. NRC maintained its responsibility for the support of major facilities in physics and astrophysics for use by universities and industry. Budget and staff cuts in the 1980's and early 1990's led to reorganizations of NRC's laboratories and caused significant loss of morale. As the century ends, physics and astrophysics in the NRC laboratories have recovered from the worst effects of the cuts, and both basic research and R/D in support of industry are of high quality.

VALEDICTION

As the century drew to a close, Gerhard Herzberg, who had done so much to foster physics at NRC and in all of Canada, died on March 3rd, 1999 at the age of 94 [20].

ACKNOWLEDGMENTS

Many persons provided helpful comments and contributions including K.M. Baird, P.T. Coleridge, G.A. Daigle, W.F. Davidson, S. Fafard, C.K. Hargrove, J.P. Hobson, J.L. Locke, I.B. McDiarmid, H. Preston-Thomas, D.A. Ramsay, A. Sachrajda, I.M. Templeton, and J.K.G. Watson, to all of whom I am greatly indebted.

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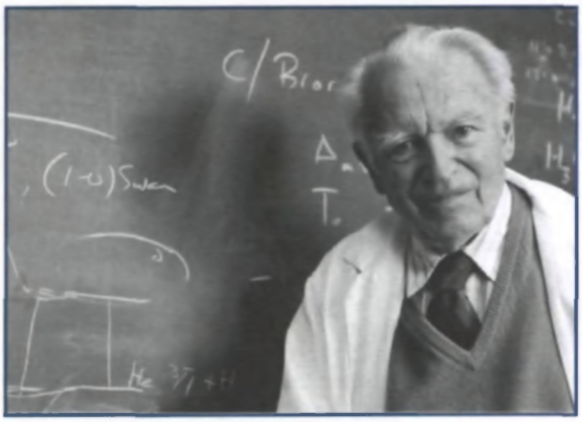
GERHARD HERZBERG, 1904 - 1999



Gerhard Herzberg

Like no other person, Gerhard Herzberg dominated much of the past century of Canadian physics. He was born in Hamburg, Germany, on Christmas day, 1904 and died at his home in Ottawa just before the close of the century, on March 3, 1999 at the age of 94. He arrived in Saskatchewan in 1935, spent a decade there, and then, after a brief sojourn at the University of Chicago, was brought to the National Research Council (NRC) by C.J. Mackenzie, in 1948. He spent the next half century at the NRC (see the article by P.A. Redhead in this issue for more details on Herzberg's years at the National Research Council).

The esteem that the spectroscopic and scientific communities held Herzberg in was evident in the conferences held every five years in his honour. The first of these took place in 1969 to celebrate his 65th birthday. At this meeting, when most would be thinking of retirement, he was appointed Distinguished Research Scientist.

In 1970, the Canadian Association of Physicists, as part of its 25th anniversary celebrations, instituted a new annual award in honour of one of Canada's most distinguished physicists. The new award, to be known as the Herzberg Medal, has a likeness of Dr. Herzberg on one side and an accurate representation of the potential curve of the ground state of the hydrogen molecule on the other side. When first introduced, the medal was awarded "for outstanding achievement in any field of research by a physicist who, in the year of the award, is not more than 38 years of age". This was subsequently changed to 40 years of age.

In 1971, Herzberg was awarded the Nobel Prize in Chemistry, for his contributions to the knowledge of electronic structure and geometry of molecules, particularly free radicals.

In 1974 the formation of the Herzberg Institute of Astrophysics was announced in his honour. It provided a place where he would be able to continue his research for as long as he wished. The most recent Herzberg conference was held in 1994 and he officially retired in early 1995, but he still came into the Sussex Drive building of NRC on a regular basis until failing health finally prevented him from doing so.

Most recently, in tribute to the life-long pursuit of excellence in research that Gerhard Herzberg exemplified and inspired, NSERC dedicated its highest award in his honour. Starting in 2000, the Canada Gold Medal for Science and Engineering will be entitled the Gerhard Herzberg Gold Medal for Science and Engineering. In addition to the medal, recipients will receive $1,000,000 in research funding.

For Canadian physicists, the picture of Herzberg standing on the NRC steps, gazing out confidently (see article by P.A. Redhead), should be burnished in the memory of every Canadian physicist. It represents what was finest about our past century. Infecting many colleagues with his enthusiasm he led the NRC laboratories to greatness. As was noted in the address for his Nobel Award, "Dr. Gerhard Herzberg is generally considered to be the world's foremost molecular spectroscopist and his large institute in Ottawa is the undisputed centre for such research". His vision, his voice, his influence, and his advocacy had a great impact on fundamental research at Canadian universities for many decades.

Gerhard Herzberg was a member of the CAP from 1950 until his death in 1999, the CAP President in 1956-57 and the recipient of the CAP Medal of Achievement in 1957. Dr. Herzberg's constant support of and affection for the CAP has now culminated in the CAP receiving a sizeable and much appreciated bequest from his estate. This bequest will allow the CAP to undertake a new initiative, probably in the area of education. Detailed plans will be announced in the near future..

Details of G. Herzberg's life and of his impact on Canada can be found in a recent and very fine obituary in *Physics in Canada* (vol. 55, page 127, July/August, 1999), by John W. Johns, Boris P. Stoicheff and James K. Watson. This vignette was abstracted, in part, from the obituary.

by Erich Vogt, Professor Emeritus
University of British Columbia
and Francine Ford, Executive Director
Canadian Association of Physicists

ATOMIC ENERGY IN CANADA: PERSONAL RECOLLECTIONS OF THE WARTIME YEARS

by Philip R. Wallace

In December 1942 I was teaching in the mathematics department of the Massachusetts Institute of Technology (M.I.T.) when a letter came from J.L. Synge, my former department head at the University of Toronto, informing me that there was an important wartime project in Montreal for which I was needed. He could give me no clue as to the nature of the project, but it had been understood that when such an occasion arose I would be ready to accept.

When I informed my department chairman, he granted me formal leave, on the understanding that I could return to the M.I.T. when the war ended. But I never did. My career was to take a very different, unanticipated direction.

I was briefed by Georges Placzek, who was to be the leader of the theoretical division of the Canadian project. He introduced me to nuclear fission and spoke of the possibility of building nuclear reactors which would produce both energy and new transuranic elements.

When my wife and I arrived in Montreal, a city which I had only briefly visited, it was brutally cold; the thermometer hovered around -20°C for a week or so. We spent a few days in a luxurious bed and breakfast in an old mansion on Sherbrooke Street, then moved to a suite a few minutes' walk from the old house on Simpson Street which was the first home of the project.

The project leaders, recruited from Great Britain, France and the European refugee community, were already at work. I was briefed by Georges Placzek, who was to be the leader of the theoretical division. He introduced me to nuclear fission and spoke of the possibility of building nuclear reactors which would produce both energy and new transuranic elements. These elements would be the raw material for weapons thousands of times more powerful than anything previously known. The role of the Canadian project was to explore the feasibility of a graphite-moderated nuclear reactor, which would be the first step into the new territory.

I knew almost nothing about nuclear physics. However, as a graduate student I had given a seminar on a paper by Peierls and Kapur on nuclear reactions. Now I learned that Peierls was the leader of a British team which was to work closely with us and with a newly formed American project, and that he had been the major figure in establishing the feasibility of the whole enterprise. Our rapid education in nuclear physics was facilitated by a very fine article by Hans Bethe in *Reviews of Modern Physics*, which served as a sort of bible on the subject.

I was very impressed by Georges Placzek, a refugee Czech theoretical physicist of international stature who had worked with Bohr, Heisenberg and Peierls, among others. Placzek was to prove himself an inspiring leader. His task was formidable, for the theoretical team being assembled consisted mostly of young physicists and mathematicians with little experience or knowledge of nuclear physics. This was particularly true of the Canadian contingent. In those days, the world of theoretical physics had its base in continental Europe. The leading lights were Einstein, Bohr, Born, Fermi, Szilard, Weisskopf, Bethe, Peierls, Schrodinger, and Wigner. The United States owed its power to European refugees, of which Canada had few. The icon of Canadian physics was Rutherford,

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who made no secret of his scorn for theorists (aside from Niels Bohr, its most incomprehensible exponent).

Theoretical physics was almost nonexistent in Canada. There had been a few isolated individuals: King and Watson at McGill, Barnes at Toronto, Archibald at Dalhousie. But only Infeld at Toronto, another emigré from Europe, had generated a "school" around himself, of which I was luckily the first member. It was primarily here that theoretical physics put down roots in Canadian soil.

Although the project was under Canadian jurisdiction, its members constituted a veritable League of Nations. A few Canadians worked with a much larger group of Britons, Americans and European refugees, including Free French and Jewish and anti-Nazi scientists from Germany.

en souvenir
du premier centre canadien
de recherches nucléaires
son altesse royale le duc d'edimbourg
a dévoilé cette plaque
le 17 mai 1962

du 1er mars 1943 au 30 juin 1946 une partie de cet immeuble de l'Université de montréal a abrité des laboratoires où plus de 580 personnes venues du canada, du royaume-uni, de france et d'ailleurs ont poursuivi des travaux de recherches et de mise au point sur l'énergie nucléaire obtenue par fission.

l'administration de ce laboratoire relevait du président du conseil national des recherches, c.j. mackenzie. parmi les canadiens qui ont participé aux travaux figurent:

e.w.r. steacie, directeur adjoint du laboratoire

g.c. butler	d.g. hurst	f.t. rosser
a. cambron	g.c. laurence	b.w. sargent
a. cipriani	j.c. mark	j.w.t. spinks
h.h. clayton	s.c. mason	h.g. thode
l.g. cook	n. miller	g.m. volkoff
p. demers	j.h.p. matheson	p.r. wallace
l.g. elliott	j.e.w. prévost	a.c. ward
	l. yaffe	

parmi les savants et ingénieurs d'autres pays se trouvent:

h.h. halban, premier directeur de ce laboratoire

j.d. cockroft, son successeur

w.j. arrot	b.l. goldschmidt	g. placzek
p. auger	j. guéron	b. pontecorvo
s.g. bauer	l. kowarski	m.h.l. pryce
h. carmichael	j.s. mitchell	w. seligman
j.v. dunworth	r.e. newell	h. tongue
d.w. ginns	h.r. paneth	c.n. watson-munro

Fig. 1 Plaque presented to the Université de Montréal by the Duke of Edinburg on May 17, 1962 in honour of its contribution of laboratory space to the nuclear research effort during the War.

My first colleague at Simpson Street was George Volkoff, whose credentials were more impressive than mine. Although he came from the University of British Columbia, George had studied under Oppenheimer, perhaps the most distinguished of the first generation of American protégés of the European theoretical establishment. George's doctoral work was on the theory of neutron stars, decades before they became a major issue in astrophysics.

We were joined by Jeanne LeCaine-Agnew, an excellent mathematician educated at Vassar, and Carson Mark, an amiable mathematician from the University of Manitoba. Neither knew much about physics, much less the new frontier of nuclear physics. From the United States came German refugee Ernst Courant, son of the famous mathematician of that name, and Bob Marshak, a brilliant nuclear physicist who had studied under Weisskopf and whose later career was very distinguished. In the later days of the project we were joined by Boris Davisson, a gentle and modest man of immense talent who had been educated in the Soviet Union, and Maurice Pryce, a theorist of outstanding intellect and experience who had collaborated with Dirac. Another world-renowned theorist in our midst was Nick Kemmer from the U.K. He accepted duties as a liaison officer and so did not directly contribute to the scientific work of the group, but was a kindred spirit to us all.

Such were the human resources available to Placzek. It is a great testimonial to him that he led this motley group to impressive achievements. Placzek's leadership drew the best from every one of us. He created an atmosphere of mutual respect and esteem in which we all thrived.

The director of the laboratory was Hans Halban, who led a distinguished group of Free French scientists including the renowned Pierre Auger. One of the early recruits to the laboratory was Bruno Pontecorvo, an outstanding young physicist from Fermi's group in Rome. Pontecorvo had been working with Joliot-Curie in Paris when the German occupation began; he had escaped over the Pyrenees to Spain and thence to the United States, where he had obtained a job with an oil company in Oklahoma involving radioactive detection techniques. When Fermi fled to the United States, he urged Pontecorvo to join the project in Canada. This was a happy decision, since Fermi's Chicago Laboratory had closer links to the Canadian project than to the American projects in Hanford, Los Alamos and Oak Ridge.

The diverse origins of the members of the Montreal project was one of its most pleasant features, but it also brought problems. From the European perspective, Quebec in the 1940's was a backward society. The University of Montreal sustained very little science, and the modern building on the north side of Mount Royal, completed in 1929, had been left unoccupied. The project moved to this building when the full team had been assembled. When the European physicists read the University's prospectus, they were astonished to find that it was dominated by the Catholic church; a specific condition of appointment to its faculty was that one be a practising Catholic. The Church censored films and books; drive-in theatres were banned on moral grounds, and there was no city-wide library system. Worst of all, perhaps, were the political attitudes of French Catholic Quebec, which had overwhelmingly backed the fascist side in the Spanish Civil War and was now supporting the collaborationist régime of Marshall Pétain in France. On the other hand, in the English-speaking community, support was strong for the Spanish Republicans and the French Resistance. The European scientists, particularly the French, found they had little in common with the French-speaking community in Montreal and were drawn closer to the cosmopolitan English-speaking minority.

Early in the Simpson Street phase of the project, we were startled to receive a volume of poems by Pushkin sent by mail from the Soviet Embassy. It was an unexpected and perhaps ominous gesture of welcome. The Soviet Union was, of course, an ally, but many recognized it as such rather grudgingly.

THE SHADOW OF HEISENBERG

It is reasonable to ask why scientists did not question their motives in working for a project with such frightening possibilities. However, the initiative which had led to the project had originated with highly respected scientists - Leo Szilard, Eugene Wigner and Edward Teller - who had convinced Einstein, a lifelong pacifist, to write a letter to President Roosevelt strongly urging him to initiate such a project. Their concern was that Germany might be first to develop a nuclear weapon. This fear was based on the conviction that Werner Heisenberg, Germany's leading physicist and heretofore a close friend, and who shared their knowledge of the possibility of a nuclear weapon, had the ability to lead such a project to fruition.

Early in the project, Placzek related to me events which had marked the immediate pre-war period, when the discovery of nuclear fission was already known to the inner circle of the world's nuclear scientists. In the late summer of 1939, on the eve of war, there was an international conference of nuclear physicists at Ann Arbor, Michigan, where the threat of nuclear weapons was the subject of intense informal discussion. Scientists such as Bohr, Bethe, Weisskopf, Fermi, Szilard and Placzek himself strongly urged Heisenberg not to return to Germany, where, they were certain, he would be drawn into a nuclear weapon project. Many of the other scientists were refugees from Nazism; a good number of them were Jewish. But no amount of argument could shake Heisenberg, who held firmly to the line that, as a patriotic German, he was honour-bound to go back to help his country win the war, and only after that would Germans turn to the problem of ridding themselves of Hitler. This response aroused fear and despair among his colleagues, to whom he had been an esteemed personal friend. It revealed Heisenberg as at least naive and unrealistic and, for some a traitor to the scientific community. In the years that followed, the Allied project was covered by Heisenberg's shadow, and we kept looking for clues to the state of the German atomic weaponry efforts.

At one point in 1944 our concern was heightened by the publication of an article by Heisenberg on fundamental physics in a German physics journal. Physicists in the Allied countries were so intensely involved in their project that they had no time even to think about basic physics research; they reasoned that if Heisenberg had the time, the Germans must already have succeeded in producing a bomb.

History would show that they had both overestimated Heisenberg and failed to reckon with the rigidity and paranoia of the Hitler regime, which lacked the insight and could not generate the motivation to match the Allied effort. After the war, Heisenberg found a convenient excuse for himself and his German colleagues, hinting that they had failed because they had stronger moral reservations about developing such terrible weapons. The historical evidence supports a far less generous estimation both of the German project and of Heisenberg's personal integrity. In any event, the fears which spurred the Allied projects were later shown to have been unfounded.

LIFE IN THE THEORY GROUP

The pattern of project work was established early on. The senior members were responsible for the general direction of the project, and thus worked closely together. At the junior level, our tasks were more specialized and there was little scientific or social interaction among members of different work groups. We were subject to the "secrecy principle", which meant that we were not told more than we had to know, although this was not rigidly enforced. Hierarchy prevailed, and the atmosphere was in some ways more military than academic. In the theoretical division, however, Placzek treated us with understanding and respect and kept things as open as possible.

Jeanne Le Caine and I were assigned an ambitious task which, Placzek informed us, was of prime importance: the study of neutron diffusion in "piles", graphite-moderated reactors driven by fissile materials. The building of such a reactor was one of the main goals of the group. Our work was to investigate the diffusion process in a wide variety of geometries and for a wide range of the key parameters. This was an exercise in classical mathematical physics, requiring little in the way of original ideas. Because of my background in mathematical physics, it was fairly routine work for me. As for Jeanne Le Caine, who was well trained in "pure" mathematics, she adapted to the task very rapidly. Along the way we both managed to learn a few tricks of the trade. To appease us for being assigned what could be considered "donkey work", Placzek assured us that our final report would be the most widely read document to come out of the project. After the war, it was published in condensed form in two articles in the journal Nucleonics.

At the end of June 1943 the project moved to a wing of the "new" University of Montreal building, still unoccupied a dozen years after its construction. Built in the architectural style of the 1920's, it is superbly situated on the north side of Mount Royal. My wife and I found an apartment in a new building in the Snowden area, about a kilometer from the university. Two of our neighbours were associated with the project: the Sargents, who lived just above us, and Dennis and Renée Ginns, who were below on the ground floor. Even after 55 years I have maintained contact with Dennis Ginns, an engineer from ICI in Manchester who, although long retired, is still active. Our eldest son, Michael, was born in November 1943, and the Ginns had two young daughters, so we naturally became friends. As for Bern Sargent, although he was a quiet man, I got to know him well because we often walked together up the hill to the university.

Social life in the theory group developed largely due to the initiative of Carson and Kay Mark. Carson became my officemate, and I learned of his problems as a young mathematics professor at the University of Manitoba. By the time he came to Montreal, he already had four children. Salaries at our rank were around $2,000 to $3,000 a year; and, in the late Depression days, professors were sometimes not paid during the summer vacation months, so Carson took camping holidays with his family. In Montreal, the Marks led a life devoid of pretension but strong on hospitality. If you arrived at their home for dinner at the prescribed hour, you were likely to be put to work helping to wash the noon dishes. There was always a certain chaos as Carson and Kay fed the children, put them to bed, and so forth, while encouraging lively conversation among the guests, who became honorary members of the family. It was anything but dull.

Since there were no good restaurants near the university, most of the younger generation brought sandwich lunches, which they ate together in a common room where conversation thrived. In this international atmosphere, we talked mostly about world affairs rather than local matters. Somewhat later we organized lunch-hour discussion sessions on various issues. Our discussions were exceptionally interesting because of the great diversity of our backgrounds. They rarely touched on problems surrounding our own work. Mostly, I think, they served to reduce our feeling of isolation from the outside world.

It was in our informal luncheon discussions that Bruno Pontecorvo made his presence felt. His contributions reflected his broad interest in physics, science and philosophy. He tended to seek out interaction with members of the theory group because he felt he could engage us in discussions of broader aspects of physics, beyond the technical problems with which the project was preoccupied. Many of the questions he raised in our discussions anticipated the revolutionary developments in physics of the decades following the war.

Bruno came to the project with a reputation of being an outstanding athlete; it was said that he had been a top-ranking tennis player in Italy. I was a regular squash player and considered myself reasonably good at it, so I invited Bruno to join me on the squash courts of the McGill gymnasium. He had never played the game before, but he took to it enthusiastically. His athletic skills soon became apparent; after the first couple of games, I almost never beat him. Still, it was a diversion we both enjoyed.

Bruno and his family lived in an apartment off Côte des Neiges Road, backing on St. Joseph's Oratory. He liked to entertain his guests by showing them to his balcony, from which one could watch worshippers mounting on their knees the many steps leading to the shrine.

Although it would later be marked by tragedy, his family history was very interesting. His wife was Swedish, and they had lived for some years in Paris and later in the American West, with the consequence that his two young sons had command of four languages -- Swedish, Italian, French and English. They had a remarkable facility for addressing each guest in her or his own language. But Bruno spoke little Swedish and his wife little Italian, so the boys were able to use this fact to advantage in family conversations.

A TURNING POINT

Early in 1945, as the bomb projects were reaching their critical stage, Placzek was assigned to duties at Los Alamos. He came to the office shared by Carson Mark and me to announce this move and to tell us that he was authorized to take one of us with him. After a brief but inconclusive discussion, Carson proposed that we decide by flipping a coin. The decision was that Carson would go. I do not remember precisely my state of mind at that moment, but it was not long before I came to a feeling of relief. Though I had made my commitment to the project, I had never been comfortable with the bureaucracy and secrecy which surrounded it. I realized their necessity, but I looked forward to the day when I could resume a normal life in academia, which had always been my goal. As time wore on, I became constantly more satisfied with the way things had turned out. Carson committed his life to the manufacture of nuclear weapons, becoming head of the theoretical bomb production group in 1947. For my part, I realized that my fulfillment lay in academic research and teaching and that I would not have been able to adapt to the sort of life Carson led. The coin toss had been lucky for me.

With the departure of Placzek, it was necessary to find a new head for the theoretical group. In my mind there was no doubt that George Volkoff was the right man for the job. And in fact, the day after Placzek's departure I found George installed in his office. When I congratulated him on the appointment, he corrected me, saying with characteristic candour, "I thought that the first person to take over the office would get the job." George was a very open and forthright person, incapable of guile. This and many other agreeable characteristics, made him an excellent administrator. He later became chairman of the physics department and Dean of Science at the University of British Columbia.

There was not a great deal of collaboration within the theory group. Each of us was involved in a particular task, and most of the interaction took place at the higher level of group chairmen. When there were collaborations, they were invariably one-on-one. Thus I worked closely with Jeanne Le Caine on producing the neutron diffusion manual, for some time exchanging ideas in our joint office with Carson and, at Placzek's suggestion, collaborating with Ernest Courant in determining whether random fluctuation effects in reactors could create critical conditions.

So it was that when our project produced its first reactor, the low-intensity ZEEP, it fell to George Volkoff, as head of the group, to predict at what point it would become critical. There were numerous elements of uncertainty in the calculations, but George's prediction came within 3% of the experimental finding. This was somewhat of a miracle, since some of the parameters of the problem were subject to larger uncertainties. Thus was born "Volkoff's Theory of Errors", the first rule of which was never to make a single error in a calculation, because a second error might cancel out the first. One was hesitant to rely on this theory unless one had a deep belief in one's luck.

ENCOUNTERS WITH OUTSTANDING PHYSICISTS

A positive feature of working on the atomic energy project was the opportunity to make the acquaintance of some of the leading physicists of the time. We enjoyed many visits from Eugene Wigner, a gentlemanly Hungarian of a conservative disposition. Wigner was a brilliant man of great imagination whose activities covered the whole spectrum of physics. The universal physicist -- Fermi, Szilard, Peierls, Weisskopf and Bethe were other examples of the species -- has since become almost extinct. Because Wigner's theory group at Argonne was concerned with many of the same problems as ours, we got to know him well and to respect him deeply. Our relationship continued after the war; in 1957, he was one of the major speakers at a conference on theoretical physics organized by the newly-founded theoretical division of the Canadian Association of Physicists in 1957.

I remember vividly a trip to Chalk River when the laboratory there was under construction, in which Wigner accompanied George Volkoff, myself and the American "liaison officer". On the long drive to Chalk River from Montreal, there was time for a great deal of conversation. The "liaison" man, undoubtedly an agent of American military intelligence, was usually cautious in his speech, though not always in his actions; he was once caught searching secret files of the Canadian project at night. This revealed an undercurrent of distrust between the two projects, and the agent was subsequently recalled. But during our long car trip he was rather indiscreet, boasting that in every research group in the American project there was a "spy" who reported regularly to the intelligence organization. This shocked Wigner, who vigorously affirmed that no one in his group would play that role. He was told just as firmly that his group was no exception and that someone was reporting on them. Wigner reacted with shock and incredulity. I believe he felt that only communist governments played such dirty games, and that in democratic societies spying on scientific colleagues was not acceptable conduct.

There is an apocryphal story about Wigner which testifies to the respect he commanded. As the story goes, he assigned a complex problem to a graduate student. In due course, the student reported his results to Wigner. Wigner took from his pocket a little notebook, thumbed through the pages and, on finding the right page, announced to the student, "Yes, you are right".

Since there were several bomb-related projects in the United States, I do not understand how a first-class American theorist came to be assigned to our theoretical division. Bob Marshak came from the University of Rochester, where he had obtained his doctorate under the direction of Victor Weisskopf, an outstanding Austrian physicist in the "inner circle" of the European pioneers of quantum physics. Unlike the rest of us, Bob was well versed in the fundamental physics underlying our project. His subsequent career attests to his talent; he organized annual international conferences on particle physics in the post-war years and ultimately became a university president. Bob's working-class background had given his personality a somewhat sharp edge, perhaps the natural accompaniment to a sharp mind. His political leanings were decidedly to the left, but his was an independent spirit, governed by personal experience and convictions rather than by conventional dogmas. In any case, he was a very stimulating addition to our group and brought to it a scientific maturity beyond his years. He treasured his relationship with

Weisskopf and inspired in all of us a lifelong admiration for "Vicki" .

Regrettably, even distinguished scientists were not immune to the anti-Semitism prevalent in Quebec at the time. This became evident when I invited Bob and his wife Ruth to join my wife, Jean, and me in a Sunday excursion to the Laurentians, where we intended to dine in a highly recommended country restaurant. We received a chilly reception from restaurant staff. The manager told us firmly and clearly that we were not welcome and that we should look for a Jewish restaurant in which to dine. Bob was livid, and I was speechless with embarrassment. We had no option but to leave. A few miles down the road we did find a "Jewish" restaurant (advertised as such) where the management apparently took no exception to gentile guests. Experiences of this sort were probably not exclusive to Quebec, but this did not blunt the shame and anger we felt at encountering such discrimination in our own country -- and at a time when we were engaged in what was claimed to be a noble crusade against a racist maniac in Europe.

Another renowned physicist who made occasional but important visits to the Montreal Laboratory was Rudolf Peierls. The scientific leader of the British team, Peierls had been the first to show that it was probable a bomb could be made. He operated at first from New York, which enabled him to interact easily with both the American project and ourselves. He was a close friend of Placzek, who sometimes visited him there. Peierls later became the senior British theorist at Los Alamos.

Two other theorists who had collaborated with Peierls before the project, German refugee Klaus Fuchs and Tony Skyrme, were assigned to assist him. One of Peierls' visits to Montreal with Fuchs and Skyrme had unforeseen consequences for me. The "top brass" organized a dinner for Peierls, and, out of regard for Fuchs and Skyrme, suggested that someone should do the same for them. This fell to me, so I invited them to my apartment, along with a few of my colleagues in the theoretical group, including George Volkoff and Carson Mark and their wives. It was an interesting evening. Fuchs entertained us with stories of his experiences in a Canadian internment camp, set up at the beginning of the war to do a precautionary screening of German scientists in order to weed out those who might have Nazi sympathies or connect-ions. Apparently the internees were separated into Jewish and gentile groups, the latter including a considerable number of Nazi sympathizers. Fuchs, a vehement anti-Nazi, found his situation uncomfortable and convinced some of his Jewish friends to declare him an "Honorary Jew" so that he might join them.

Cold War paranoia would later transform this amiable evening into a possible clandestine rendezvous of spies. For, as would later be revealed, Fuchs had made another visit to Montreal, alone, in order to pass information to a Soviet agent. So it was that, some years later, I was visited by an officer of the RCMP who wanted to talk to me about my contact with Fuchs during a Montreal visit. It was of course not difficult to establish that there had been two quite different visits, under quite different conditions.

Another question inevitably arose: did Peierls know of Fuchs' communist sympathies? Indeed, Peierls' relationship with Fuchs was later discussed, with dark overtones, in an English journal. But Peierls was an ardent anti-communist; he sued the journal and was awarded an impressive sum in compensation for the damage to his reputation, an outcome which delighted all of his fellow scientists.

As a physicist, Peierls was of the old school. He was no specialist; the whole of physics was a challenge to his clear, incisive mind. Possibly it was the sheer breadth of his interests which denied him the Nobel Prize which many of his colleagues felt he merited. Later on, I had the good fortune not only of working in his department, but of having him and his wife Genia as neigbours in Old Boar's Hill, south of Oxford, through the efforts of Genia herself.

Unfortunately, circumstances gave us very little direct contact with Hans Bethe. However, he so dominated the world of nuclear physics that all were conscious of, and learned from, him. There seemed to be no problem beyond his capacities.

By good fortune, and through the initiative of Maurice Pryce, some of us had the opportunity to spend an evening with Niels Bohr. Bohr's elder brother Harald, a mathematician and one-time football player, was the scientific attaché of the Danish Embassy and lived in a mansion on Pine Avenue. George Volkoff and I were invited, together with Maurice. The experience confirmed several aspects of Bohr's personality and manner which had become legendary. Bohr spoke with a heavy Danish accent, his voice sometimes dropped to the level of mumbling, and he had a habit of changing his train of thought in mid-sentence. Even when I could follow the words, I had some difficulty following his thought. Although there were moments of clarity, I gained very little from the encounter and can recall almost nothing of what was said.

The Theoretical Division was considerably enhanced in 1944. John Stewart and Haank Clayton came from the Canadian army, while Boris Davisson, Maurice Pryce and E.A. Guggenheim all arrived from Britain. Maurice was the most distinguished; he had been Dirac's sole collaborator and had an international reputation. Guggenheim was known for his work on statistical mechanics. Boris Davisson, however, had the most interesting history (see article by W.J.L. Buyers, in this issue). He was the son of a British engineer who had lived for many years in the Soviet Union, where Boris had been educated. While his background was primarily in mathematics, he had a solid grasp of the fundamentals of physics. One very quickly discovered that Boris was strongly anti-communist and looked back with no pleasure on his life in the Soviet Union. In addition, his health was poor; tuberculosis had already cost him a lung.

Boris was a very amiable and popular colleague. He was modest to the point of self-deprecation and rather fatalistic in outlook. Yet there was a gentleness in him, and an underlying sense of humour and irony. In a short time, he became a friend to all of us; no one in the project was more universally liked and esteemed.

Moreover, the quality of Boris' scientific work soon became evident. Whatever his social or political problems in the Soviet Union, he had been well trained in a rigorous educational system. He showed his wry sense of humour by proclaiming that he had not learned classical Newtonian mechanics in university, but was thoroughly versed in quantum theory. His manner of solving classical problems, he avowed, was to solve the corresponding quantum problem and then put Planck's constant equal to zero.

Boris was a very self-sufficient worker; his interaction with the rest of us was social rather than scientific. His method of working was quite unique. He would simply open his notebook and start writing. His ideas flowed smoothly onto paper. There were no afterthoughts or corrections; his notes seemed to emerge directly in publishable form. Nor was any problem too difficult or complicated. It was because of the quality of his work that, when Placzek, Carson Mark and Bengt Carlson went to Los Alamos, Boris was also seconded there. Boris had just recently been married to a very gregarious Russian girl, and all seemed well. However, the thin air at the altitude of Los Alamos created pulmonary problems, and he had to return to Montreal.

Boris' testimony to the dark side of Soviet life was reinforced by George Volkoff. One day he told me his family history. They had emigrated from Manchuria to Canada when George was quite young. During the Depression of the 1930's they fell upon hard times. Relatives still in the Soviet Union wrote his father to say that he could find good employment there. His father decided to return, leaving his family in Canada until he was well established. With time, letters from him became less and less frequent, and he ultimately disappeared in the Stalin purges. Despite his feelings about the Soviet regime, George showed a strong and justified feeling of national pride when the Soviet Union was turning the tide of war against Nazi Germany.

FEYNMAN FROM A DISTANCE

My first experience with Richard Feynman occurred just after the war ended, and was due to the fact that we both worked in the atomic energy projects of our respective countries. In Montreal, I had cooperated with Ernest Courant on the problems of neutron density fluctuations in nuclear reactors. Since they were multiplicative devices, there was concern that fluctuations might also reach a critical (explosive) level. Our work showed that this was not a danger. Fluctuations of local density in a gas were well known to be proportional to the square root of the number of molecules involved, so that fluctuations could be significant only in small regions containing few particles. We found that in systems in which there was a chain reaction, the fluctuations in the high density limit were more or less proportional to the density itself. This would not lead to criticality in a subcritical system, but merely affect the level of overall neutron density at which criticality would occur.

At this time much of the wartime secrecy had been relaxed, but more so in Canada than in the United

States. Ernest and I decided to publish our results, but before submitting them for publication we learned that Feynman had worked on the same problem at Los Alamos. We thought it unfair that we could publish and he could not, so we proposed preparing a joint paper which could await clearance in the United States. Feynman rejected our proposal, saying that we should proceed to publish immediately and that he was not concerned with credit for the finding. This was typical of Feynman's attitude toward physics: to him, the important thing was the discovery, not who made it. But, in retrospect, I regretted losing the opportunity to co-author a paper with Feynman.

THE CLIMAX

When word came of the successful explosion of a test bomb, we were all very excited. Everyone's attention was suddenly directed to the problems of global and domestic politics. We put aside our technical problems for a while and started to evaluate the consequences of what had been done. That the end of the war was in sight was, of course, a source of elation, but the question of whether the bomb would be immediately used on Japan was on everyone's mind. Only Bruno Pontecorvo was certain of the answer: for political reasons, he said, the Americans would have to use it on Japan before the Japanese could surrender and before the Russians could play a role in their surrender.

Shortly after, when the bombs were dropped on Hiroshima and Nagasaki, elation gave way to sober second thought about how we might all be affected by the irreversible consequences of our efforts. In a sense, however, we experienced a liberation; our isolation behind a cloud of secrecy was over, and we were now at centre stage of a great historical event. My wife, who had had no idea what I had been doing during the three years of the project, had a brief but understanding comment: "Shame on you."

LOOKING AHEAD

Although there were several layers of bureaucracy between most of us and the people who made the important decisions, we were always conscious of their power over us and over our future. Our prime minister was a remote and mysterious character, more a symbol of power than than a real embodiment of it. Our ultimate boss was the dominant minister in his cabinet, the powerful and tough-minded C.D. Howe. He cast a large shadow over our landscape.

His deputy minister, C.J. MacKenzie, was quite another story. Although he was seldom seen, his decisions directly affected our lives. He was an engineer by training, highly regarded and trusted by his superiors, but somehow also enjoying the trust and respect of those under him. If Howe had the brawn, it seemed that C.J. MacKenzie had the brains and initiative to make things happen. It was, in fact, MacKenzie who set the direction of the whole project.

Before the war, the National Research Council of Canada had been an organization at the edges of academic science; it functioned primarily as a sort of bureau of standards. When it was put in charge of the atomic energy project, it took on a new stature. This was really a big league job, and C.J. MacKenzie was at its head. After the bombing of Hiroshima and Nagasaki, the question of the future of the enterprise came to the fore. But MacKenzie, it seemed, already had his vision of the future -- and it was an ambitious one.

I am not entirely sure why, but MacKenzie invited George Volkoff and me to meet him; he wanted to "have a talk with us". Why us? Perhaps because a number of senior members of our group had gone off to Los Alamos and others who had come from abroad were expecting to return home, while George and I were committed to staying in Canada. MacKenzie revealed to us his intention to turn the National Research Council into an agency of basic science which would provide the resources, human and financial, to nurture science in the universities and laboratories of the country, and thus raise Canada to the position of a world power in science. We would build on what had been accomplished in our wartime project to carry Canadian science to a higher level than it had known in the past -- more global, less isolated and provincial.

MacKenzie's attitude was benignly paternal. He expressed the hope that we would be a part of his vision. Perhaps it was just a case of spreading word of his plans as widely as he could. But the vision was clear and inspiring, and I could not help being grateful for the opportunity to share it.

It was the end of an experience which none of us would have hoped for, full of the agonies of war. There were dark clouds on the horizon. But, in MacKenzie's vision, this period of trial and stress would give way to a new and hopeful beginning.

GEORGE CRAIG LAURENCE, 1905 - 1987

George Laurence was Canada's first reactor physicist who went on to a distinguished career in the development of CANDU and, later, in reactor safeguards when he headed the Atomic Energy Control Board (AECB). He was born in Charlottetown, P.E.I. in 1905 and obtained his B.Sc. degree from Dalhousie University in 1925. After his degree, he completed a research project at Dalhousie on a novel new way of measuring accurately the ranges of alpha particles from uranium. His success with this difficult experiment led to an 1851 Exhibition Scholarship to work on his Ph.D. degree in Cambridge, under Rutherford. Having completed his doctorate in 1930, with more alpha particle measurements, Laurence returned to Canada to work at the new National Research Council (NRC) laboratories in Ottawa.

George C. Laurence
(Photograph reprinted with permission from *Transactions of the RSC*, 1989, fifth Series, Volume IV, p. 381. Copyright 1989, Royal Society of Canada.)

Laurence working at the NRC was the right person at the right place at the right time. During his first twelve years at the NRC he headed a small laboratory to standardize the measurement of X-rays and radium gamma rays in terms of the Roentgen. After fission was discovered and announced in January 1940, he became the first person in the world to induce fission in a very large quantity of uranium surrounded by carbon, to investigate the possibility that the fission chain reaction could be produced in this way. In his experiments, in 1940, he used a ton of uranium oxide and ten tons of carbon powder arranged in a lattice in a nine-foot diameter sphere. Fermi built a similar lattice in mid-1941. Fermi found then, as Laurence did a few months later, that higher purity uranium oxide would be required to produce a self-sustaining graphite uranium reactor. Laurence was clearly on the ground floor of such experiments but it was Fermi, with his greater US resources, who soon after built the first chain reaction, with graphite and uranium, at Stagg Field in Chicago.

The arrival in Canada of the world's supply of heavy water, as well as the decisions of Churchill, Roosevelt and King at Quebec City in 1943, led to Canada being assigned the development of heavy-water-uranium reactors at the Montreal Laboratory, as described elsewhere in this issue. The graphite-uranium reactors became part of the American program. Laurence joined the Canadian effort at Montreal.

The work of Laurence at the Chalk River Nuclear Laboratories (CRNL) for the CANDU program was of great importance. He directed the groups developing and often fabricating the new instruments needed for CRNL's first reactor, ZEEP, and then for NRX. He also was the leader of the branches involved in the design of NRU. These were the best reactors in the world for neutron physics. The NRX accident in 1952, in which a power surge occurred due to operator error and equipment malfunction, had a very deep impact on Laurence. Subsequently he devoted much of his career to the safety of nuclear power in Canada. This naturally led to his appointment, in 1961, to succeed C.J. Mackenzie as President of the Atomic Energy Control Board (AECB), a post which he filled with great distinction.

As President of the AECB, Laurence was also responsible for the construction and operating grants to university accelerator laboratories in Canada. He was very visionary and highly effective in achieving the construction funding of TRIUMF in 1968. He was a civil servant who remained a true physicist and who reported directly to the relevant federal cabinet minister. Although a true pioneer for nuclear energy, Laurence retained a youthful enthusiasm for science throughout his administrative years. He was a good man, an excellent physicist, and a true servant of Canada. He died in Deep River, Ontario, on November 7, 1987, in his eighty-third year.

Erich Vogt, Professor Emeritus
University of British Columbia

JOHN STUART FOSTER, 1890 - 1964


J. Stuart Foster

First and foremost, John Stuart Foster was a physicist by instinct, training and profession. He was bright, visionary and creative. His scientific insight was always clear and powerful; at times it seemed supernatural. His method of reasoning often seemed to involve no method whatsoever; he merely jumped from the premise to the correct conclusion. It was never clear whether he went through or simply skipped all the intermediate steps in the process that a less gifted person would have had to take to get there. He belonged to the first generation of Canadian-born physicists who had achieved international recognition. He was known for his important contribution to the understanding of the Stark effect, his invention of the Foster Scanner in radar and, of course, his beloved cyclotron and Radiation Laboratory at McGill. Foster was also famous for his magnificent sense of humour, for his wild and contagious laugh and for his obliquity of speech. He was truly a remarkable man!

Stuart Foster was born in Clarence, Nova Scotia, on May 30, 1890; he graduated from Acadia University just before the 1914-1918 war. During the war, he served in the U.S. Armed Forces, 'armed', as he used to say, 'with a soldering iron down in Monmouth, New Jersey'. This service enabled him to receive an American National Research Fellowship and, subsequently, to win the highly competitive Loomis Fellowship to attend graduate school at Yale in 1920. He obtained his Ph.D. in 1924 and immediately moved on to accept an Assistant Professorship appointment at McGill. By then he was already well-known for his experimental work on the Stark effect.

Although Foster always denied being anything but an experimentalist, the lack of a theoretical understanding of the Stark effect at the time must have bothered him. In 1926 he received a fellowship to spend a year in Copenhagen at the Niels Bohr's Institute for Theoretical Physics, where the new quantum mechanics was being hammered out. It was a fruitful sojourn in Copenhagen; he published the important definitive paper on the quantum mechanical theory of the Stark effect in 1927. This paper typified his taste and attitude in physics; he preferred direct, simple and intuitive forms of theory and experiment. Bohr and Heisenberg were his abiding heroes. His work on the Stark effect won him many honours and awards. Among them: Fellow of the Royal Society of Canada (1929); Levy Medal of the Franklin Institute (1930); Sterling Fellow of Yale (1930); Honorary D.Sc. from Acadia (1934); Fellow of the Royal Society (London, 1935). An FRS only seven years after his Ph.D.!

Foster was a visionary physicist. In 1935, only three years after his great friend and Yale classmate, Ernest O. Lawrence, had succeeded in making the cyclotron work, he assembled a team at McGill and started designing the world's second largest cyclotron and a Radiation Laboratory to house it. In the Fall of 1937, the Governors of McGill voted to finance his project. This was no simple matter for a private university like McGill. Even to this date people still wonder how he managed to do that. Unfortunately, the project had to be delayed due to the outbreak of the 1939-1945 war.

During the war, like many of his McGill colleagues, Stuart Foster devoted his effort to war time radar research. In 1941 he was sent to the newly established Radiation Laboratory at the Massachusetts Institute of Technology (M.I.T.) as the liaison officer for the National Research Council of Canada. It was a funny appointment because Foster was never much of a liaison man. He had little patience for paper work and his way of dealing with it was any handy nearby wastebasket, especially when his mind was on science (which was most of the time). He preferred to disappear into the laboratory and started inventing things; he invented the Foster Scanner for radar rapid-scanning antenna which involved a new concept that subsequently evolved into a subfield of antenna design. For his war effort, he was later awarded the Medal of Freedom and Bronze Palm of the United States (1947). Oh yes, he also earned the title as "Mad Professor" from the custom officers at the Canada-U.S. border for his frequent smuggling of radar components across the border during the war.

The crown of Foster's career was undoubtedly his cyclotron and Radiation Laboratory. He resurrected and updated his project upon his return to McGill in 1944. By 1946 University financial backing was at hand ; the cyclotron was under construction and the first phase of the Radiation Laboratory was complete. The cyclotron was officially commissioned in 1949. The cost of this phase of the whole project was less than $300,000, an incredibly low figure for a 100-MeV machine; thanks to the large team of highly skilled graduate students, mostly veterans of the war. Many important pioneering research works were carried out at the facility which had helped to place Canada on the map of international nuclear physics. Foster was always proud to say that the Laboratory under his tutelage (he retired in

1960) produced more than 100 Ph.D. graduates who staffed various Canadian and U.S. institutions.

No description of Foster is complete without reference to his sense of humour, which could be depicted as Mark Twain or Stephen Leacock with a down-east background. Examples abound. To a traffic policeman, threatening a $20 fine: "Haven't you got anything cheaper?" During a tour of Leningrad, when the guide from the Soviet Academy of Science was boasting about the efficiency of their underground system in comparison with those in Paris, London and New York, Foster remarked: "Seems reasonable." To the humanists who complained about their lot:"They can go to work too." To a geologist talking about his research problem: "When you get stuck, turn on the water."

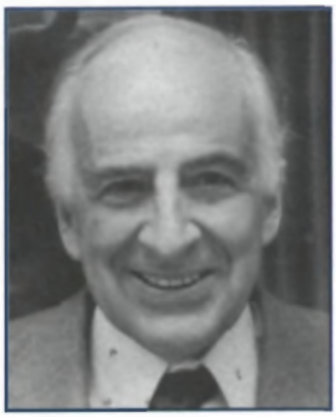
As devoted to physics as he was , Foster was exceptionally quick to appreciate good work in art, music and letters generally. He liked to recognize the musical or artistic talents among his graduate students and their families. He was fiercely loyal to McGill, his family, friends and graduate students. Once convinced of a student's worth, he would tirelessly promote his interests long after graduation.

Foster received many honours and awards which are too numerous to be listed here. Apart from those already mentioned above, suffice it to add: Tory Medal of the Royal Society of Canada (1946); President of Section III of the Royal Society of Canada (1948-49); D.Sc. from McMaster (1950) and from Dalhousie (1960); Medal of Achievement in Physics of CAP (1958). His achievement is, as he used to say of the others, "enough for any one man." Throughout his life, until his death in 1964, Foster was a mover and shaker of modern Canadian science.

S. K. Tommy Mark
McGill University

BRUNO PONTECORVO, 1914 - 1993

Bruno Pontecorvo was only briefly in Canada (1943-1948) but he was the most legendary and flamboyant of the stars that illuminated Canadian physics during the past century. Born in Pisa, Italy, on August 22, 1914, he was the youngest and most dashing member of Fermi's group in Rome, perhaps almost the opposite in personality to Rasetti who had such a strong influence on Laval University. Pontecorvo will be remembered for the depth and elegance of his ideas, particularly for experimental neutrino physics and neutrino astrophysics, two fields for which he was the founder and leader for many decades.



Bruno Pontecorvo
(Photograph reprinted with permission from *Physics Today*, 47(10), 1994, pp 87. Copyright 1994, American Institute of Physics.)

At the Montreal Laboratories (see Phillip Wallace's article on "Atomic Energy in Canada: Personal Recollections of the Wartime Years", in this issue) and in the early days of Chalk River, Pontecorvo was very impressive. Working with Geoffrey Hanna and others, he suggested the chlorine absorption of neutrinos as the basis for radiochemical detection of neutrinos. It later was this method which allowed the first detection of solar neutrinos. From the spectrum of tritium beta decay, he found the first good limit for the neutrino mass. Also, at the Chalk River Nuclear Laboratories (CRNL), he pioneered the study of muon decays and proposed the universality of the weak decay for electrons and muons. His imagination and creativity were extraordinary, similar to that of his great teacher, Fermi, whom he emulated.

Pontecorvo's verve extended to his private life. He excelled at tennis, let his furnace ashes simply accumulate in his Deep River basement and, in the close-knit community of Deep River, his escapades sometimes bent the rules. After a brief sojourn in England, he shocked his friends in the West by leaving with his family for Russia in 1950. At Dubna, near Moscow, his physics continued to flourish, but he could not travel outside Eastern Europe until 1978.

Pontecorvo died in Dubna on September 24, 1993. His brilliance as an experimental and theoretical physicist was long remembered at CRNL.

Erich Vogt, Professor Emeritus
University of British Columbia

NUCLEAR PHYSICS ACTIVITIES AT CHALK RIVER

by James S. Geiger and Tom K. Alexander

The initial focus of the wartime atomic energy project in Canada was construction of the ZEEP and NRX reactors. Upon completion of the NRX reactor, the NRC scientific staff and the UK attached staff were presented with the opportunity of using this new resource to tackle physics problems which its high neutron flux brought, for the first time, within experimental reach. NRX clearly outclassed any of the then available competitors as an experimental tool. Completion of the NRU reactor in the mid-1950's added to these capabilities. In addition to the reactor-based studies, one saw a variety of other studies undertaken. Accelerator-based studies evolved from those based on Cockcroft Waltons, to 3MV Van de Graaff studies, to 5 MV EN Tandem work, to 10 MV MP Tandem work and ultimately to the Tandem Accelerator Super-conducting Cyclotron (TASCC) facility. The EN Tandem installation, the first of its kind, placed the laboratory in another unique position, this time with a tool ideally suited to address low-energy heavy-ion reactions.

The laboratory staff had the benefit of a management that demanded excellence, provided the resources necessary to achieve excellence and that operated an internal refereeing system which insured that the publications that left the laboratory were of the highest quality.

The research programs had the benefit of a very strong laboratory infrastructure and strong support on both the financial and technical side. The infrastructure included a strong electronics group that developed state of the art automated data acquisition systems to support the research activities, a counter development group that custom built detector systems optimized for planned applications, and a radioactivity standards laboratory. It is noted that Lloyd Elliott arranged for the Reactor Operations group to set up a Van de Graaff operations section staffed by special operators and engineers to run and maintain the accelerator, thus freeing up the experimental physicists to devote full time to research. The Operations group was headed by Phil Ashbaugh and later by Neil Burn who, before he retired, saw it become a TASCC Division branch.

The laboratory staff had the benefit of a management that demanded excellence, provided the resources necessary to achieve excellence as noted above, and that operated an internal refereeing system which insured that the publications that left the laboratory were of the highest quality. Lloyd Elliott was Editor of the Canadian Journal of Physics (CJP) for several years, and strongly encouraged staff to publish in that journal, an action that contributed significantly to the prestigious nature of CJP. In the case of abstracts for meetings, where current practice tends to have them reflecting what the author hopes to achieve between the date of submission and the time of the meeting, if the data on which the abstract was based were not in hand, together with at least a preliminary analysis, the abstract did not see the light of day. In addition to Physics Division programs, the laboratory had strong programs in chemistry, metallurgy, biology, and reactor physics, and the 8:30 a.m. laboratory colloquia had the benefit of strong multidisciplinary attendance. The persons primarily responsible for maintaining this highly productive work environment through the 1950's and 1960's were W.B. Lewis and L.G. Elliott. Dr. D.A. (Daddy) Keys' visits to, and interest in, the individual research activities and their progress added a valued human touch. Experts were eager to

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respond to requests for assistance or special apparatus and their assistance frequently resulted in the project making a quantum leap forward. Such interactions often led to longer term collaborations and some of these will become apparent in the few examples of research described.

The experiences of one of the authors (TKA) when starting his employment career give some idea of the laboratory climate for a junior researcher. "In late 1955, I started work at Chalk River in Art Ward's Reactor Physics Branch. A year or two later, then in the Electronics Branch of the Physics Division, I became fascinated by the new transistors and their use in nuclear instrumentation as pioneered by the Branch Head, Fred Goulding. He and Art Ward totally changed the way I approached research. I know W.B. Lewis read some of my reports because he suggested ways to improve the electronics. Bert Brockhouse was the first to say the device we designed for him worked fine. We developed for the Physics group, among many new transistor devices, a two-parameter coincidence kicksorter (pulse-height analyser), employing Lloyd Robinson's excellent ADC's (analogue-to-digital converters) and a pulse-shape discriminator to separate neutrons from gamma rays detected in organic scintillators like stilbene and liquid NE 213. In the summer of 1962, I got to use both instruments and the world-famous angular correlation methods of Litherland and Ferguson, in a very successful EN Tandem experiment to measure the spins and lifetimes of excited levels of ^{17}O and solve a vexing puzzle in the spectroscopy of this important nucleus. The work was done with the collaboration of Cyril Broude and Ted Litherland and formed part of my Ph.D. thesis with the group of Ken Dawson, Croy Neilson and Jack Sample at the University of Alberta."

An early experiment that drew international attention was Geoff Hanna and Bruno Pontecorvo's determination of a 500 eV upper limit on the rest mass of the neutrino. They added reactor-produced tritium to the fill gas of a proportional counter and determined the shape of its beta spectrum from the pulse height spectrum. The experiments made use of a 30-channel kicksorter built by Geoff Hanna and Carl Westcott that was superior to anything available at Los Alamos at that time. Their 500 eV limit came from the shape of the spectrum near the end point.

Another experiment of general interest to the physics community was John Robson's determination of the half-life of the neutron. In this case, the quantity measured was the beta spectrum that characterizes the neutron decay. The measurements were done with a beta spectrometer mounted at the reactor face. Reactor-produced neutrons provided the source and events characterizing neutron decay were selected by requiring that a proton, detected in a secondary detector viewing the source region, be in coincidence with the decay electron. The decay energy was measured and the 12.8(2.5) minute half-life followed from beta-decay theory. John Robson and Mac Clark went on to measure the proton-electron angular correlation in the neutron decay.

Neutron scattering studies were started in the 1940's and rapidly became a major area of reactor-based physics and one that is actively pursued at Chalk River to this day. The fundamental contributions made to this field by Bert Brockhouse and his colleagues are described elsewhere in this collection of articles.

The fission studies of John Fraser and Doug Milton were another reactor-centred activity. John was the first person to observe neutron emission from individual fission fragments and he and Doug were the first to observe the effects of shell structure in the prompt fission fragments. An interest in charged particle induced fission saw this work migrate to the MP Tandem in the early 1960's. Hans Specht developed a unique parallel-plate spark chamber detector for the Brown-Buechner spectrometer and gained notoriety as the only experimentalist who could man a one week (24 hr day) experimental run single handedly.

Research activities rapidly spread to areas only weakly related to reactor issues. One example was the mu-meson lifetime measurement of Ted Hincks. Another was the cosmic-ray neutron detector "station" developed by Hugh Carmichael's group that included Mort Bercovitch and John Steljes. This project led to an international network of stations that monitored the neutron flux at the earth's surface over several sun spot cycles. The "station" consisted of an array of BF3 gas proportional counters, each surrounded by a cylindrical plastic moderator and shielded by lead. Canadian stations were located in Deep River, Banff, Inuvik, Resolute and Goose Bay. In addition there was a trailer-housed station that was taken to various sites in the continental U.S., Mexico and Hawaii. Upon Hugh's retirement, the operation of the Canadian stations passed to Mort Bercovitch, then at NRC. The Deep River station was in operation from 1957 until 1997. Several sister stations in other countries are still operating.

Dr. Lewis' interest in a spallation-based neutron source led to a program of proton cross section measurements that involved a significant number of staff. Work was done at the McGill cyclotron (Bob Bell) and experiments were carried out at Echo Lake in Colorado (Mort Bercovitch) utilizing cosmic ray protons (the 'Deitron'). John Fraser and Doug Milton did the first Monte-Carlo calculations of the spallation neutron yield for 1 to 3 GeV protons incident on heavy elements. Their results were confirmed by an experiment carried out at the Brookhaven Cosmotron by John Fraser, John Hilborn, Ralph Green and Doug Milton, together with an Oak Ridge team. As the project progressed, it added an accelerator development component to the laboratory's activities. The studies ultimately led to the intense neutron generator (ING) proposal that went forward in the mid-1960's but failed to be funded. The Chalk River Accelerator Physics Branch was an outgrowth of this project and spallation-neutron-based reactor fuel breeding remained a field of active interest to AECL through the 1970's and 1980's.

Gamma-ray studies in the 1940's were almost always internal conversion electron studies, external conversion electron studies or, for high-energy gamma rays, electron pair studies. There were a number of lens spectrometers devoted to such studies, and there was the pair spectrometer that Kinsey and Bartholomew used in their studies of neutron capture gamma rays. (Warwick Knowles introduced curved- and flat-crystal gamma-ray diffraction spectrometers to the laboratory and led the world in precision gamma-ray measurements in the following decades. He carried his innovative research into many other ventures). Bob Bell and Bob Graham used a double-thin-lens spectrometer set-up to select cascade radiations and determined the intermediate-state lifetime using their nanosecond lifetime measurement technique.

Lloyd Elliott, who led these activities, recognized the potential of a much higher resolution spectrometer for internal conversion electron studies and initiated a program to develop such a device. Joe Wolfson did the initial studies, with the leadership subsequently passing to Bob Graham. Preliminary work led to the choice of the iron-free $\pi\sqrt{2}$ design with a three-coil-pair arrangement to create the magnetic field. Graham Lee-Whiting played a pivotal role in accurately calculating the coil parameters required to provide the magnetic field shape needed to achieve the performance promised by the $\pi\sqrt{2}$ spectrometer design. Subsequent tests of the instrument constructed by the team of Bob Graham, George Ewan and Jim Geiger showed it to meet the design criteria. The resolution of a few parts per thousand that characterized most studies allowed resolution of the L subshell conversion line components and gave accurate information on transition multipolarities as well as energies. In addition to this nuclear-type information, studies done with the spectrometer provided information on atomic phenomena including atomic level widths, Auger-electron spectra, and L subshell fluorescent yields; these last studies being led by Ian Campbell of the University of Guelph. The instrument was primarily a point-by-point measuring device and it required high-specific-activity source material if high resolution was to be realized. The advent of the high-resolution germanium detector and the shift in interest from studies of reactor-produced activities to accelerator-based studies resulted in the instrument seeing little service for many years. However, in the early 1980's, it was used for the 17 keV neutrino studies of Don Hetherington, Bob Graham, Aslam Lone, Jim Geiger and Graham Lee-Whiting. Several laboratories built scaled-down copies of this 1 metre radius instrument.

One of the experimental facilities planned for the EN Tandem installation was a large scattering chamber to be used for charged particle reaction studies. The assumption was that the particle detectors would be scintillation counters. This was in the mid 1950's and Allan Bromley was encouraging I.L.(Dick) Fowler to get the counter development group involved in the development of solid-state charged-particle detectors. Jim McKenzie, a postdoc in the group, took up the challenge and produced such detectors. This initiative had implications. One was that a large scattering chamber that had been built for charged particle reaction studies using scintillation counters stood unused for many years and finally disappeared. Another consequence of major importance was the fact that this work led to the involvement of the counter group in Li-drifted germanium, Ge(Li) detector manufacture. Alister Tavendale developed techniques for making large volume detectors. George Ewan worked with him in applying these novel devices to a large variety of physics problems and demonstrating that they would have a profound impact in improving and simplifying high-resolution gamma-ray studies. Adoption of these detectors by scientists in all areas of potential application was limited only by their availability.

Work with the EN Tandem Accelerator led to major contributions to our understanding of the atomic nucleus. Especially interesting were the experimental and the theoretical discoveries that increased our understanding of the s-d shell nuclei, i.e. the nuclei from ^{16}O to ^{40}Ca. The high resolution and variable energy of the Tandem Van de Graaff beams and the state-of-the-art detectors available for measuring the reaction products, were well suited to studies of nuclei in this region of the periodic table. Also theoretical physicists had reached the stage in shell model calculation where realistic modelling for these nuclei was practical and unique predictions could be made of experimentally measurable nuclear properties.

Harry Gove headed the accelerator-based Nuclear Physics group during a remarkable period in the 1950's that was exceedingly productive. Ted Litherland, John Ferguson and Harry Gove discovered collective-like excitations in light nuclei that closely resembled those described for heavy nuclei in the famous 1953 paper by Bohr and Mottelson. During the same period, Einar Almqvist, Allan Bromley and John Kuehner discovered that energetic collisions between two ^{12}C nuclei sometimes formed states of ^{24}Mg that had the characteristics expected for a nuclear molecule; an unexpected collective behaviour that was described to the media of the day as "kissing nuclei ".

Fig. 1 Chalk River physicists (left to right) John Kuehner, Allan Bromley and Einar Almqvist in the experiment control room of the 3MV vertical Van de Graaff accelerator. The year is 1957 and in the background, on the right, can be seen relay racks each containing six channels of a Moody kicksorter (so called after its designer).

This was the beginning of the study of nuclear reactions with precision beams of heavy ions. Ted Litherland and John Ferguson developed their famous alignment techniques, Method I and Method II, for measuring angular correlations of gamma rays from states formed in nuclear reactions. Bill Sharp provided theoretical guidance for this development and he and Jim Kennedy calculated the coefficients needed to interpret these correlations. This work revolutionized the determination of spins and was quickly adopted by other laboratories. This group of physicists made many exciting discoveries with the EN Tandem and were world leaders in nuclear structure research.

These early EN Tandem studies had a major impact when presented at the International Nuclear Physics conference held at Queen's University in 1960, under the joint sponsorship of AECL and Queen's. A further noted feature of this conference was the speed with which the Proceedings appeared under the joint editorship of Allan Bromley and Erich Vogt. Erich's recollection of this exciting time is: "The hard-cover volume of over 1000 pages was mailed to the conference participants four weeks after the conference. Every page was retyped either from rough manuscripts or from transcribed recordings of talks and discussions at the conference. All the drawings and figures were redrawn. The typing, redrawing and paste-up of the manuscripts were done in two weeks at CRNL by a team of about 20 typists (including Marilyn Buyers) working round the clock with the editors. The University of Toronto Press went from the paste-up to the bound volume in the following two weeks. All of this was done in an era before participants came to conferences with photo-ready copies of their talks. This is one of the few conference proceedings that have ever recognized the fact that such proceedings decay with a half-life of several months and therefore the period for their emergence should be weeks, not months."

In the early 1960's, Allan Bromley, and later, Harry Gove left Chalk River to lead MP Tandem Accelerator nuclear research projects at Yale University and at the University of Rochester respectively. They left a few years before the replacement of the EN Tandem at Chalk River with the more powerful 10 MV MP Tandem machine. The EN Tandem was moved to the University of Montreal, where it is still in use. Geoff Hanna, the branch head, skillfully oversaw the procurement and installation of the new MP Accelerator in a facility with expanded machine, target, and control rooms. Later, Lloyd Elliott became Head of Research, Geoff Hanna became Director of Physics, and Doug Milton became Head of the Nuclear Physics Branch. Over a short period, around 1967-8, the Tandem Accelerator nuclear group dispersed to the expanding university laboratories; Ted Litherland to the University of Toronto, John Kuehner and Phil Ashbaugh, the head of Tandem Operations, to McMaster University and Robin Ollerhead to the University of Guelph. Einar Almqvist, who added such strength to the group, sadly passed away. John Ferguson, the senior member, Cyril Broude, who later left to go to the Weizmann Institute, and Tom Alexander, who had joined in 1964, remained, bolstered for a period by postdocs and visitors, including Otto Hausser, John Sharpey-Schafer, Brian Hooton, Dietrich Pelte, and Finn Ingebretsen.

Otto Hausser stayed and initiated a series of brilliant experiments to measure quadrupole and magnetic moments of nuclei using the new heavy-ion beams available from the MP Tandem. The reorientation effect in Coulomb excitation, hyper-fine interactions in highly stripped ions, pulsed beams, and liquid-metal targets mounted in magnetic fields, were a few of the challenging experimental techniques he mastered in this quest. Later, this would lead to Otto achieving beautiful discoveries relating to the mesonic effects in the structure of nuclei in a collaboration that included David Ward, Faqir Khanna and Ian Towner. Otto went on to an outstanding career at Simon Fraser University and TRIUMF in 1983.

A merging of groups occurred during the mid- to late-1960's. Bob Graham, Jim Geiger and George Ewan complemented their research into the precision spectroscopy of heavy nuclei with studies of heavy-ion induced reactions, especially (HI,xn) reactions, using the newly won power of Ge(Li) gamma-ray detectors. They were joined by David Ward and later by Bob Andrews and John Hardy. At about the same time, Gordon Ball, Walter Davies, Jim Forster and, later, Art McDonald came to the MP Tandem group and brought it back to full strength and ability. It wasn't long before Doug Milton had the MP Tandem upgraded to 13MV on the terminal, and enhanced the laboratory considerably with the addition of powerful data analysis computers. New computers eventually replaced the PDP1 computer with which Chalk River had pioneered computer-based data acquisition in an accelerator laboratory. A target preparation laboratory was established, along with an experiment preparation area. A Q3D magnetic spectrometer and the on-line isotope separator were added to the experimental facilities. The sense of pride that pervaded the Tandem laboratory was an affirmation of the inspired scientific leadership of Doug Milton and Geoff Hanna.

Strong collaborations existed with researchers from Queen's University including Hugh Evans, George Ewan, Bern Sargent, Bill McLatchie, Hay-Boon Mak, Hamish Leslie, Peter Skensved and others, and with Ted Litherland and his students, including Bill Diamond, from the University of Toronto. These were later to expand to include physicists from Laval, the University of Montreal, McMaster and Manitoba. About 1970, a collaboration, including Tom Alexander, Otto Hausser, John Ferguson and Art McDonald from CRNL, and Ted Litherland and Bill Diamond from the University of Toronto, carried out a landmark study of the E2 transition rates and alpha-particle widths for the decay of the ground-state band of ^{20}Ne.
Daniel Disdier from Strasbourg, an exchange visitor, and I.M. Szoghy from Laval University contributed to the alpha scattering experiments. The experiments showed that the shell-model predictions of Malcolm Harvey described the nature of this nucleus even to the many collective-like features that were measured. The experiments, combined with the calculations of Malcolm Harvey, Ian Towner, Faqir Khanna, Paul Lee, and Ron Cusson, clearly showed that the ^{20}Ne band effectively truncated at spin 8^+, a fact predicted by the SU_3 shell model, but not the collective model. The theoretical calculations indicated that the possible 10^+ level of the structure was pushed to much higher energies and effectively

separated from the "band". This series of experiments used the powerful methods of nuclear research that had been pioneered and developed at CRNL over many years: radiative capture and the Doppler-shift attenuation methods to measure gamma-radiation widths, and resonance scattering to measure alpha-particle widths. The radiative capture experiment was the key experiment carried out with the differentially-pumped ^{4}He target and benefited considerably from improvements made to that system by Bill Diamond. John Ferguson, an expert in all aspects of these types of experiments, automated the resonance searches to make the experiments very enjoyable. There was a marvellous "resonance" of people and talent in this venture.

The Doppler-shift attenuation method had a particularly interesting history at CRNL. As early as 1948, Lloyd Elliott and Bob Bell discovered and used this method to measure the lifetime of the first excited state of moving ^{7}Li nuclei created in solid material by irradiating ^{10}B with neutrons from the NRX reactor. The method was quickly adapted to accelerator-based experiments. Later, the power of the method was greatly enhanced by Ted Litherland and his collaborators when they used heavy-ion beams and light targets to achieve high recoil velocities of the excited nuclei, and NaI(Tl) gamma scintillation counters as detectors. In ~1963, when the high resolution Ge(Li) detectors developed at CRNL by George Ewan, Ivan Fowler, and Alister Tavendale became available, the method became even more powerful. It was quickly applied by Ted Litherland and Cyril Broude. The high resolution of the Ge(Li) detectors allowed easy observation of the Doppler broadening of the gamma rays which gave line shapes characteristic of the recoiling ion, stopping medium and the mean lifetimes of the decaying nuclear states. The newly developed data acquisition systems, employing transistorized ADC's with large dynamic range and computers with enhanced memories, became available just in time to allow full advantage to be taken of the increased resolution of the new detectors. These devices were first supplied by the Electronics group, and later by commercial suppliers and by strong CRNL technical groups. Bruce Winterbon made important contributions to the analysis of these experiments through his theoretical work on stopping powers.

Following a suggestion from Ted Litherland in the summer of 1964, Ken Allen and Tom Alexander developed a new way of applying the recoil-distance method called the "plunger" method for measurement of lifetimes in the 10^{-10} to 10^{-12} second range.
Ken Allen was a summer visitor from Oxford, who knew his way around CRNL from his work there in the early days when the group was headed by Bern Sargent, and accomplished much during that summer. Geoff Hanna and Lloyd Elliott quickly knew of the plunger development and immediately assimilated the details and contributed with their knowledge and encouragement. Dr. Keys, the scientific advisor to the president of AECL, also soon knew, as he was a regular visitor to the EN Tandem laboratory. The plunger method took advantage of the high resolution of the Ge(Li) detectors to measure directly the decay curves of short-lived excited levels of nuclei traversing a small distance between a target foil and a thicker metal stopper foil. This technique bridged the gap in experimental methods between direct electronic timing methods and the Doppler-shift attenuation method and made possible direct and accurate measurement of the E3 transition in ^{16}O and other light nuclei. Joe Gallant, who became famous for his abilities to make targets for accelerator experiments, later, about 1969, devised a method to produce the exceptionally flat targets necessary for application of the method to shorter lifetimes and heavier nuclei.

The study of hyperfine interactions in stripped ions was a very interesting topic that was hotly pursued in the 1970's. One Tandem group, including Bob Andrews, Jim Geiger, Bob Graham, David Ward, Otto Häusser, and their collaborators, studied not only the transient but also the static fields created by the electrons remaining on the nucleus of a partially stripped ion. This was done by studying the time dependence of perturbed angular correlations of the gamma rays from nuclei formed in heavy-ion-beam-induced reactions and allowed to recoil into gas or vacuum. The plunger apparatus was used in some studies since the effect of the interactions could be "switched off" after a controlled period of time by the ions entering the stopper. The enormous fields created at the nucleus allowed magnetic moments of short-lived levels to be determined as never before.

As these developments occurred, there was an explosion in the number of lifetimes measured in nuclear-structure laboratories in Canada and around the world. However, Canada maintained a lead due not only to its excellent detectors but also the improved accuracy and breadth of the stopping power data, vital to the Doppler-shift attenuation method, at its disposal. A systematic investigation of stopping powers by a group, including Bob Andrews, Gordon Ball, Walter Davies, Jim Forster, Ian Mitchell and David Ward, significantly improved the accuracy of lifetime measurements. They were also to develop light-ion implanted metal target foils suitable for better exploiting the use of inverse-reactions (a heavy-ion beam accelerated onto a light- nucleus target) to produce nuclei recoiling at high velocity where the stopping powers were accurately known from their measurements. The stopping power data were intrinsically interesting aside from their use to nuclear experimenters, offering new insights into the physics and material-sciences research of Ian Mitchell and Bruce Winterbon.

During Dr. Lewis' reign, a Future Systems Working Party concerned itself with potential new AECL initiatives. Subsequent to his retirement, some of these activities were taken on by a Physics Advanced Systems Study (PASS) committee chaired for many years by Gil Bartholomew. One of the major studies of this committee concerned laser fusion, which is seen as a potential neutron source for reactor fuel breeding. An important component of this study were trips to Livermore and Los Alamos led by Arthur Ward. The director of the laser fusion, research program at Livermore, when asked what he felt could be achieved with a $5M per year program, replied that, for that money, he would be willing to send a postcard every week informing AECL of the progress being made in laser-induced fusion. AECL chose to restrict its activities to a watching brief, led for many years by Jim Geiger.

Shortly after coming on staff, John Hardy initiated the construction of an on-line isotope separator and built up a "nuclei far from stability " research group that included Vern Koslowsky, Erik Hagberg, Hermann Schmeing and, latterly, Guy Savard. The group established collaborative ties with the Queen's group, Dick Azuma at the University of Toronto, and Harry Duckworth's (later Bob Barber's) group at the University of Manitoba. The isotope separator was an unusually high resolution type ideally suited to precision measurements. Extensive work was done on the development of techniques for the He-jet transport of short lived radioactive species from a production target to the ISOL ion source. The coupled system was capable of delivering analysed beams of refractory elements with half-lives as short as 100 ms. A very fast tape transport system was developed to rapidly transport mass separated product from the ISOL focal plane, or the He-jet nozzle, to a radiation detector station. Studies included the level schemes of nuclei far from stability, delayed proton and alpha decays, nuclear mass measurements, and the weak interaction; most notably superallowed beta decay, where measurements of outstanding accuracy were performed. This work had the benefit of a strong collaboration, on the theory side, with Ian Towner. The group's work provides our current best value for the V_{ud} element of the Kobayashi-Maskawa matrix.

Malcolm Harvey, Faqir Khanna, Paul Lee, Ian Towner, and their collaborators were very interested in the rapid developments occurring in particle physics from 1970 on. Their primary interest was in understanding the role the quark structure of the nucleons played in determining the structure of the nucleus.

In 1974 Dave Earle and Art McDonald dealt remarkably quickly with a claim that a two-photon decay mode had been observed in addition to the single 2.2 MeV gamma decay associated with the radiative capture of n+p. They set an upper limit of $5*10^{-6}$ for the two photon branch. Later in their careers Dave became a participant in the SNO project with major responsibilities relating to the heavy water vessel and Art, then at Queen's University, became SNO Director.

Consideration was given to the addition of a post-accelerator in the early 1970's, and it was these discussions that prompted Bruce Bigham and Harvey Schneider to come up with their proposal for a superconducting cyclotron. The Accelerator Physics Branch went on to develop the concept, test a full scale superconducting magnet, and later to construct the cyclotron for the TASCC facility.

About 1980 David Ward proposed the building of a large 4π array of Compton-suppressed germanium gamma-ray detectors to support the studies on high-spin states in nuclei. Bob Andrews and Otto Hausser were collaborators in the conceptual phase and Vern Koslowsky and Hermann Schmeing, who became intrigued by the discussions of possible designs for the instrument, came up with the geometric design that was adopted.

The timing roughly coincided with the start of construction of the superconducting cyclotron facility. With the passage of time the accelerator-based work had become a dominant portion of the basic research at AECL, and university collaborations played an important role in these activities. The nuclear physics research was seen increasingly as a "National Laboratory" function. Despite increasingly stretched financial resources, AECL found the funds to support the addition of a superconducting cyclotron post accelerator to the tandem accelerator facility, but indicated that staff would have to look elsewhere for funds for major experimental equipment.
David Ward and Bob Andrews established a collaboration with Jim Waddington of McMaster University and Paul Taras of the University of Montreal to seek the major portion of the funding for this "8π spectrometer" from NSERC. Their efforts were successful, and the instrument they designed and built proved to be the pre-eminent instrument in the field for a decade or more and attracted scientists from both the USA and Europe to the laboratory as users. David Radford joined the group, bringing unique expertise in computerized analysis of the spectrometer data, and Gordon Ball became active in the group.

Fig. 2 This 1987 photograph shows the 8π spectrometer at the temporary location it occupied in Target Room 2 prior to the funding of Phase 2 (completion of work on two new target rooms and installation of the beam lines) of the TASCC project. Paul Taras (University of Montreal) is seated at the data acquisition computer terminal and David Radford is looking into the oscilloscope on the left. David Ward (left) is touching the spectrometer, open for target inspection, with Xuan Tran, a technologist from McMaster University, looking on.

Many experiments could be carried out with relatively modest manpower requirements and the group, together with their many visitors, were able to effectively use large blocks of accelerator beam time. Victor Janzen contributed to the work, first as a postdoc and later as a staff member. Angular momentum coupling and superdeformation were areas of concentrated investigation. Alfredo Galindo-Uribarri, who did an important part of his thesis work on the 8π when a graduate student of Tom Drake at the University of Toronto, developed a particle detector mini-ball that fitted into the ample 8π target chamber cavity and permitted particle-gamma coincidence measurements. Experiments by Alfredo provided the first evidence for hyper-deformed rotational states in rare-earth nuclei.

Dag Horn worked closely with René Roy and Claude St. Pierre of Laval University and Tom Drake in establishing a charged-particle reaction-mechanisms program at the TASCC facility. David Bowman later came on board to support these activities. This program was blessed with, and provided the training ground for, a large number of Laval University graduate students.

A ^{14}C dating program was started under Bob Andrew's initiative and had Doug Milton, Walter Davies, Vern Koslowsky, Barrie Greiner, Yoshio Imahori and Gordon Ball, with Jack Cornett, Gwen Milton and Bob Brown from the Environmental Research Branch, as participants. In its later stages, the program expanded to include ^{36}Cl and ^{129}I studies. In the course of the ^{14}C studies it became apparent that the ^{14}C levels at the Chalk River site were considerably above normal, and further study led to enhanced understanding of the production and migration of this reactor product. The ^{129}I dating proved to be a technique applicable to nuclear non-proliferation safeguards work. In addition, the surprising result that ^{36}Cl was present in spent fuel in significant amounts, and in the long term would become one of the dominant activities, was revealed.

Jim Forster led a program that applied ion channeling techniques to fission lifetime measurements and materials analysis, with superconducting material being a focus of interest in the final years.

In 1986 AECL underwent a major reorganization, with Doug Milton assuming the position of Vice President Research and TASCC becoming a Division, with two branches, under John Hardy. The Operations group became the TASCC A&D branch under Neil Burn, later Hermann Schmeing, and briefly under Bill Diamond. Nuclear Physics under Jim Geiger formed the other branch. In keeping with its "National Laboratory" role, the laboratory instituted External Program Reviews and a TASCC staff position was established at McMaster University and filled by Stephane Flibotte. In order to defray some of the operating expenses of the facility, staff sought out clients who would purchase beam time on the facility at commercial rates and provided support to these clients during their runs. Jim Forster and Bob Andrews were major players in this activity.

The last major TASCC initiative was the ISOL group's Penning trap proposal championed by Guy Savard and carried forward as a collaboration with Kumar Sharma and Bob Barber of the University of Manitoba and John Crawford, Johnathan Lee, and Bob Moore of McGill. While construction and installation of this facility were completed before the TASCC closing, commissioning was not.

In the mid-1990's AECL found itself facing a serious financial crunch. Several research programs were cut, and the neutron scattering and TASCC programs were forced to seek alternative government funding to support their operation. John Hardy made a valiant effort to gain this support for the TASCC programs but was ultimately unsuccessful, and the TASCC laboratory was closed in 1997. (The neutron scattering program transferred from AECL to NRC under an interim three year funding arrangement.) Of the major pieces of experimental equipment, the 8π spectrometer went to the Lawrence Berkeley Laboratory and is just now on its way to ISAC (the new radioactive beam facility at TRIUMF), the Penning trap is now at the Argonne National Laboratory, and the charged particle detector array is at Texas A&M University. In each case they continue to be used by the university consortia that championed their construction. The particle group's earlier detector array has gone to the National Accelerator Centre in South Africa. Some components of the on-line separator went to ISAC and some Tandem ion-source components to the University of Toronto.

Perhaps the most important contribution that the basic research made to AECL was its role in providing AECL with a high international profile. Chalk River placed Canada on the map as far as nuclear research is concerned. Many of the Canadians currently active in subatomic physics had their initiation at Chalk River. Above all, the work at Chalk River demonstrated that a small country can, with a dedicated effort, be at the top of the world in excellence in research and development. The spirit that encouraged and brought out the best a young researcher could achieve, started in the first days of the laboratory, was very much alive in the TASCC Division well into the 1990's. The challenge to future generations is to match or surpass the Chalk River achievements. The memory of the glory days of Chalk River will remain with those who were privileged to play a role in the laboratory's activities.

ACKNOWLEDGEMENTS

We have short changed many of our friends and especially our technical colleagues who outnumbered the physicists by a large factor. They made outstanding contributions to the science. Our acknowledgement is inadequate but sincere.

This article is limited to activities that the authors felt competent to cover; it is not intended to be a comprehensive history. We apologize for any omissions. We appreciate the work of former colleagues in reviewing the draft article.
Some material was extracted from a manuscript by Faqir Khanna.

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LLOYD GEORGE ELLIOTT, 1919 - 1970

Lloyd Elliott provided outstanding leadership to physics research at the Chalk River Nuclear Laboratories (CRNL) for two of its finest decades. He was born in Clarence, Nova Scotia (the same town in which John Stuart Foster was born, three decades earlier), in 1919 on the family farm in the Annapolis Valley. A brilliant student, he graduated from high school at 15 and from Dalhousie University at 19. By the time of his Ph.D. degree from the Massachusetts Institute of Technology (M.I.T) in 1943, he was already the co-author of ten papers. He then moved to the Montreal Laboratory and soon after to Chalk River, where he spent the rest of his career.

Lloyd G. Elliott

(Photograph reprinted with permission from *Proceedings of the RSC*, 1971, fourth Series, Volume IX, p. 51. Copyright 1971, Royal Society of Canada.)

In the early years of Chalk River, Elliott collaborated with Bob Bell on a precision measurement of the deuteron binding energy, which led to a significant revision in the binding energy of the neutron. They also were the first to measure very short gamma ray lifetimes (less than a picosecond). The interest he had developed at M.I.T on beta ray spectroscopy and spectrometers for this purpose continued at CRNL. Continuing on his precocious trajectory, Elliott was elected to the Royal Society of Canada at age 30 and, in 1951, at age 32, was chosen as head of the physics division at CRNL.

Elliott contributed a great deal to the flow of fine physics from CRNL during the 1950's and 1960's. Although not usually directly involved in Chalk River experiments, he had a strong drive to fully understand all of the greatest current issues in nuclear (which he pronounced "nucular") and neutron physics. He had very high standards for science and was excellent at choosing world-class physicists and outstanding research directions. Whenever a major new development in science occurred - for example the discovery of lasers or of parity violation in the weak interactions - he was relentless in achieving an understanding of it, by himself and his colleagues, and of assessing its potential impact on the CRNL program. He was somewhat shy and more formal than the free-ranging cast of characters he directed, but his leadership managed to get the best out of the laboratory. All oral presentations at conferences by CRNL physicists were carefully rehearsed, and all published papers carefully read. Everyone who worked or collaborated with Elliott admired him greatly and were very saddened at his premature death, in 1970, of a heart attack while swimming. He came to swimming late in life but pursued it, like everything else, with great intensity, even undertaking swimming under the ice. He epitomized the finest traditions at Chalk River and his precocious trajectory blazed out, like a shooting star, much too early.

In 1971, the Canadian Association of Physicists (CAP), very appropriately, named the University Prize in honour of Lloyd G. Elliott. The CAP University Prize Examination, a nation-wide competition for senior undergraduates studying physics, recognizes individual scholarship and seeks to stimulate academic excellence in Canadian universities. These are basic components of the philosophy that made Lloyd Elliott so wise a leader in the Canadian physics community.

Elliott created a stimulating and challenging environment where scientific achievement was certainly the driving force, but he always emphasized that the activities of scientists depend on a degree of public understanding that can only come from improved education at all levels of society. Thus the CAP recognized the very fundamental importance of education, as well as outstanding academic achievement, in naming its University Prize in honour of Lloyd Elliott.

by Erich Vogt, Professor Emeritus
University of British Columbia
and Francine Ford, Executive Director
Canadian Association of Physicists

NEUTRON AND OTHER STORIES FROM CHALK RIVER

by William J.L. Buyers

Here are a few stories about just a few of the scientists that I know something about. It is a personal selection that illustrates how great doers worked with simple means.

BERTRAM BROCKHOUSE

Bert Brockhouse is AECL's most famous pioneer in the field of science. The neutron was 18 years old[1] when he arrived at Chalk River. Donald Hurst, who hired him, and who passed away in 1999, had already built a neutron diffractometer at NRX, and told Bert to do something interesting with neutron beams. He did.

In 1950, Atomic Energy of Canada Limited (AECL) hired a scientist who created a new field of science using thermal neutron beams, and who was co-winner of the 1994 Nobel Prize in Physics.

The triple-axis spectrometer he invented showed that thermal neutron beams from a reactor could reveal the motions of atoms and the precessions of their atomic magnets. Today neutron scattering applications have expanded well beyond physics to encompass chemistry, biology, earth sciences, materials science, and engineering. Only because Bert built a laboratory in fundamental neutron science was it possible for these practical applications to emerge. Of course, he did not "build" a laboratory - he simply did the next experiment that needed doing. He was filling in pieces of what he has called the "Grand Atlas" of the physical world. [1]

Long before the triple axis spectrometer, one of Bert's first experiments, with Myer Bloom and Don Hurst, verified, through scattering, the famous Breit-Wigner formula for heavily absorbing elements. Myer Bloom, who came as a summer student that year and worked on this tough topic, relates that Bert had to finish the project off for him. Later Bert and Don observed the effect of thermal vibrations on the scattering cross-section of light and heavy elements (aluminum, graphite and lead). To do this a beam of 0.35 eV neutrons, of which there are only a few from a reactor, was scattered through a right angle by the material and then travelled through cadmium before reaching the detector. Now cadmium is almost black to slow neutrons - it is used to block the beam! However, because its absorption varies inversely as the neutron velocity, the cadmium transmitted fewer neutrons if they had been scattered with reduced velocity. A low velocity showed that the neutrons had lost energy by creating phonons. This was the first quantitative experiment in slow neutron spectroscopy and was published in *Physical Review*. [2]

By 1951 scientists in France, Britain and the U.S.A. had started to build time-of-flight spectrometers to measure the speed of the neutron before and after scattering. Brockhouse and Hurst thought that a time-of-flight spectrometer would be too technically demanding, and they decided to build a crystal spectrometer. Keeping things simple, a Brockhouse characteristic, was a wise choice. A war-surplus Bofors gun mounting was adapted for the crystal table. If he had chosen instead to spend lots of money, he might not have taken the path that led to the triple-axis crystal spectrometer, to his seminal discoveries, and ultimately to Stockholm.

How does neutron scattering directly reveal the

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[1] If the neutron had not been discovered by Chadwick in 1932, it would have been invented, according to Bert Brockhouse.

structure and dynamics of materials? One neutron property is the basis for diffraction, elastic scattering, and structure determination:

> *The wavelengths of neutrons from a fission reactor moderator are a beautiful match for the typical spacing between the atoms in materials.*

Bert Brockhouse focused on another beautiful property of neutrons from a reactor:

> *The neutron energies are a very good match to the energies of atoms as they vibrate about their equilibrium positions.*

When a neutron is scattered, it can give a kick to, or be given a kick by, the moving atoms. It can then leave the sample at lower or higher speed and in a different direction than the elastic Bragg scattering. A vibration of a crystal lattice is similar to a sound wave, but its wavelength can be as short as the distance between atoms.

The frequency of such atomic vibrations is extremely high, more than a THz (10^{12} cycles per second) or tens of meV in terms of energy. Bert and others realised that if the frequency of atoms in solids could be measured it would give the force or spring constant between two atoms. To determine the interatomic forces directly would represent a major breakthrough in our understanding of all kinds of condensed matter.

For short vibration times, that is, for high frequencies, the neutron energy will undergo a large shift, while, for motions involving long times, the neutron energy shift will be small. This is similar to the diffraction from structures, where the diffraction pattern is big when the spacing is small. So the world of scattering is somewhat like what Alice saw through the looking glass - the reciprocal of the world of space and time. Bert was very good at touring his visitors through the concepts of neutron science. His colleague, Guiseppe Caglioti, who returned home to build the neutron program in Italy said [3]

> *"Brockhouse was a real Cicerone to all the subtleties of reciprocal space, for all the researchers converging to his group from Canada and from all over the world."*

The first reliable measurement of the spectrum of phonons, the name for quantized vibrations of a crystal, was made in 1955 for aluminum. It was an unequivocal demonstration that short wavelength vibrations existed in a metal. By 1958 Brockhouse had published the most complete set of data for all three symmetry directions in aluminum. He succeeded partly because he could select the momentum with the triple-axis crystal spectrometer, and partly because Chalk River then had the highest flux of thermal neutrons in the world.

One of Bert's collaborators was Alec Stewart who became an international leader on positron research in solids. At Chalk River, scientists Alec Stewart, Bob Bell, and Bob Graham were the first to have shown that positron annihilation could be a useful tool in solid-state research. They discovered, by 3-photon coincidence, that long-lived positronium formed in interstitial positions in amorphous insulators, thereby confirming an earlier conjecture by Bob Bell, Bob Graham and Howard Petch that was based on the less direct observation of a long lifetime. When NRU went down for a period, Alec Stewart, on leave from Chalk River at Dalhousie University, supervised an M.Sc. student called Ralph Green. Their measurements were the first to clearly show that the angle between pairs of gamma rays arising from annihilation of free positrons with electrons was a measure of the electron momentum distribution in solids. Ralph went on to become Vice-President for Research at AECL. Alec pioneered this angular correlation method, now in use throughout the world, and applied it later at Chapel Hill and Queen's University. But his first love had been neutrons. Alec's seminal article on neutron scattering, with Bert Brockhouse, in *Reviews of Modern Physics* [4] helped bring scientists from all over the world to Chalk River to work in Bert's small group.

I read the Brockhouse and Stewart review with amazement while I was a graduate student in Scotland. I had just completed years of hard thesis work to derive the phonon frequencies in rock salt from the intensity of X-ray scattering. In order to obtain the one-phonon thermal diffuse scattering I had to subtract large corrections for Compton, multiphonon, absorption and background effects. The intensity had also to be put on an absolute scale. Only then could measurements at two equivalent momenta be combined to extract the acoustic and optic modes of this diatomic, but simple, crystal. Bert and Alec's review showed that phonon peaks could be seen directly in the neutron spectrum since the spectrum of scattered energies could easily be analysed. It seemed they only had to plot their data by hand to get a dispersion curve ready to be sent off to the journal. I could not believe that life could be so simple, so I came to Chalk River and found out it was true! Neutron scattering was really easy.

Fig. 1 Bert Brockhouse looking at the triple-axis spectrometer. The neutron beam comes from the left out of a large shielded drum containing the monochromator. The cryostat and analyser arm are carried on a Bofors gun mount driven by steel belts. To the right is the shielding around a long BF3 neutron detector. The "swipes" were taken not by frustrated physicists, but by health surveyors ensuring that the shield was clean.

By 1959 Bert had built a Constant-Q triple axis spectrometer (Figure 1) which could be programmed to look for an excitation at a controlled momentum, Q, and independently scanned to find its energy. There to help him was Bill McAlpin who, with his Scottish upbringing on the Clyde, designed spectrometers to battleship standards; some are still running today. The Brockhouse Triple-Axis Constant-Q spectrometer is now in use at every major international neutron laboratory. Its advantage is that it is flexible enough to be adapted to a wide variety of experiments. Bert also built the first Rotating Crystal Spectrometer. It used time-of-flight to measure the velocity and therefore the energy of the neutrons before and after scattering. Scientists returning to their own countries built instruments based on what they saw at Bert's laboratory.

"Programming" of a triple-axis spectrometer was initially done by an array of 52 rotary switches preset to go through an energy scan of 26 points. An ac motor drove the primary monochromator angle linearly in increments of multiples of 1/8 degree. Two secondary motors were slaved to it by steps set by switches that could be varied throughout the 26 steps, so as to approach closely the non-linear solution of the constant-Q equations. Even stepping motors and encoders had a 1950's analogue. A motor drove each angle with a steel belt that carried a cam with peripheral indentations into which a relay could drop and give a pulse. When the number of relay pulses reached the number set on the 52-switch controller, the motor power was switched off. At an international conference where this non-linear control was reported, it was jokingly described as a triumph of experiment over mathematics. One of the best things about Bert's large "programming" box, was that his technician, Ed Glaser, got it going in six months. Today, I don't think you can interface a control system to any complex device nearly so fast. Besides, there are protocols to write, environmental assessments to obtain, project managers, accountants, human factors, ... It was a lot easier to get things done then!

Just as the neutron can scatter from nuclei, its magnetic moment enables it to scatter from the atomic magnetic moments carried by the spin of the electrons in solids. In 1958 Brockhouse carried out the first application of crystal spectrometry to a magnetic system. Bert showed that, in magnetite, "the excitations were in the spin system itself", a result that first confirmed theoretical predictions that the spin excitations occurred in quantized packets called magnons.

The discoveries of the existence of phonons in metals and of spin waves in magnets were qualitative breakthroughs. Today we are more concerned with quantitative science, where the conceptual framework has largely been established. Bert was always concerned as to whether a new concept would remain on the map of the physical world or would disappear with time. Most of his ideas are still with us.

Today neutron beams and instruments are found in large laboratories visited by "users" from the universities and industry. Compared with Bert, who invented new instruments and did the science at the new frontier, today's scientists can be said to have a "free ride". They should be glad he cut a path through the jungle.

After he arrived, in 1958, Dave Woods was Bert's closest collaborator. Bill Cochran came from Cambridge for a year's sabbatical and, with Dave and Bert, developed the famous "shell model" for lattice vibrations. [5] This Woods-Cochran-Brockhouse shell model has nothing to do with the nuclear shell model, but is a simple way of seeing how the movement of each atom polarises its outer shell of electrons so as to communicate the force to the next atom by distorting its shell. Prior to that even the simplest alkali halides could not be understood because their short wavelength vibrations were much softer than expected from a simple Hooke's Law (Born-von Karman) effective force between the atoms. The Cochran theory also accounted for the Lyddane-Sachs-Teller relation between the optical mode vibration frequencies and the dielectric constant. Yes, Teller did a few things other than design bombs!

During the years at Chalk River, before he went to McMaster in 1962, Bert was well known as a singer. He took part in the local Gilbert and Sullivan productions. And he was known to wander about the reactor hall exercising his vocal chords to the surprise of the operators in white overalls. He is said to have occasionally practised on the midnight bus going back from "the Plant" to Deep River.

Bert trained many fine students. According to Eric Svensson, he would get them in a room and tell them what they had to do to succeed at physics using the Brockhouse Rule:

"An experimentalist has to get his data right."

(Some of the students thought this meant it was all right to screw up the analysis!)

and the Brockhouse Manifesto:

1. *Being a Graduate Student is not a 9 to 5 job.*
2. *Necessary work takes precedence over coffee breaks and reading newspapers.*
3. *Use your intuition if you have a good one! This can save you all kinds of messy algebra that you might get wrong anyway.*

Anyone who talked with Bert knew he had superb intuition. Bert's work led to a present community of about 10,000 neutron users world-wide who continue to be starved for strong neutron sources. The proposed Canadian Neutron Facility will meet part of the need, particularly in North America following the 1999 announcement not to restart the High Flux Beam Reactor (HFBR) at Brookhaven.

ROGER COWLEY

In the early 1960's Bill Cochran sent his graduate student Roger Cowley from Cambridge to Chalk River to do some of his thesis research on the ferroelectric $SrTi0_3$. Watson had much earlier asked Cochran, the Cambridge expert on X-ray diffraction, what might cause the strange spots on his X-ray pattern from DNA. Cochran is said to have replied "have you tried a spiral?" For ferroelectrics, Cochran had surmised that their transitions on cooling to a phase with a net ordered electric dipole moment, were caused by the softening of a lattice vibration frequency. Roger Cowley obtained the neutron data that proved this. Moreover he brilliantly developed the theory of anharmonic interactions of phonons in crystals into a practical form, where he could calculate the dynamics of phase transitions, the renormalization of phonon energies and lifetimes, and the specific heat and thermal expansion. [6] This theory accounted for the temperature dependence of not just ferroelectrics, but insulators and metals.

Roger returned to Chalk River as a research scientist in 1964. With Gerald Dolling, who had worked with Bert on semiconductors, the first magnon-phonon coupling was observed, in uranium dioxide (a highly appropriate material to work on at Chalk River!). With others at Chalk River, the zero point fluctuations of antiferromagnets were seen, and the fundamental studies of magnetism were begun. With Dave Woods, Roger mapped out the spectrum of the quantum fluid liquid helium, and found the two-roton scattering.

From what is now called deep inelastic scattering, they obtained the first hints of the zero-momentum condensate of Landau, whose magnitude was later obtained accurately by Eric Svensson. In 1970 Roger took up a Chair at Edinburgh University. He is now head of Physics at the Clarendon Laboratory, Oxford, but maintains to this day a Chalk River connection.

When equipment like the early temperature controller did not seem to work, Roger would walk away saying "there are some things I choose not to know about". He could afford this luxury because technical experts like Harold Nieman and Ed Glaser were around to solve such problems. One of the technicians was Rick Dutkiewicz, whose fame came not through neutrons but later as bass guitar in the Gordon Lightfoot band.

JOHN HILBORN

Most physicists like to work on exotic ideas like the non-linear sigma model, rather than solve the problems encountered in inventing, developing and building a research reactor. A person who got interested in physics after learning on his first job how to measure radioactivity in the Eldorado Mine at Great Bear Lake is John Hilborn. John got the job by responding to an advertisement in the Globe and Mail. After an interview in a booth at the 1949 Canadian National Exhibition, John headed north. In those days you had to make your own Geiger counters from glass bodies and find a gas filling that worked.

John belongs to the breed of reactor physicist-designer who relied primarily on simple hand calculations and intuition rather than on complex computer models. A lot of reactor design is knowing about plumbing and water flow as well as the behaviour of neutrons. The SLOWPOKE - a reactor with a passive safety system, natural convection and only one moving part - is his invention.

The SLOWPOKE story starts in Los Alamos, with the publication of a paper describing a beryllium-reflected critical assembly requiring less than 300 grams of U-235. This surprising result led John Hilborn to the conceptual design of the SLOWPOKE research reactor. Conceived as a simple, low-cost neutron source, SLOWPOKE is a Canadian compromise. It was smaller than the American TRIGA reactor, but powerful enough to play an important role in teaching and research at five Canadian universities and one in the West Indies, from the early 1970's to the present day. At a power level of only 20 kW, SLOWPOKE produces a thermal flux of 10^{16} n/m^2.s at five sample sites. The resulting ratio of neutron flux to fission power is the highest of any research reactor in the world. The unique core design is such that the reactor is inherently safe with respect to the most common mechanical and electrical faults. Consequently it requires only one motor-driven control device which is automatically activated by one neutron detector. There are no additional safety devices, and no pumps since it is convection cooled. The reactor is continuously monitored at a remote location to operate and is licensed to operate without a person in the reactor room. The power level is intrinsically limited to safe levels.

John recalls he had some anxiety during the final testing of the prototype at Chalk River. These tests were designed to prove the SLOWPOKE did not need an engineered safety system. But to carry out the tests, the reactor was provided with conventional engineered safety devices that would shut the reactor down instantly before the power reached dangerous levels. The tests proved beyond doubt that SLOWPOKE's inherent safety characteristics were entirely adequate and agreed with predictions. The engineered safety system was unnecessary and could be removed. John did not get much sleep the night before that action was scheduled to take place. Had they thought of all possibilities? Had they overlooked anything? After all, no nuclear reactor had ever been operated without an engineered emergency shutdown system. The redundant safety devices were duly removed, the final tests were completed as planned, and for almost 30 years all of the subsequent SLOWPOKE reactors have operated safely and reliably.

The original fuel was an alloy of highly enriched uranium and aluminum that would last about 20 years. Each reactor core required approximately one kilogram of enriched uranium, which was obtained from the United States under long-standing agreements. However, when the core for Jamaica was ready for shipment, the U.S. State Department suddenly intervened, claiming that the proposed sale of highly enriched uranium violated their policy of non-proliferation. They wanted AECL to use a low-enriched fuel that had just been developed at the Argonne National Laboratory. When the Canadians pointed out that the physics of the core did not permit the use of the Argonne fuel material, they suggested that AECL's calculation must be in error. It was not. After a year of wrangling, AECL agreed to develop a special low-enriched fuel for all future SLOWPOKE reactors provided the ready-and-waiting enriched core for the Jamaica reactor could be released for shipment. In retrospect the action of the State Department turned out to be a blessing in disguise. The new low-enriched fuel, designed specially at Chalk River, not only works, but has been found to be technically superior to the original SLOWPOKE fuel.

AECL's Commercial Products Division (later Nordion International) manufactured and installed eight SLOWPOKE reactors, but, in spite of intense marketing efforts, they were unsuccessful in selling SLOWPOKE internationally. The larger and more costly TRIGA reactor dominated the market, and we can only speculate that, if SLOWPOKE had been available ten years earlier, many more SLOWPOKES would have been sold. It is somewhat ironic that China never purchased a SLOWPOKE reactor, but has been marketing a close copy of SLOWPOKE for the past ten years.

John also invented the Self-Powered Neutron Detector, a simple solid-state device for monitoring thermal neutron flux inside a nuclear power reactor. At Ontario Hydro's CANDU generating stations they are known as Hilborn detectors.

He read about this device in a Russian scientific journal and, by choosing suitable materials that could with-stand the intense radiation, adapted it for measuring neutron flux inside a nuclear reactor. Within a few days he was able to test a simple prototype in the NRX reactor at Chalk River, and was amazed to discover that it produced a direct current of microamperes without amplification. Within a few months he measured a neutron flux profile in the NPD power reactor [2]. To carry out that kind of prototype development and in-reactor testing today would take years of preparation and a mountain of paperwork.

The device itself is incredibly simple. In essence it is a coaxial cable a few millimetres in diameter, comprising a central wire, ceramic insulation, and a metal jacket. When exposed to thermal neutrons, the central wire becomes radioactive and emits energetic electrons (beta particles) which penetrate the insulation and generate a continuous direct current proportional to the neutron flux. If the half-life of the emitter material is short, the electrical signal from the coaxial cable will rise and fall with the neutron flux and power of the reactor. The speed of the response is enhanced by secondary electrons from prompt neutron-capture gamma rays.

John Hilborn was co-founder of a Canadian company that manufactured and sold Self-Powered Neutron Detectors under a government patent. The company is still in business today in Cambridge, Ontario. Meanwhile, other physicists continue to work on the non-linear sigma model! Both kinds of activities are of course worthwhile.

BORIS DAVISSON [7]

One of the important figures in the development of the CANDU reactor was Boris Davisson, who taught reactor physics at the University of Toronto to a generation of nuclear engineers in the 1950's and whose book Neutron Transport Theory [8] became the definitive treatise on the subject. Boris had an unusual background. Born and raised in Leningrad of a Russian mother and a Scottish father, Boris was somehow allowed to leave the Soviet Union in the late 1930's to study theoretical physics with Rudolph Peierls in Birmingham, England. In 1944 he joined the British-Canadian Atomic Energy Project at NRC's University of Montreal Laboratory, which shortly thereafter moved to the new Chalk River site. Boris returned to the U.K. in 1947 to work at the Atomic Energy Research Establishment in Harwell. Although non-political, he later fell victim to the cold-war hysteria that followed the Klaus Fuchs incident in Britain. No longer welcome in Britain because of his Russian background, nor in Russia because of his British background, Boris returned to Canada in 1954 at the invitation of the Head of the Physics Department at the University of Toronto, W.H. "Willie" Watson -- another expatriate Scot who had earlier been head of the Theoretical Physics Branch at Chalk River. Boris visited Chalk River frequently to collaborate on research with Steve Kushneriuk and others until his untimely death in 1961.

BRUCE BIGHAM

In the early 1970's, the Nuclear Physics group asked Accelerator Physics to develop a booster for the Tandem. They wanted to add energy of about 10 MeV/nucleon for heavy elements like uranium and up to 50 MeV/nucleon for lighter elements. There were several possibilities, but few that could be done simply and cheaply. In 1972, Harvey Schneider went to a magnet conference and heard some new ideas on how to make stable superconducting magnets that would not quench. One idea was to twist the superconducting filaments on the magnet winding. Harvey realised that it should now be possible to make an affordable superconducting cyclotron with an average field in the 5T region. John Fraser, Harvey Schneider and Bruce Bigham took the idea to the experts at Michigan State University (MSU) where Henry Blosser was very sceptical. Within months, however, he had his own project going at MSU and Chalk River co-operated with him throughout the 10 years of design and development.

Around that time Harvey and Bruce patented an idea for a small cyclotron for cancer treatments, with neutrons mounted on a gantry so that it could be rotated. It gave a forward beam of neutrons from

2. The small Nuclear Power Demonstration reactor, a short distance west of Chalk River at Rolphton, was the first reactor to supply power to the Ontario grid.

25 mA of 30 MeV deuterons on an internal target of beryllium. Henry Blosser built a similar one under licence from the Chalk River group that has treated prostate cancer patients in Detroit.

For the booster for the Tandem, Bruce and Harvey had to explore the options more widely than experienced builders, and this led to some unique features. They shimmed the magnet with an array of adjustable rods instead of coils. Clarence Hoffmann's extraction channel used both iron and superconducting coils to cope with the wide range of beam parameters. The RF accelerating structure is the only one to have had up-down resonators operating in 0 or π mode (the asymmetry averaged out for the beam) and the plunger for tuning them had unique sliding contacts. No one else managed to use a "weak" copper liner over the steel poles with a guard vacuum outside. The trim rods and the up-down resonators are unique to the Chalk River design. All of these features kept the cost down yet met the required wide range in operating parameters.

Isochronous cyclotrons are very intolerant of imperfections, requiring very careful trim rod settings. To change to a different ion requires changing the frequency, the field, and the field profile to take care of relativistic effects. A control computer was used to do this. With it Bruce Bigham spent many nights trying to set up beam patterns like that of the very first beam that had been accelerated, which John Ormrod had set up by field mapping. Bruce recalls that it wasn't until after he retired that Nathan Towne discovered the small error in the set-up software that had defeated him.

The robust magnet is probably the only one of the superconducting cyclotron magnets that never had a quench. This says something for Harvey's careful coil design and John Hulbert's cryogenics.

Like many others, Bruce is disappointed that, after the nuclear physics program was shut down in 1997, the Tandem Accelerating Superconducting Cyclotron (TASCC) facility was not converted to a proton therapy facility. He believes it would have cost little more money than it took to cut the cyclotron into small pieces and clear out the building. However, Bruce and the entire Chalk River accelerator team should take pride in their tremendous achievements, ever since the heady days of the Intense Neutron Generator in the 1960's, in the science and engineering of high-performance accelerators. To this day no nation has built a spallation neutron source that can come even close to the 65 MW power and steady-state 10^{20} n/m^2.s flux of the proposed ING design. The forefront today is only 2MW of pulsed neutrons from the spallation source that has just started construction in Oak Ridge at a projected cost of US$ 1.3 billion.

MORE PHYSICS STORIES FROM CHALK RIVER.

Many of the Chalk River physics highlights may be found in "Canada Enters the Nuclear Age" [9], and in histories of theoretical physics [10] and of accelerator physics [11].

ACKNOWLEDGEMENTS

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WILFRED BENNETT LEWIS, 1908 - 1987

In the past century of Canadian science no leader was more Napoleonic than W.B. Lewis, with his grand visions and major projects, with his single-mindedness in achieving his objectives, and with his enormous capacity for work and his great technical ability. In his twenty-seven years at Chalk River, Lewis was the leader who accomplished the development of CANDU which many of us regard as Canada's greatest scientific achievement of the century.

Wilfred B. Lewis
(Photograph reprinted with permission from *Transactions of the RSC*, 1998, Volume **III**, p. 163. Copyright 1998, Royal Society of Canada.)

Lewis was born in Cumberland in northern England, on June 24, 1908, to a family with strong engineering traditions. He entered Cambridge university as an undergraduate student in 1927 and became a graduate student in Rutherford's Cavendish laboratory in 1930. His forte in graduate work was his great knowledge of electronic circuit theory. This equipped him well for his outstanding work in WWII as a leader of radar development at the Telecommunications Research Establishment in Malvern in the Midlands of England.

The appointment of Lewis, in September 1946, to replace Sir John Cockcroft as the scientific head of Chalk River was an inspired choice. The outstanding scientific staff had recently moved from Montreal (see Wallace's article on the Montreal Laboratory in this issue). Critical choices had to be made immediately about the direction of the reactor research. The ambitious CANDU plan emerged. It was technically challenging and required outstanding leadership. Lewis was that leader. During the following 27 years, he dominated CANDU and Chalk River.

Lewis had fine scientific sensibilities and wonderful technical skills and intuition. He built the finest electronics group anywhere and he appreciated that the solution of CANDU's metallurgical problems required the combined skills of the world-class scientific team which he led. He nurtured the team's fundamental research, but brought their brains to bear on CANDU's problems.

Lewis, in search of the solution to a technical problem, was, to the observer, a magnificent natural phenomenon. He assembled the necessary team. He aggressively led the probing of the pertinent questions. A speaker with wishy-washy responses could be led to tears. However, suggested improvements or clear proofs that Lewis' intuition was wrong were gratefully acknowledged. Progress came. CANDU prospered.

Lewis always rushed around carrying two full briefcases and personally became involved with almost every scientific pursuit or paper at Chalk River. He shuffled along like a dishevelled English schoolboy. Apart from minor digressions - into determining the selection of books for the Deep River library and in racing, unsuccessfully, his Y-flyer sailboat - his whole life was devoted to his work at Chalk River. For Lewis, only one gender existed for professional appointments at CRNL: he never married and counted on his mother and then his sister to make his personal life comfortable.

Like Napoleon, he rarely failed. In his last decade at Chalk River he promoted electric breeding (the ING project) as a new major undertaking for Chalk River. It was not to be. Ernest Lawrence's exceptional efforts in the 1950's were not sufficient to overcome the ferocious technical problems for the accelerator and the target of an electric breeding system. It is not clear that Lewis could have succeeded in building ING in the late 1960's, even if Canada had funded it. (Recently Carlo Rubbia has devoted his exceptional skill to this dream and even now it may be too big a challenge).

Lewis received many awards and distinctions, commensurate with his accomplishments. It is sad that this great man was afflicted, at the end of his life, with Alzheimer's disease and that, after his retirement, Chalk River did not continue to have the great scientific leadership which Lewis provided.

Erich Vogt, Professor Emeritus
University of British Columbia

EMERGENCE OF PHYSICS GRADUATE WORK IN CANADIAN UNIVERSITIES 1945-1960

by Mel A. Preston and Helen E. Howard-Lock

In the decade following World War II, the Canadian university community experienced a most dramatic phase change. In 1945, as the war ended, there were 28 universities in Canada; of these, only two, Toronto and McGill, were research institutions with established graduate programs leading to the Ph.D. degree. Even in these two universities the enrolments were hardly what now would be considered academically viable. In the 20 years, 1920-1939, the University of Toronto granted 231 Ph.D. degrees, of which only one or two per year were in physics. In 1941 the total doctoral student enrolment in all departments at McGill was 100, and at Toronto, 140. Most of the other universities offered masters' degrees and some granted an occasional doctorate -- in 1925, Queen's gave its only physics Ph.D. in the twenty-year period.

> In the decade following World War II the Canadian university community experienced a most dramatic phase change. In 1945, as the war ended, there were 28 universities in Canada. By the mid 1960s the number of Canadian universities had increased to 50, and of these at least a dozen had doctoral programs.

It seems quite fair to say that in the 1930's and 40's there was a general sense amongst the academic leaders of our universities that there was no justification for a substantial graduate enterprise. They felt it was enough to give Canadians a good education and then, if some wanted to study further, they could go to the leading American and European universities, for which they would be well prepared. In fact, the typical promising graduate did not even consider staying in Canada for a Ph.D., although this attitude was beginning to change somewhat after NRC established a small scholarship program in the 30's.

The universities did recognize that, in order to achieve excellent education, a good faculty was required, and that therefore some research opportunities were necessary. Consequently many universities encouraged masters' level work in selected disciplines. They felt no need, however, to give much priority to graduate students, even though without them research and scholarship are inhibited.

Of course there were Canadian academics who did pursue research, often of outstanding quality, and indeed with support from their institutions. For example, Rutherford at McGill, McLennan at Toronto, and Herzberg at Saskatchewan. But, in general, research funds were not readily available and support for graduate students was quite limited, both in finances and in the time faculty could make available for advanced instruction and research guidance.

Now, the change: By the mid 1960's the number of Canadian universities had increased from 28 to 50, and of these at least a dozen had doctoral programs operating in many disciplines. Indeed, in 1962, there was felt to be a need to establish the Canadian Association of Graduate Schools. The number of doctorates awarded in Canada in the year 1960 was 306, three times as many as in 1945. By 1965, the number was 696. And these were not "dubious"

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degrees; many of the departments were now doing internationally recognized research. It is fascinating to examine the cause and mechanism of this dramatic and rapid expansion, and the sudden emergence of a national system of research universities. In this short paper, the story is confined mostly to the science disciplines and to physics in particular. Even within this scope an effort to deal in any detail with the postwar development at each university would either be voluminous or consist of dry statistics. Instead I will try to illustrate the overall experience with references to a few typical situations. Not surprisingly, some will be ones I (M.A. Preston) know personally.

The immediate enrolment growth in 1946 was a result of the government rehabilitation program for war veterans. As the veterans returned to Canada and to civilian life, 53,000 of them entered universities in the six postwar years. This required large university expansion and gave the universities much larger funding. But that in itself would not inevitably have led to scholarly development. Indeed, a mind set emphasizing undergraduate instruction might well have continued, especially since it was thought (wrongly) that the enrolments would drop again. The change in research activity was not attributable mainly to demographics but rather to the leadership of some remarkable people with a clear vision of a strong Canadian role in basic research.

It was widely appreciated that a major transition in Canada's cultural affairs was underway. The pressure for opportunities would grow as the veterans finished their undergraduate education and sought scholarly activity, and there was an inescapable role for the federal government if Canada were to become a culturally, economically and technologically advanced country. As early as 1949 the government responded by creating A Royal Commission on National Development in Arts, Letters and Sciences. The report of this Commission emphasized the need for nurturing basic and applied research. Toward this end, the government accepted its recommendations that the National Research Council (NRC) play a much wider role outside its own laboratories and that the Canada Council be established as an independent body to support not only the arts but also humanities and social sciences in the universities.

It is no coincidence that one of the five members of the commission was Chalmers Jack Mackenzie, the president of NRC. He was arguably the single most important influence in the immediate post-war growth of Canadian science. Just as war began in 1939, he came to NRC from the University of Saskatchewan where he had been dean of the College of Engineering since its founding in 1921. He brought with him a clear understanding of the need to improve the research environment in the universities, and a definite intention to do so. By 1943 there had developed a policy that, although NRC would have some groups working on "pure" science, its own research would emphasize applied areas and it would support basic research in universities. Throughout the 1930's the deep economic depression had starved all efforts at academic development. The National Research Council would now support the universities both with grants for research expenses and with the relatively new idea of national scholarships for graduate students. It was foreseen that at war's end there would be a very sudden increase in demand for research personnel. During the war, Canadian industry grew in support of the military effort, and much associated research took place, both within NRC and in several universities. The level of government funding grew rapidly when the war ended. In 1947-48 NRC grants to universities reached nearly $1,000,000 - five times the prewar level. By 1960 NRC was granting nearly $10,000,000 per year. During the 1950's some additional government agencies began to give research grants, notably Atomic Energy of Canada, which in 1960 gave $700,000 in university grants.

Another major initiative introduced in 1945 was the awarding of postdoctoral fellowships. Although the rapid university expansion meant that there was no shortage of faculty jobs, this funding for full-time research workers was of great importance, both for the fellows and for the burgeoning research groups which they joined.

In 1952 Edgar W.R. Steacie became president of the National Research Council. He was a physical chemist who had been on the McGill faculty and director of NRC's chemistry division. He vigorously continued Mackenzie's policy, taking initiatives to promote university development and to increase federal funding.

There was a positive legacy from the war years in several physics departments: Some had become involved in research in radio physics and in the training of military personnel in radar. A natural outgrowth developed in electronic physics and related areas such as solid state physics. The nuclear physics activity in Montreal (described in this issue in the article by Philip Wallace) was a background to the immediate postwar developments at McGill under the leadership of J.S. Foster -- acquisition of Canada's first cyclotron in 1949 and the initiation of a theoretical physics group.

Another very important element fostered in this era by NRC and other government institutions was scientific collaboration. Many university physicists had research projects or worked with groups in laboratories at NRC and at AECL, Chalk River; government scientists had leaves and adjunct appointments in universities. Also inter-university groups developed, often involving professors at developing universities. Although they are somewhat later developments, TRIUMF (Tri-University Meson Factory) and the joint Guelph-Waterloo Ph.D. program are examples of the continuity of the cooperative spirit of the postwar era.

International collaboration is basic to scientific progress. The new faculty members of 1945-1960, whether or not they were Canadians, overwhelmingly had taken their graduate studies abroad. So the connections were there, and fortunately they were fostered by NRC's postdoctoral scholarship programs. And the reverse flow began at this time. Foreign students wanted to study in Canadian departments. This development was an indication of the growing reputation of our research quality.

To many of us, the internationalism of science is very important. In the mid-1970's, provincial governments "began to suggest" higher tuition fees for foreign students, and the federal government introduced constraints on the appointment of non-Canadian faculty. However valid or invalid such policies are, they did not exist in the 1945-1960 era we are describing, and Canadian physics became a significant part of the world physics community.

I have already said that the post-war research growth was dependent on the vision of a number of remarkable leaders. Dr. Mackenzie and Dr. Steacie were very influential in the development of the new government policies. These policies would be effective only if there were also people in the universities eager to use them, and able to generate other opportunities and mechanisms for local development. There will be a number of examples in the rest of this story.

THE SASKATOON STORY: THE AURA OF THE AURORA AND A BETTER BETATRON

The University of Saskatchewan was founded in 1909 and it was guided into the 1930's by its first president, Walter Murray. A good university developed, which was well suited to the perceived needs of the province. In keeping with the general position we have noted, however, President Murray said, in 1922, "the University has no intention of preparing candidates for the Doctor's degree... It would be folly...to add another feeble graduate school to those that encumber the land." At the same time he boasted about the wide acceptance of Saskatchewan graduates in leading American schools. On the other hand it was considered important to have well qualified faculty with Ph.D.s and research was encouraged, particularly if it had practical applications. As a result there were some masters' students who participated in research.

Yet, in the depths of the Depression, this same Walter Murray stretched the resources of the university to appoint Gerhard Herzberg. In 1932, a young chemist, Dr. John Spinks, had been asked to save the university money by taking a leave on minimal pay, and he was able to arrange to work with Herzberg in Germany. Later, in 1935, Herzberg felt compelled to flee Nazi Germany and he wrote to ask Spinks if he could help him go to Toronto where there was extensive work in spectroscopy. Spinks took the problem to Murray. After Toronto and McGill, the only places with doctoral programs going, decided they could not help, Murray invited Herzberg "with joy" to join the University of Saskatchewan's physics department, even though there was neither suitable equipment nor money. The appointment was made possible only because Murray convinced the Carnegie Corporation that he had a good use for a grant. Herzberg had ten very successful years in Saskatoon, completing two of his authoritative books on spectroscopy, and investigating new spectra as some apparatus was obtained. He supervised ten masters' students, most of whom went on to demonstrate the saying that "one of Saskatchewan's major exports is good people". Although Herzberg left just as the war ended, his presence had helped lead to the recognition of the physics department as a place where research was encouraged, and so placed it in a position to be able to take advantage of the opportunities provided by the new government policy.

Professor E.L. Harrington, head of the department from 1925-1952, had a special genius for design and construction of apparatus. In the 1930's he had been asked by the Saskatchewan Cancer Commission to build a radon plant. This he did, not only introducing novel design features, but also doing much glass-blowing himself. Thus, the physics department had some continuing involvement with medical uses of nuclear radiation. Also through Newman Haslam, there was a connection with more basic nuclear physics. Haslam was a native of Saskatoon who was able to spend the two years, 1933-35, in Leipzig as a postdoctoral assistant to Werner Heisenberg, one of the founders of quantum mechanics. Incidentally, Newman had done his doctoral work at McGill, a departure from the usual pattern of going abroad. After his time with Heisenberg, Newman was able to obtain an appointment at his home-town university--this was an achievement for the Depression years, even though the rank was instructor. Haslam did research on photonuclear reactions. Thus the ground was laid for post-war expansion into nuclear physics and its medical applications.

Harold Johns had finished a Ph.D. at Toronto in low-temperature physics just as the war began in 1939. He had won a scholarship for research abroad but the scholarships were cancelled for the duration of the war. Harold was fortunate to secure employment at the University of Alberta, although there was little opportunity for research there. In addition to his teaching, which included radar instruction for the military, Harold became familiar with energetic X-ray technology, inspecting aircraft castings made in western Canada. This interest in radiology made it reasonable for Professor Harrington to bring Harold Johns to Saskatoon in 1945 by arranging a joint appointment with the Saskatchewan Cancer Commission with which, as we have noted, he had close contacts.

Also Leon Katz, a Queen's graduate who obtained his Ph.D. at the California Institute of Technology in 1942, came to Saskatchewan in 1946 with the hope of doing research in nuclear physics. At that time, betatrons were commercially available. These electron accelerators give high energy X-rays and electron beams. The younger members of the department, Haslam, Johns and Katz, each thought that a betatron would be a splendid tool for his research, but they saw no way they could get one. On the other hand, Professor Harrington told them that they were a department that was to be a place of top quality research, and they must not be daunted. He took the lead in obtaining federal funds for the machine and in inducing the provincial government to provide the laboratory for it. Harold Johns had the principal role in negotiating the purchase. They wanted a 25 MeV betatron model, manufactured by Allison-Chalmers. However, Allison-Chalmers had agreed to sell only agricultural equipment in Canada and scientific equipment in the USA, while General Electric would sell only scientific equipment in Canada and agricultural in the USA. Johns knew that Allison-Chalmers had the better betatron. He called General Electric and said if they wouldn't let Allison-Chalmers sell it to him he was going to call a press conference at 4 o'clock and publicize their policies. Within two hours they called back and agreed. Nowadays we would say that Johns broke a monopoly.

The betatron acquisition in 1948 was an early portent of the future. The physics community saw that Saskatchewan had ambition and determination to develop a strong research department, and undoubtedly other departments were encouraged by their success.

There was another significant pre-war activity that prepared Saskatchewan for rapid research growth. It was the auroral and meteorological research of Balfour Currie, who began his scientific career as a young physicist in the Canadian program for the International Polar Year, 1932-33. Later, on commission by the Meteorological Service of Canada, he made a comprehensive study of the climate of the prairies and the northern territories, leading to papers and a book. But his real love was the "Northern Lights". By the war's end Currie's excellent work was well known and this field was set to develop rapidly.

The urge to develop research on the Saskatoon campus was not confined to physics, and the College of Graduate Studies was established in 1946, largely as a result of the desire in the sciences to attract research students. In 1948, President Murray's fear of encumbering the land with another feeble graduate school was fully abandoned and the enrolment of Ph.D. students was authorized. The first Ph.D.'s were granted in 1952 and, perhaps not surprisingly, they were in physics. Both were students of Leon Katz. Alastair Cameron became a professor of astrophysics at Harvard, and Ray Montalbetti remained at Saskatchewan and was for a long time department head. In 1948 then, the foundation was laid in Saskatchewan in two major areas.

Throughout the 1950's, funding for radar and instruments for auroral studies was generous. In 1957 the Institute for Upper Atmospheric Physics was set up with Dr. Currie as Director and with sustained funding, much of it from military sources in Canada and the USA because of the importance of Northern Canada's skies to missile defence. Despite this, the research was not pushed into an overemphasis on applications. Soon there was a group of professors working on auroral studies. And the quality of their work attracted others. By the time of the international Geophysical Year, 1957-58, the Saskatchewan physics department had become recognized as one of the world's most important centers for auroral studies. As the field of research has broadened over time, this status has continued, and the current members of what is now called the Institute for Space and Atmospheric Studies engage in a great deal of international research activity.

The post-1948 development of the radiological and nuclear side of the department had its first widely publicized success in 1952, when Harold Johns designed and built the first ^{60}Co unit for the treatment of cancer. Throughout the late1940's and early 50's, much research was done by Johns and his students and colleagues on the medically significant interaction of X-rays with matter, including living tissues. In 1954 he was awarded the medal of the Roentgen Society. In 1956, Harold left Saskatchewan to accept a position in Toronto, again in both the Cancer Foundation and in the University. He did so with considerable reluctance, but he saw an opportunity for greater impact as a leader of the biophysics and cancer research in the Toronto medical community.

The nuclear physics area burgeoned with the activities of Leon Katz and Newman Haslam. Katz's research was with students, colleagues and apparatus at both Saskatoon and Chalk River. The work focussed initially on the identification of new isotopes, and of nuclear energy levels and spectra, together with theoretical interpretation. Towards the end of the 1950's, the nuclear group saw that their future research depended on the higher energy accelerators that were becoming possible. This time Leon took the lead and in 1961 the first shovelful of ground for an accelerator was turned by Sir John Cockcroft of Cambridge in company with Dr. Steacie. This was made possible by NRC's first significantly large grant under a new policy to support a few "big science" projects. The linear electron accelerator (LINAC) was to stimulate research not only in nuclear physics, but also in radiation chemistry and biology. Thus the interdisciplinary activity that used the betatron continued. Inter-university collaboration was also a major aspect of the LINAC, with users from several countries. Scientists from many institutes used the accelerator just as Saskatchewan physicists also used accelerators of different types at other sites. This brings us to the end of the post-war period, but it is significant to note that, just as with auroral studies, nuclear physics continued to flourish at Saskatoon.

As our knowledge grows, learning interesting new nuclear physics requires higher energies than the LINAC can provide. But the LINAC is being put to excellent use as the basis of the Canadian Light Source that is now under construction. Again this major development, which required a great deal of both scientific and political expertise, was headed by a physicist, Dennis Skopik, who had used the LINAC but then devoted his efforts to ensuring the growth of science in Saskatoon, even though he could no longer do his own nuclear research there.

This account of the emergence of Saskatchewan's department as a physics research center illustrates many of the factors outlined in my general introduction. One other thing worthy of note is that the successful leaders were not only very productive scholars, but also were good at working with people and were willing to assume organizational and administrative responsibilities. Balfour Currie had succeeded Harrington as department head in 1952 and was in turn followed by Newman Haslam, who a few years later became Dean of Arts and Science. In 1961, the year of the LINAC, Leon Katz became vice-president of the Canadian Association of Physicists, and a year later, president. Also in 1961, Currie received the CAP gold medal for achievement in physics, and became Dean of Graduate Studies; he later became Vice-President (Research). Even after his retirement he continued to be active in university affairs. Indeed, in 1977, he was to some extent responsible for recruiting me to Saskatchewan where

I followed immediately in the footsteps of Haslam as Vice-President (Academic). There can be productive scientists who simultaneously commit themselves to the progress of academia.

THE HAMILTON STORY: CRITICAL MASS, RADIOISOTOPES, AND A NUCLEAR REACTOR

Another outstanding scientist and administrator was Henry George (Harry) Thode, one of the pioneers of isotopic geochemistry and the leader of the development of the modern McMaster University. When Harry came to McMaster in 1939, it was a small liberal arts college that had moved to Hamilton from Toronto ten years before, just as the Depression began. When Harry retired as its president in 1972, McMaster was a research intensive university that had increased enrolment by a factor of 10 over the past 20 years, and that had more students in the graduate school than the whole university had in 1952. Throughout this time and indeed until his death in 1997, Harry was a major leader in the field of isotopic chemistry and geochemistry, and was recognized as one of Canada's most influential science administrators.

Sharing the common ethos of the 1930's, McMaster saw undergraduate work as its predominant function and, indeed, discouraged "specialization". During the design of the Hamilton campus, Chancellor Whidden contemplated quite happily a single science building, designed for "general science" and unable to accommodate "advanced work". However, in 1930, its first year in Hamilton, McMaster was joined by the chemist Charles Burke, who was an experienced professional in both academic and industrial areas. He was a McMaster graduate of some 20 years standing who had maintained close interest in his alma mater. After only two years he was appointed associate dean with responsibility for science. He introduced a wider perspective. The desire to attract good students led him to encourage innovation in the courses offered, an approach initially opposed by the senior physicist H.F. Dawes. Burke also wished to strengthen the faculty, particularly by recruiting both a physical chemist and a physicist able to supervise the work of M.Sc. students. By 1939 funds were in place and two persons of "great promise" were found. They were Harry Thode and Gerald Wrenshall. While at McMaster, Wrenshall continued to work on nuclear physics in both Hamilton and Rochester, but unfortunately for McMaster he left after two years.

Thode, another important Saskatchewan export, had taken his Ph.D. at Chicago and had just finished two years as a research associate with Harold Urey who had won the Nobel Prize for discovering deuterium. Harry Thode worked on the separation of the rare isotopes ^{13}C, ^{15}N and ^{18}O. His intention to continue isotopic studies required a mass spectrometer. Immediately on arrival he began construction of the first one in Canada, aided by a $3000 grant from NRC that Urey helped to arrange. Thode also offered an evening course on topics of interest to industrial chemists. This shows his interest in being closely tied to the Hamilton community, a "town-and-gown" relationship that proved very important in the post-war development, just as had Harrington's work with the Saskatchewan Cancer Commission.

The impact of the war-time research was very significant for McMaster. Harry's first project was analysis of sulphur isotopes related to chemical warfare and the production of ^{18}O. In 1942 he was persuaded to join the Anglo-Canadian-US project located in Montreal, working on nuclear research and reactor design. Although Harry spent some time in Montreal, his contention was accepted that use of his equipment already in Hamilton would save a great deal of time. Part of the top floor of McMaster's only science building, Hamilton Hall, became a site of secret work, but the students of course knew that something mysterious was going on. The results included the discovery of the radioactive isotope ^{85}Kr and a great deal of data significant for understanding the fission process, and for the later development of the shell structure model of nuclei. The importance of this work would lead to a sudden awareness of McMaster by other scientists and, on the campus itself, it began to prepare the way for an improved status for science. By 1945, Harry had seven research assistants, two of whom played key roles later in the development of the physics department.

The physics department involved itself in war-time projects. In response to urgent requests in 1940, its two members, Henry Dawes and Boyd McLay, organized and taught courses in radar and electronics for the air force, navy and army. They built for this purpose special equipment that was also used in the regular laboratory classes. In addition, Boyd, who had an interest in marine matters, acted as the commanding officer of the University Naval Training Detachment. There was clearly little time for research. Professor Dawes, who was appointed in 1910, retired in 1947, and Boyd became acting head and then was chair of physics from 1950-56.

Between 1945 and 1947 there had been significant developments. It was the policy of the Ontario government to give no financial support to a "denominational institution". McMaster was under the aegis of the Baptist Church. Indeed only Baptists could be members of the Senate. Moreover, it was the position of Baptist institutions that they ought not to seek state aid that would "endanger the absolute freedom of the church from the state". It was suggested that this dilemma, at least for the government, would vanish if there were an affiliated college devoted to science education and research, totally separate from the university in finances and governance. This proposal clearly would need public and political support. It ran the risk of causing a schism in the church since the college would be teaching McMaster students. George Gilmour, the Chancellor and himself a Baptist clergyman, guided the university through this controversy. Additional money from private sources would be needed, and it was important to have the deep involvement of the major Hamilton industries and business community. In this connection, the contacts that the scientists, especially Burke, already had forged in Hamilton proved significant.

Hamilton College was established by legislation late in 1947 with a Board of Governors reflecting Hamilton's industrial leadership. It was then accepted by the McMaster University Senate and Board. The organization was now in place for aggressive development in the sciences. After Dean Burke died suddenly in May 1949, Harry Thode became the first principal of Hamilton College. He had already taken the lead in persuading the university to offer Ph.D. studies. Conservative faculty opposition was overcome, in part by establishing the condition that the university's reputation be guarded by offering degrees only in fields in which there was undoubted competence, judged by distinguished external consultants. (This appraisal system was later extended throughout Ontario, a development in which I played a leading role when I joined the decanal ranks.) Authorization for Ph.D. studies came for chemistry in 1949 and for physics in 1951.

Very soon after the war's end, a senior position was authorized in physics and in 1947 Fricis Gulbis was appointed. He had been the Professor of Physics at the University of Riga. Latvia had been occupied successively by both Germany and Russia and, like many Baltic academics, Gulbis was a refugee. Also in 1947 Professor Dawes retired and Martin Johns was appointed. Johns' research interests in nuclear spectroscopy and Gulbis' in cosmic rays fit McMaster's growing emphasis on sub-atomic physics.

Martin Johns had completed his Ph.D. at Toronto in 1938, one year before his brother Harold, and he had immediately joined the staff of Brandon College, where there were no research facilities. He arranged to come to McMaster for several summers and to work with Harry Thode's group. He tells me that, in 1946, he was being recruited by Queen's but Harry told him that that move would be unwise. He should instead go to Chalk River and really get into nuclear research. He did so and one year later came to McMaster. Again NRC played a crucial role: Martin got an equipment grant of $10,000, albeit in two instalments, the second of which required Thode's personal intervention.

More research space was becoming essential. Hamilton College found the money and in 1951 opened the Nuclear Research Building with laboratories, a small seminar room and a few offices, including Thode's. This was the first new building after the war, and it was important for the future because it established that science, and nuclear science in particular, was to be emphasized at McMaster.

There were now the facilities to make a fourth appointment in physics possible. Like Martin Johns, Harry Duckworth had worked in Thode's wartime group. He had completed doctoral work at Chicago in 1942 and joined the Canadian Army, but was assigned to war research at NRC and then in 1944 to Hamilton. After one year on the faculty at his alma mater University of Manitoba, Duckworth taught for five years at Wesleyan University, in Connecticut, where he built a mass spectrometer. In 1951, Thode and Johns decided he should return to McMaster. (We're still well before the days of appointment committees). Duckworth agreed, took over one of the new laboratories, and soon had a functioning spectrometer and a very active group of students. Duckworth later served as McMaster's Dean of Graduate Studies (1961-65), and Vice-President of the

University of Manitoba and President of the University of Winnipeg (1971-78).

The next faculty appointment was a theorist, Mel Preston. I had been in the army but was back in Canada before the war's end, and so was able to return quickly to Toronto for an M.A. I then went to Birmingham for the Ph.D. studying nuclear theory with Sir Rudolf Peierls. In 1949, I became an assistant professor at Toronto, but spent the summers at Chalk River with the theory group, because there were no nuclear physicists to talk with in Toronto. In 1952 Harry Duckworth asked me to come to Hamilton once a week to teach a course for McMaster's few graduate students. I agreed but with no thought that any sane person would leave Toronto for one of the "little places". My attitude changed as I became aware of McMaster's plans. When I received a challenge from Thode to join in building "Canada's best physics department", I decided to do just that. Of course, before accepting, I had ensured there would be support for the graduate students and postdocs needed to begin a theory group.

In 1954 what might be seen as the core of the department in the 50's was completed by the appointment of Howard Petch. He was one of the veterans who started university in 1945 at McMaster. He obtained his Ph.D. in 1952 at one of the other rapidly developing universities, the University of British Columbia. After a post-doctoral year at McMaster and then a Rutherford Fellowship at Cambridge, he came to McMaster to begin the development of solid state physics. He later served as vice-president of the University of Waterloo and president of University of Victoria (1975-1990).

McMaster's first three Ph.D.s were awarded in 1953, to Benjamin Hogg who had worked with Duckworth, Carmen McMullen with Johns, and Robert Wanless with Thode. Hogg went to teach at the Royal Military College and later at the University of Winnipeg. He maintained research on the measurement of atomic masses; in Winnipeg he worked with the group established at the University of Manitoba when Duckworth went there in 1965. McMullen stayed at McMaster, initially working for the Defense Research Board on classified work and later joining the faculty. Wanless's career was with the Department of Mines and Technical Surveys in Ottawa, working initially on mass spectrometry.

Department growth accelerated through the second half of the 1950's. The policy was to strengthen the established research fields to a "critical mass" rather than to start new ones. The first faculty appointment in this period was Bob Summersgill in nuclear physics. Later Rudy Haering and then Sy Vosko came to develop the theoretical side of condensed matter physics, an area that has continued to flourish steadily.

The number of graduate students also grew rapidly. The five Ph.D. graduates in 1956 included the first non-Canadian, Kailash Kumar, who, after postdoctoral positions at McGill and Purdue, returned to India for some time and for many years now has been a professor at the National University of Australia in Canberra. In 1961 Agda Artna became one of the first women to earn a physics Ph.D. in Canada. By 1957 university-wide development of graduate studies had led to the establishment of a Faculty of Graduate Studies with its own dean, Arthur N. Bourns.

The decade culminated for McMaster with the opening, in 1959, of the nuclear reactor, the first one at a university in the British Commonwealth. It was clear by 1955 that reactors would be research instruments in many areas of basic science, and not simply power generators. They could be used to study nuclear structure and nuclear phenomena and to make isotopes having medical applications. Also the neutron beams were beginning to be used to study the structure of materials. These were all principal research areas at McMaster. Harry Thode's gifts of leadership became evident again. As Chancellor Fox said at the reactor opening: "He had the vision of what was wanted and he enjoyed the confidence of those people who made it possible". Amongst those people were Mackenzie and Steacie, by now the principal figures at AECL and NRC, and also those who brought financial assistance from Ontario Hydro and from some other industrial sources. The extent to which the universities had public support in the 1950's is illustrated by the fact that Prime Minister Diefenbaker would come to open the reactor and call it "a symbol of mankind's quest for peace and an assertion of faith in the constructive benefits of science."

To examine the degree to which the reactor enabled such goals to be achieved would take us beyond our

1960 cut-off, but it must at least be said that its presence was a significant factor in persuading Bert Brockhouse to come to McMaster in 1962. Even then we thought his work was due for a Nobel prize; more than twenty years before the award was given, I helped Harry Welsh prepare the first nomination.

The presence of the reactor naturally made McMaster an important centre for the training of nuclear engineers and health physicists. Although its importance for physics research has lessened, the reactor continues to fill a useful role, and it is used now extensively for biological and medical research. As at Saskatchewan, the principal foci of McMaster's research continued successfully after the immediate post-war era. A tandem Van de Graaf accelerator was obtained and, although it is no longer useful for nuclear physics, the nuclear group is active with off-campus accelerators. The condensed matter group developed steadily, produced many significant findings and now has an endowed chair named for Brockhouse. Medical physics, now an important part of the department's teaching and research, developed mostly after 1960. And it is only a few years ago that the department became the Department of Physics and Astronomy.

Research emphases change with time but the Saskatchewan and McMaster stories illustrate that once a research ethos was established it persisted.

THE ROLE OF THE CAP

One more significant factor in the research growth of the 1945-60 years was the Canadian Association of Physicists (CAP). It began in 1945, partly because some physicists in industry felt the need for a professional association, but it also had academic goals. Its annual conferences gradually became an important factor in promoting the informal communications that can be so significant in establishing a community of scientists and in generating ideas and catalysing research. This led to the establishment of subject divisions and the organization of summer institutes. (See the articles by D.D. Betts and F.M. Ford in this issue for more information on the CAP's history and evolution of activities.)

Recently, lobbying the government for research funding and advising on granting policy have been very significant roles of the CAP, but this also had occurred earlier. In 1955, some physicists began to suggest that Canada should maintain its enviable reputation for scientific and technological progress by building a high energy accelerator. The CAP established working committees to examine the possibilities and, in 1958, it presented a brief to the Minister of Trade and Commerce with specific recommendations. They were the result of much careful work, including visits to places in the USA and Europe having operating or planned accelerators, consideration of the most promising energy and type of accelerator, detailed analysis of proposed sites and of organization. The result was a proposed 15 GeV proton accelerator, to be located in Kingston near Queen's University, costing $25 million, organized as a corporate subsidiary to NRC with university shareholders. It was even established that at least five suitable Canadian physicists would consider the position of director.

This CAP proposal shows how far research in universities had come in the ten years since 1945. The committee preparing the proposal was headed by Dr. R.J. Hay of Aluminum Co. of Canada and its members came from NRC, Laval, McMaster, Saskatchewan, UBC and Montreal. Queen's administration strongly supported their potential involvement, as did that of UBC which was the alternative site recommended. UBC made very rapid progress in physics research, again with important leadership, in this case from Gordon Shrum. A vignette of Shrum appears elsewhere in this issue but one tale illustrative of his positive attitudes may be in order. When the committee was visiting Vancouver, two serious problems were raised. If the accelerator were at Point Grey, obtaining a supply of sufficient cooling water and adequate electrical power would be difficult. Looking over the broad expanse of English Bay, Shrum asserted "I'm sure we can find a way to use that salt water -- and we can put electrical cables under it if we have to".

The accelerator initiative ended with a government decision in March 1959 not to fund it. Although the nuclear reactor at McMaster opened the same year and cost $2 million, Ottawa was not ready for sums like $25 million. A few years later, money was found for TRIUMF -- Shrum had not given up.

CONCLUSION

It is the author's hope that this article may convey something of the ebullient atmosphere of Canadian university physics between 1945 and 1960. Some universities were able to develop much more rapidly than others, and I have described two of these in some detail. They are examples of the remarkable progress and expansion that is really the story of the nation-wide physics community. The University of British Columbia was probably the institution that grew most rapidly. It was granting Ph.D.s by 1952 and the first were in physics; by 1960, UBC was Canada's third largest university and the physics department had produced almost 100 Ph.D. degrees.

Another initiative of the 1950's was at the University of Manitoba where Robert Pringle began very productive research in nuclear physics that led to the birth of Nuclear Enterprises Ltd., Winnipeg and Edinburgh, a short time later. B.G. Whitmore, who succeeded Pringle as department head in 1957, together with K.G. Standing, initiated the acquisition of a negative ion cyclotron for Manitoba. Under the leadership first of J A. Gray and then of B.W. Sargent, who had been at Chalk River, Queen's University, by 1958, had come to the point where it was the recommended site for the proposed proton accelerator. Although the accelerator did not materialize, important nuclear research has continued to the present. As another article in this series describes, F. Rasetti gave Université Laval a strong beginning in graduate work in physics in the 1940's and it developed extensively in the 1950's.

This article is intended to portray the emergence of new programs, but a complete 1945-1960 picture of physics graduate research would have to include the developments at McGill and Toronto. McGill's initiatives in nuclear physics and theoretical physics have already been mentioned. The major emphases of Toronto's physics research in the 1950's were on the optical and spectroscopic studies of M.F. Crawford, H.L. Welsh and Elizabeth Allin, and on the pioneering work on plate tectonics of an expanding geophysics group led by Tuzo Wilson. In 1951, when the University of Toronto acquired Canada's first major computer, it was Calvin Gotlieb of the physics department who took the leadership in developing Canadian computer science.

In contrast with the situation in 1945, the Canadian universities had, by 1960, entered upon a new age. By ending this narrative at 1960 we fail to describe the unfolding of this new age in which physics research groups developed, not only in the older universities but also in the many newly established ones. Some of the universities first chartered between 1959 and 1969 were Waterloo, York, Windsor, Victoria, Simon Fraser, Guelph, Calgary, Winnipeg, and Québec.

Not all the stories of growth in the '60's have the same factors that we have portrayed in the '50's, but in all, the successful leaders had multi-disciplinary research interests and they were skilful at building their own apparatus, including glass-blowing. They were not only very productive scholars, but also were good at working with people and were willing to assume organizational and administrative responsibilities. They were willing to move around the country and spread their influence. They were stubborn in the face of opposition. All these characteristics of the leading science administrators have been seen over and over. In all the stories, the essential elements have been vision, leadership, enthusiasm and support from the external scientific community.

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GORDON MERRITT SHRUM, 1896 - 1985

Gordon Shrum moved. Throughout his eighty-nine years, spanning most of the past century, he was a man of action: forceful, shrewd, decisive, intelligent, efficient and successful. Rarely missing a day of work, he strode boldly even in the last month of his life and died, suddenly and efficiently, in his sleep. His impact on Canada, British Columbia and Canadian science was huge.

Gordon M. Shrum

He was born on a farm near Smithville, Ontario, in 1896 and entered the University of Toronto before WWI. He served with great bravery in the Great War, fighting at Vimy Ridge and in the subsequent trench warfare. He entered the war as a sergeant in the artillery, earned the Military Cross and was discharged as a corporal.

Soon after WWI he completed his degree at Toronto and came under the influence of John McLennan whom he revered and emulated. He was McLennan's most distinguished protégé and together they discovered the origin of the auroral green line.

In 1925 Shrum accepted an appointment in the physics department of the University of British Columbia. He soon found that the university and the province provided great scope for his immense talents. He became Physics Department Head in 1938, and later dominated the university by being, in addition, dean of graduate studies, head of the extension department and chairman of the BC Research Council.

During WWII he headed the COTC at UBC. In the postwar surge of veteran students there was no space for classrooms or housing. Shrum noticed the many wartime huts abandoned around the province and simply purloined them. As he said: "there was a lot of red tape involved in acquiring them so I simply took them".

Shrum served on the NRC Council for a record thirteen years. Council members could not serve for more than six years at a time so NRC president C.J. Mackenzie simply told him, at the end of the sixth year, that he should continue to come to meetings for the seventh year but not vote, and then he could be reappointed for another six years. He also served with distinction on the Defense Research Board and the Atomic Energy of Canada (AECL) Board.

He was an outstanding teacher of physics but had little time for his own research at UBC. However he knew what a good department should do and had excellent and instant recognition of outstanding people, whether they be physicists, chemists, or football coaches. In his forays into Europe after WWII he found the professors who built research and graduate teaching at UBC. As head of the BC Research Council he attracted Gobind Khorana to his staff, who then carried out the work on DNA for which he later won the Nobel Prize. In turn, the staff Khorana attracted to UBC led to a second Nobel Prize, for Michael Smith.

After retiring from UBC in 1961 he entered into a new career as the Province's master builder. Simultaneously he created the Peace River Hydroelectric Project, as co-chairman of BC Hydro and Simon Fraser University. SFU owes its site, its style and its great innovative reputation to Shrum. The instant creation of SFU also established Arthur Ericson as Canada's leading architect. Shrum handled the public purse with the same care as his own; his projects were completed on time and within estimated costs. He also later managed the construction of the courthouse buildings which dominate Vancouver's downtown.

Shrum is probably the only Canadian scientist who accumulated great wealth from a meagre professor's salary. In the 1920's he saved some of his UBC salary and invested it in the stock market until, in October 1929, just days before the market crash, he withdrew his $10,000 and invested it in the construction of the house in which he lived for the next fifty-five years. Then he began to use a small part of his salary to acquire small wooden apartment blocks. He made shrewd choices of managers so that the rentals rapidly paid off the capital costs. When he died he owned well over a thousand apartments.

Gordon Shrum could appear to be terribly intimidating to colleagues, students and wives. He was always fair and listened to arguments until a decision was made. He could be very kind and his two children, his five grandchildren and many of his close colleagues found him to be demanding but a true friend. I remember in 1965, I had to defend, in his Hydro office, our ambitious plans to build TRIUMF. He listened, assessed me and my colleagues carefully, and decided instantly to back us with great affect, particularly with his high school classmate, Prime Minister Lester B. Pearson. Many of us will remember how he moved Canadian science, his province and his nation.

Erich Vogt, Professor Emeritus
University of British Columbia

ROBERT EDWARD BELL, 1918 - 1991

Robert E. Bell

Bob Bell, as he was known to his many friends and colleagues, was a world renowned nuclear physicist. He belonged to the first generation of post-war physicists who had helped place Canadian nuclear research at the center stage of international nuclear physics. He was known for his pioneering experimental work on nuclear interactions, his invention and exploitation of the method for direct measurements of very short nuclear transition life-time, and his discovery of delayed proton radioactivity. At the peak of his scientific career, he was appointed the Principal and Vice-Chancellor of McGill University when leadership was needed to guide the university through the difficult turbulent times of the Vietnam war era. He was a scholar with a sharp mind and a quick but gentle wit.

Born of Canadian parents on November 29, 1918 in New Malden, England, he grew up in Ladner B.C., and attended UBC on scholarships. He graduated with Honours in Mathematics and Physics in 1939 and obtained an M.A. in Physics in 1941. When World War II broke out, like many of his contemporaries, he joined the radar research effort at the National Research Council (NRC) in Ottawa. He worked on many aspects of antenna design and developed a K-band scanner. His flair for research was quickly recognized. The radar work brought him into contact with J.S. Foster, who was doing similar things at the Radiation Laboratory at the Massachusetts Institute of Technology (M.I.T.). Bob Bell was to recall amusingly that, on his first meeting with Foster, while looking at the working of the Foster Scanner on the roof of the Radiation Laboratory at M.I.T. and in response to a witty remark from Bell, Foster suddenly threw up his arms and emitted one of his famous laughs, almost knocking Bell off the edge of the parapet very nearly making that encounter their first and last. Fortunately that was, instead, the beginning of their long lasting friendship which helped bring Bell to McGill later.

When the war ended in 1945, Bell enrolled in the Ph.D. program in Foster's Radiation Laboratory at McGill and carried out his research at Chalk River under the supervision of Dr. Lloyd Elliot. He received his Ph.D. in 1948 for a piece of classic research: measurement of the deuteron binding energy. The subject of proton-neutron interaction was of immense interest at the time. He joined the staff at Chalk River upon his graduation. It was there he made the first observation of the Doppler effect on the nuclear transition. His instinctive flair for electronics and electronic instrumentation led him and Drs. R.L. Graham and H.E. Petch to the invention of the direct electronic timing technique, the so-called "fast-slow coincidence system", for nuclear transition life-time measurements in the nanosecond and subnanosecond time range. This invention and its subsequent exploitation made him a world expert on the subject.

The McGill cyclotron was fully commissioned in 1949 and the field of nuclear research at accelerator energies was wide open for exploitation. In 1952 it was arranged to have Bob Bell on loan to McGill so that he could take advantage of the research opportunities offered by the new facility. He joined the staff at McGill in 1956 as Associate Professor. By then he was well recognized, and was already elected Fellow of the American Physical Society (1954) and Fellow of the Royal Society of Canada (1955). He succeeded J.S. Foster to the Rutherford Chair in Physics and the Directorship of the Radiation Laboratory at McGill in 1960. Bob Bell's scientific career was crowned with the discovery (with student R. Barton) of a new form of radioactivity---the delayed proton, in 1963. He and his student, J.C. Hardy, subsequently developed this work into a powerful spectroscopic tool for the study of nuclear isotopic analog states. With his induction into the Royal Society (London) in 1965, the award of the Canadian Centennial Medal (1967) and the CAP Medal for Achievement in Physics (1968), he was rewarded for his work.

His meteoric rise in fame in the scientific world coincided with the tumultuous changes in society, particularly on campuses across North America. Many universities were looking for new leadership to navigate them through the turbulence. The Board of Governors of McGill found it in one of its own eminent scholars, when, on June 1, 1970, Bob Bell was appointed Principal and Vice-Chancellor. He came to the Principalship with impeccable scholarly credentials. He applied scientific logic to university administration with great success. During his nine-year tenure in the post, he restored harmony, trust and financial solvency to the campus. He redirected the energy often wasted on futile academic debates back to the discovery of new knowledge. It was fascinating to watch him using his sharp mind and quick wit to bring a convoluted academic debate down to earth. Many McGill colleagues still remember vividly how refreshing it was to listen to their Principal delivering his "state of the union" addresses in the format of plenary talks in scientific conferences. He was the last Principal of McGill to be appointed with unlimited term and voluntarily subjected himself to the "new rule" of five-year term which the Board of Governors had adopted at his urging. Upon his retirement from McGill in 1983, he took on the Directorship of the Arts, Science and Technology Center in Vancouver for two years, laying the foundation for its eventual evolvement into an interesting institution called Science World. Unfortunately, he died at the age of 73, after a long and difficult illness.

Bob Bell was a modest man with an unassuming manner, and had a tendency to shun formality. He was generous, be it to praise another's accomplishment or to help a friend in need; he always had something good to say about his adversaries. He loved jazz music and shared an appreciation for English literature with his wife, Jeanne Atkinson, who was a Shakespeare Gold medalist graduate from McGill. He was fond of rhymes and word play, and wrote several humorous poems. He was a cultured man.

In addition to the honours and awards already mentioned above, he received a great many others. Just to give a sample of them: President of the Canadian Association of Physicists (1965-66); honorary degrees from ten major Canadian universities; Companion of the Order of Canada (1971); Queen's Silver Jubilee Medal (1978); President of the Royal Society of Canada (1978-81); Centennial Medal of the Royal Society of Canada (1982). He held membership in a great many prestigious organizations. His long list of honours, awards and appointments identifies a remarkable man.

S.K. Tommy Mark, McGill University

BOOKS RECEIVED / *LIVRES REÇUS*

The following books have been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Books may be requested from the book review editor Erin Hails by email at ehails@physics.uottawa.ca or c/o CAP Office, Suite 112, McDonald Building, 150 Louis Pasteur Avenue, Ottawa, Ontario K1N 6N5. Tel: (613) 562-5614; Fax: (613) 562-5615.

Les livres suivants nous sont parvenus pour la critique qui peut être faite en anglais ou en français. Si vous êtes intéressés de nous communiquer une revue critique sur un ouvrage en particulier, vous êtes invités à vous mettre en rapport avec la responsable de la critique des livres, Erin Hails par courrier électronique via ehails@physics.uottawa.ca ou a/s de l'ACP, bureau 112, Immeuble McDonald, 150 rue Louis Pasteur, Ottawa, Ontario, K1N 6N5. Tél. : (613) 562-5614. Télécopieur : (613) 562-5615.

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Seeking Ultimates: An Intuitive Guide to Physics, P.T. Landsberg, IOP Publishing, 1999, pp: 293, ISBN 0-7503-0657-2, Price: $32.00 (pbk).

Measurement, Instrumentation and Experiment Design in Physics and Engineering, M. Sayer and A. Mansingh, Prentice-Hall of India Private Ltd., 1999, pp: 359, ISBN 81-203-1269-4, Price: $19.50 (pbk).

The World in Eleven Dimensions: Supergravity, Supermembranes and M-theory, Edited by M.J. Duff, IOP Publishing, 1999, pp: 513, ISBN 0-7503-0672-6 (pbk), 0-7503-0671-8 (hc); Price: $49.00 (pbk), $130.00 (hc).

GRADUATE TEXTS AND PROCEEDINGS

CP Violation, I.I. Bigi & A.I. Sanda, Cambridge University Press, 1999, pp: 376, ISBN 0-521-44349-0 (hc); Price: $95.00.

Beyond Conventional Quantization, J. Klauder, Cambridge University Press, 1999, pp: 311, ISBN 0-521-25884-7 (hc); Price: $85.00.

From Physics to Philosophy, J. Butterfield & C. Pagonis, Cambridge University Press, 2000, pp: 229, ISBN 0-521-66025-4 (hc); Price: $59.95.

Spectral Asymptotics in the Semi-Classical Limit, M. Dimassi & J. Sjöstrand, Cambridge University Press, 1999, pp: 220, ISBN 0-521-66544-2 (pbk); Price: $39.95.

New Directions in Atomic Physics, Edited by C. Whelan, R. Dreizler, J.H. Macek and H.R. Walters, Kluwer Academic/Plenum Publishers, 1999, pp: 384, ISBN 0-306-46181-1; Price: $177.50 (hc).

Problems on Statistical Mechanics, Edited by D. Brewer, IOP Publishing, 1999, 284, ISBN 0-7503-0521-5 (pbk), 0-7503-0520-7 (hc); Price: $39.00 (pbk), $110.00 (hc).

Globular Clusters, Edited by C. Martinez-Roger, I. Perez-Fournon and F. Sanchez, Cambridge University Press, 1999, pp: 353, ISBN 0-521-77058-0; Price: $69.95 (hc).

BOOK REVIEWS / *CRITIQUES DE LIVRES*

POLYMERS AT SURFACES AND INTERFACES, R. Jones, R. Richards, Cambridge University Press, 1999, pp: 377, ISBN 0-521-47965-7 pbk.(-47440-X pbk.), Price: $39.95 pbk. ($90.00 hc)

It is an unfortunate fact that traditional condensed matter physics has largely neglected the study of polymeric materials in spite of the fact that polymers are found in a multitude of applications. The success of polymers is due, in part, to their physical properties at surfaces and interfaces. There are truly several topics on this specific subject which can be covered in a book.

Chapter one of this book is an introduction and overview of the polymers at surfaces and interfaces.

In the following chapters, the authors then cover a number of important topics including polymer/polymer interfaces, adsorption and surface segregation and, adhesion and mechanical properties of polymer interfaces. The book also includes discussions on tethered polymers at interfaces and polymers spread at air/liquid interfaces. Many experimental methods are relevant in the study of these systems.

Therefore, one chapter is dedicated to an overview of experimental techniques including a discussion on the advantages and disadvantages of each technique. A description of the relevant theories and how they can be applied is also given. In particular the authors provide an excellent discussion of the limitations of mean field theory in these systems.

Perhaps the most striking feature is the scope over which material is covered in this book. ``Polymers at Surfaces and Interfaces" include a large number of important topics in current polymer science. As noted by the authors, the breadth is chosen deliberately ``to make clear the large number of areas in which the interfacial behavior of polymers is relevant and important and to point out the close parallels between different aspects of the subject". As a result, each chapter is an overview of the ongoing research and current understanding on the topic.

For each topic, the authors give a brief account of the underlying physics of the problem and discuss the relevant theoretical and experimental studies. The reader is left with a broad overview of the current subject and the lack of depth is accounted for by the fact that the reader is aware of the major aspects of each topic.

For a more in-depth discussion, the reader is supplied with a comprehensive list of references and review articles. This book would serve well as a good reference for an advanced undergraduate or graduate course, or as a good introduction for a researcher with an interest in polymers.

Marc Pépin
Department of Physics
University of Ottawa

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Raynald Laprade, directeur
Département de physique, Université de Montréal
C.P. 6128, succursale centre-ville
Montréal (Québec) CANADA H3C 3J7

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Prof. Jean Barrette, Chair
Department of Physics
McGill University
3600 University St.
Montreal, QC
Canada H3A 2T8

A copy of the complete application should also be sent to:
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Brookhaven National Laboratory,
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For full consideration all materials should be submitted by **May 12, 2000**.

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