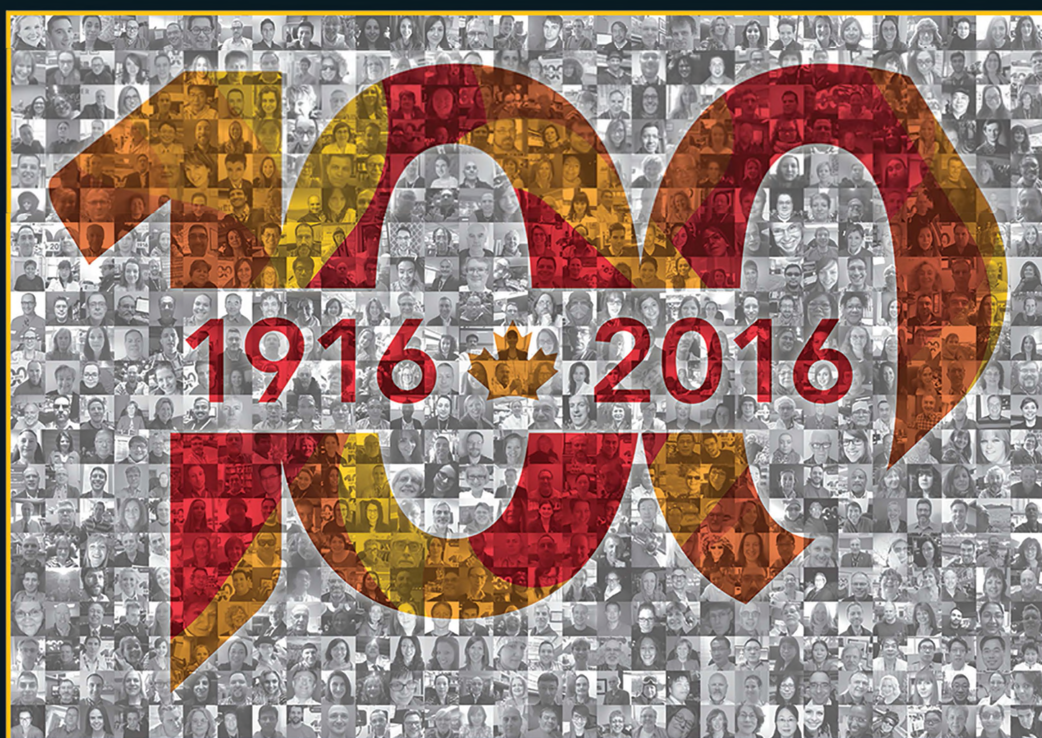
Volume 72, No. 4
2016

# Physics in Canada
# La Physique au Canada

This is who we are · Voici qui nous sommes

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Serving the Canadian physics community since 1945 / Au service de la communauté canadienne de physique depuis 1945

# A Century of Physics at the National Research Council

# *Un siècle de physique au Conseil national de recherches du Canada*

Canadian Association of Physicists / Association canadienne des physiciens et physiciennes

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# Physics in Canada
# La Physique au Canada

Volume 72 No. 4 (2016)


Canadian Association of Physicists
*Association canadienne des physiciens et physiciennes*
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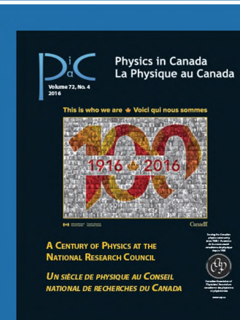


NRC's story is found in the mosaic of imprints of everyone who passes through.

*L'histoire du CNRC est marquée d'empreintes laissées par tous ceux qui y sont passés.*

The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest of up to four journal pages in length are particularly welcome. Suggestions for theme topics and guest editors are also welcome and should be sent to bjoos@uottawa.ca.

*Le comité de rédaction invite les lecteurs à soumettre des articles qui intéresseraient et seraient compris par tout physicien, ou physicienne, et étudiant ou étudiante en physique. Les articles de synthèse d'une longueur d'au plus quatre pages de revue sont en particulier bienvenus. Des suggestions de sujets pour des revues à thème sont aussi bienvenues et pourront être envoyées à bjoos@uottawa.ca.*

**Canadian Association of Physicists (CAP)**
**Association canadienne des physiciens et physiciennes (ACP)**

The Canadian Association of Physicists was founded in 1945 as a non-profit association representing the interests of Canadian physicists. The CAP is a broadly-based national network of physicists in working in Canadian educational, industrial, and research settings. We are a strong and effective advocacy group for support of, and excellence in, physics research and education. We represent the voice of Canadian physicists to government, granting agencies, and many international scientific societies. We are an enthusiastic sponsor of events and activities promoting Canadian physics and physicists, including the CAP's annual congress and national physics journal. We are proud to offer and continually enhance our web site as a key resource for individuals pursuing careers in physics and physics education. Details of the many activities of the Association can be found at http://www.cap.ca. Membership application forms are also available in the membership section of that website.

L'Association canadienne des physiciens et physiciennes a été fondée en 1946 comme une association à but non-lucratif représentant les intérêts des physicien(ne)s canadien(ne)s. L'ACP est un vaste regroupement de physiciens oeuvrant dans les milieux canadiens de l'éducation, de l'industrie et de la recherche. Nous constituons un groupe de pression solide et efficace, ayant pour objectif le soutien de la recherche et de l'éducation en physique, et leur excellence. Nous sommes le porte-parole des physiciens canadiens face au gouvernement, aux organismes subventionnaires et à plusieurs sociétés scientifiques internationales. Nous nous faisons le promoteur enthousiaste d'événements et d'activités mettant à l'avant-scène la physique et les physiciens canadiens, en particulier le congrès annuel et la revue de l'Association. Nous sommes fiers d'offrir et de développer continuellement notre site Web pour en faire une ressource clé pour ceux qui poursuivent leur carrière en physique et dans l'enseignement de la physique. Vous pouvez trouver les renseignements concernant les nombreuses activités de l'ACP à http://www.cap.ca. Les formulaires d'adhésion sont aussi disponibles dans la rubrique «Adhésion» sur ce site.


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LA PHYSIQUE AU CANADA

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# CELEBRATING 100 YEARS OF PHYSICS AT NRC

My career at NRC began with a mug: a 75th anniversary mug to be specific, handed to me as I first set foot on the campus as a member of the team in 1991. How interesting it is, mug still in hand, to now be writing a foreword to articles written by people I have known and respected throughout my scientific career, recognizing NRC's 100th anniversary. And while the sum of the accomplishments I have seen would take up far too much space to list, there is a pleasant nostalgia when thinking through these years.

Einstein spent his life working on expanding the realm of physics and mathematics. His last obsession was in establishing a unified theory. In 1923, he said "the intellect seeking after an integrated theory cannot rest content with the assumption that there exist two distinct fields totally independent of each other by their nature." And while he may have been ultimately unsuccessful, and ironically became increasingly isolated by his work, the concept of connectedness—that all things can be linked to one greater concept—is extremely appealing.

Connected we are, especially if you happen to be in this field. It is easy to forget, when in the midst of our own personal obsessions, how influenced by, and influential to, our colleagues we actually are. More surprising is just how much of that influence stays with you, even those that are no longer present. "No man is an island, entire of itself; every man is a piece of the continent, a part of the main. Any man's death diminishes me, because I am involved in mankind." We have been diminished by the departure of some great minds, but their achievements enhance us still. In our case, we plant trees commemorating their contributions, and in recognition of how evergreen their presence is, so that they may continue to inspire others. I am, myself, surrounded by their contributions, reminding me of the uniqueness of NRC.

Whether it is our work on the Système International, including the redefinition of the kilogram and kelvin, the discovery of how molecules actually come together, the attosecond, the discovery of DNA, radar, the Storable Tubular Extendible Member (STEM) antenna, or 3D imaging technology, walking in the footsteps of these giants of science can sometimes feel daunting. Even though these individuals are not all currently at NRC, that link is still firmly traceable. Some have moved on to work in universities; others have gone through the Canadian Space Agency, while still others have held various positions within the CAP. The world is truly as paradoxically small as it is great. Regardless of where they are now, I am incredibly proud of their accomplishments, and feel privileged to be a part of an organization that has continued to have an influence on Canada, and the world, since its very beginning one hundred years ago.

A great deal has happened in physics in my lifetime, and I have only been a witness to a small part of the sum. An important fraction of the work performed at NRC is introduced in the following articles, written for the celebration issue you are reading now.

The authors of the following articles celebrating NRC researchers' many achievements over the last 100 years are leaders in their fields. They will walk you through some of the more pivotal moments in NRC's history of physics, and shine a light on the incredible dedication, flexibility and imagination that are required to create the type of research that will be spoken of in another 100 years.

While it can be practically said that a lab is simply a collection of tools and devices that enable you to further your ideas and research, working in NRC labs feels different somehow. It quickly becomes an extension of you. Even though many of us work in completely different fields, there is a sense of unity and connectedness. It is a place where people of all backgrounds and from countless places come together to share ideas, to challenge the status quo and to ultimately succeed together. Even if you leave, you tend to take it with you, much like a 75th anniversary mug.

Alan Steele, National Research Council of Canada
Guest Editor, *Physics in Canada*

*Comments from readers on this foreword are more than welcome.*

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# CÉLÉBRATION DU 100E ANNIVERSAIRE DE LA PHYSIQUE AU CNRC

Une chope a marqué le début de ma carrière au CNRC. Plus précisément une chope du 75e anniversaire que l'on m'a remise à mon arrivée dans l'équipe du campus en 1991. Comme c'est palpitant, chope à la main, d'écrire l'avant-propos d'articles rédigés par des gens que j'ai connus et respectés tout au long de ma carrière scientifique, pour saluer le 100e anniversaire du CNRC. Et même si la liste de l'ensemble des réalisations dont j'ai été témoin serait beaucoup trop longue, l'évocation de ces années suscite une agréable nostalgie.

Einstein a passé sa vie à élargir la portée de la physique et des mathématiques. Sa dernière obsession a été d'établir une théorie unifiée. En 1923, il a affirmé : « l'intellect en quête d'une théorie intégrée ne peut se contenter de l'hypothèse qu'il existe deux domaines distincts, tout à fait indépendants l'un de l'autre de par leur nature ». Et même s'il peut avoir finalement échoué et, ironiquement, s'être trouvé de plus en plus isolé par ses travaux, la notion d'interdépendance — soit que toutes choses peuvent être reliées à un concept plus vaste — est très attrayante.

Nous sommes vraiment interdépendants, surtout si l'on œuvre dans ce domaine. Au milieu de nos obsessions personnelles, il est facile d'oublier à quel point nous influençons nos collègues ou sommes influencés par eux. Plus étonnant est le fait de savoir à quel point cette influence nous imprègne, même ceux qui ne sont plus là. « Aucun homme n'est une île, entière en elle-même; tout homme est une fraction du continent, une partie du tout. La mort d'une seule personne me diminue, parce que je suis solidaire du genre humain ». Nous avons été diminués par le départ de certains grands esprits, mais leurs réalisations nous élèvent encore. Pour notre part, nous plantons des arbres commémorant leur apport et reconnaissant à quel point leur présence est toujours d'actualité de façon qu'ils puissent continuer à en inspirer d'autres. Je baigne moi-même dans leurs contributions qui me rappellent le caractère unique du CNRC.

Même si ce sont nos travaux sur le Système international, dont la nouvelle définition du kilogramme et du Kelvin, la découverte du mode d'assemblage réel des molécules, l'attoseconde, la découverte de l'ADN, le radar, le mât tubulaire télescopique transportable (ou STEM, c'est à dire Storable Tubular Extendable Member), ou la technologie d'imagerie en 3D, suivre les traces de ces géants de la science peut parfois être décourageant. Même si ces personnes ne sont plus toutes au CNRC, ce lien demeure très perceptible. Certaines ont commencé à travailler dans les universités; d'autres sont passées par la l''Agence spatiale canadienne, et d'autres encore ont occupé divers postes au sein de l'ACP. Vraiment, le monde est paradoxalement aussi petit qu'il est grand. Peu importe l'endroit ou ils sont actuellement, je suis incroyablement fier de leurs réalisations et c'est pour moi un privilège de faire partie d'une organisation qui continue d'exercer son influence sur le Canada et sur le monde depuis ses tout débuts, il y a 100 ans.

De grands changements sont survenus en physique au cours de ma vie et je n'ai été témoin que d'une petite partie de l'ensemble. Une part importante des travaux réalisés au CNRC est exposée dans les articles qui suivent, rédigés en vue de la célébration pour le numéro que vous lisez.

Les auteurs de ces articles, célébrant les nombreuses réalisations des chercheurs du CNRC au cours des 100 dernières années, sont des chefs de file dans leurs domaines. Ils vous feront vivre certains moments parmi les plus marquants de l'histoire de la physique au CNRC, et ils mettront en lumière le dévouement, la souplesse et l'imagination remarquables que requiert l'instauration du type de recherches dont on parlera encore dans 100 ans.

Même si l'on peut affirmer en pratique qu'un laboratoire n'est qu'une série d'outils et de dispositifs qui permettent de faire avancer des idées et des recherches, travailler dans les laboratoires du CNRC laisse une impression quelque peu différente. Cela devient rapidement un prolongement de soi. Même si beaucoup d'entre nous travaillent dans des domaines tout à fait différents, nous partageons un sentiment d'unité et d'interdépendance. C'est un endroit où des gens d'origines diverses et d'innombrables endroits se réunissent pour échanger des idées, remettre en question le statu quo et finalement réussir ensemble. Même en quittant, on a tendance à les emporter avec soi, un peu comme une chope de 75e anniversaire.

Alan Steele, Conseil national de recherches du Canada
Rédacteur honoraire, *La Physique au Canada*

*Les commentaires de nos lecteurs (ou) lectrices au sujet de cette préface sont les bienvenus.*

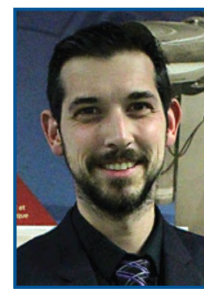
*NOTE : Le genre masculin n'a été utilisé que pour alléger le texte.*

All photos that appear in the feature articles on pages 189 to 207 were provided courtesy of the NRC Archives.

*Toutes les photos qui apparaissent dans les articles de fond des pages 189 à 207 sont une courtoisie du service d'Archives du CNRC.*

# A CENTURY OF PHYSICS AT THE NATIONAL RESEARCH COUNCIL OF CANADA (NRC)

BY HÉLÈNE LÉTOURNEAU AND PAUL RENAUD



## BIG IDEAS HAVE HUMBLE BEGINNINGS (1916-1938)

When first established in 1916, the National Research Council of Canada (NRC) was instructed to coordinate and promote scientific and industrial research in Canada. Members of the newly established organization soon realized that few of Canada's companies even had research labs, and those that did had labs so small they were staffed by a single person. Canadian universities presented no better opportunity as fewer than a dozen PhDs in Pure Science had been granted up to that point. In addition, Canadian research in physics was almost entirely published in foreign journals. NRC's members recognized these limitations to be gravely problematic, being a major impediment to the development of an industrializing nation.

NRC would address this compound problem in a few key ways. NRC's first priority became expanding research in Canadian universities through grant programs and scholarships. To ensure research into industrial and social needs would remain paramount in Canada, NRC's second priority was to establish its own laboratories. Interestingly, NRC performed research in rented lab spaces until 1932, when the Sussex Drive laboratories in Ottawa opened.

H.M. Tory, a physicist from the University of Alberta, was appointed as NRC's first full-time President in 1928. In the short span of a year, nearly 600 people worked at the organization and the first edition of the *Canadian Journal of Research* was published, finally providing a forum for consolidating results in a Canadian publication. A few years later, the journal was split into subsections. *Section A,* devoted exclusively to the physical sciences, would eventually evolve into the *Canadian Journal of Physics*.

Hampered by the resource restrictions of the Great Depression, NRC conducted applied research for non-military industrial problems. Physics-related research dealt primarily in acoustics, electrical measurement, radio, radiology, metrology and standards. After A.G.L. McNaughton was appointed NRC's new president in 1935, research efforts began incorporating a more militaristic angle. By 1937, NRC was deep in discussion with the Department of National Defence regarding the possibility of developing aircraft-detecting technology. On the eve of the Second World War, NRC was poised to mobilize national science for Canada's Allied R&D effort.

**SUMMARY**

**From microelectronics to the atmospheres of stars, NRC's achievements in physics have expanded our knowledge and impacted Canadians and the entire world for over a century.**

## WWII, THE PHYSICIST'S WAR (1939-1945)

The First World War is often considered a chemist's war because of the agents that were used in the manufacture of lethal gases and explosives. If that is so, the Second World War was undoubtedly a physicist's war. With NRC at the helm, Canada's wartime efforts pioneered research and development in radar, nuclear energy, optics and many other technologies.

One of the most important scientific developments of the War resulted from the Tizard Commission to the U.S. and Canada. The Commission divulged British secrets of military science, including the cavity magnetron and the proximity fuse. At the insistence of the British, U.S. and Canadian governments mounted massive programs to develop radar, particularly microwave radar. Canadian researchers improved the designs for the cavity magnetron, and found resources to produce enormous supplies for the war effort, all in absolute secrecy. In total, 12 types of radar were mass-produced, and smaller quantities of 20 other types were manufactured for the military.

By July 1940, Canada established Research Enterprises Limited (REL), a crown corporation in Toronto, to mass produce both optical and radar equipment for the Allied forces. NRC researchers were involved in other projects for the war effort, including the development of a prototype sonar system for defense against acoustic torpedoes, and the development of degaussing countermeasures for ships at the Bedford Basin near Halifax.

In Ottawa, George Laurence began construction of a nuclear pile in the Sussex Drive laboratories, using half a ton of uranium oxide and ten tons of calcined coke. While

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and

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Operations room for ground control radar detection of aircraft during WWII. NRC was the center of Canadian research and development on radar technology such as CHL and GL radars, ASV Mk. II, IFF transponders, height finder radar and microwave-frequency early warning radar. By 1945, NRC had developed about 30 different types of radar for various military purposes. (1943)

unsuccessful due to the lack of quality of the materials, Laurence did achieve Canada's first nuclear fission. Much was learned from this area of research leading to the creation of a joint Canada-U.K. nuclear laboratory in Montreal.

By war's end, NRC provided the foundation for new industries, hi-tech manufacturing and atomic energy.

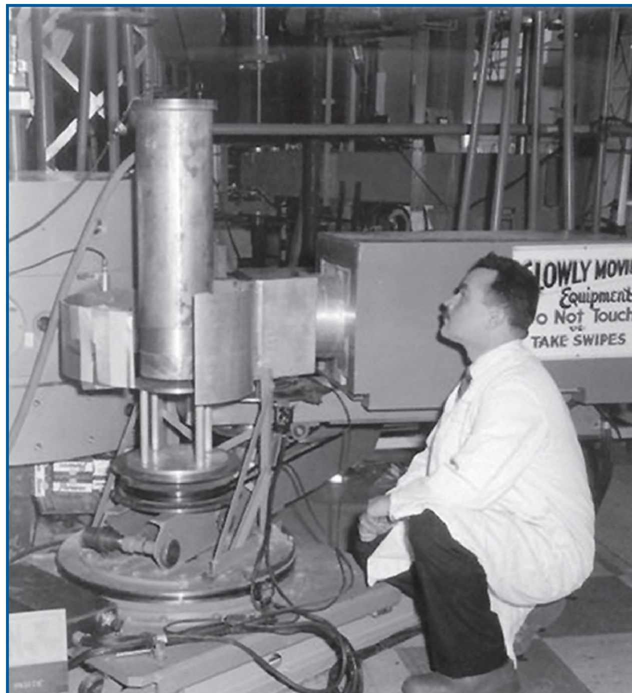
## NRC GOES ATOMIC (1945-1959)

The credibility gained by NRC's wartime activities resulted in increased government support for its post-war objectives. Despite having redirected its focus for a time, NRC's original goals were to promote research at Canadian universities, to build research capabilities in Canadian industry, and to grow world-class research excellence in its own laboratories.

During this period, university grants and scholarships grew substantially, and in 1949, NRC began its Post-doctorate Fellowship (PDF) program. Not only did this keep new blood flowing through the NRC labs, it created a pool of qualified young physicists, many of whom moved on to Canadian universities and industry. The Industrial Research Assistance Program (IRAP)—also created during this period—successfully supports Canadian business R&D to this day.

In NRC labs, measurement and standards achieved its research excellence goals, and by 1958, the world's first continuously-operating cesium clock was Canada's primary time standard. As NRC returned to demilitarized research, its early nuclear energy program would form the basis for nuclear medicine.

Canada successfully collaborated with Britain and France to design ZEEP, Canada's first operational nuclear reactor. NRX was developed in 1947, which was the world's top reactor




Dr. Bertram Brockhouse pioneered inelastic neutron scattering, a technique that measures the dynamics of atoms in materials. In this picture Brockhouse is seen working with his spectrometer at NRU (Nov. 1958 - Jul. 1959).

for several years. Its successor, NRU, is today the world's oldest operating reactor. Its ongoing applications include developing and producing medical isotopes to diagnose diseases and treat cancer, testing for reactor fuel and components, designs for CANDU power reactors, and producing neutrons for research.

It is interesting to note that Natural Resources Canada cites nuclear as the second largest contributor of non-emitting electricity, powering 16% of the Country, and 60% of Ontario. As at 2014, this sector provided 30,000 direct jobs to the Canadian economy.

## ALL RESEARCH, BIG AND SMALL (1960-1989)

During this period NRC transferred its university granting function to the Natural Sciences and Engineering Research Council of Canada (NSERC), and NRC shifted its first priority to the support of industrial-directed research.

The world's first Microtron, a type of electron accelerator, had been built at NRC in 1947-48, and while it was eventually transferred to the University of Western Ontario, NRC played a substantial role in helping to build a capacity for particle physics in Canada, including major initiatives such as TRIUMF, the Canadian Light Source and the Sudbury Neutrino Observatory (SNOLAB).

The Dominion Radio Astrophysical Observatory in Penticton (DRAO), houses a 26-metre telescope and was one of two observatories to first use Very Long Baseline Interferometry or VLBI to create high-precision images by merging radio signals with another observatory located 3074 kms away in 1967. (Circa 1970)

After assuming stewardship for the Dominion Astrophysical Observatory (DAO) and Dominion Radio Astrophysical Observatory (DRAO) in 1970, NRC took astronomy to new heights with the construction of the Canada-France-Hawaii Telescope (CFHT). CFHT was only the beginning. Its construction led to the creation of other partner observatories, further establishing Canadian firms and engineers as experts in the design, manufacture and construction of instruments and enclosures. While these observatories have reported incredible astronomical discoveries, they have also yielded advances for industry, including high-performance computing systems, stealth aircraft detection and GPS operation.

In 1967, using recording equipment from the Canadian Broadcasting Corporation, NRC astrophysicists were the world's first to successfully merge observations using very long baseline interferometry, or VLBI, across a vast distance with two radio telescopes–DRAO in Penticton, British Columbia, and ARO in Algonquin Park, Ontario.

Canada's pioneer in molecular spectroscopy, Gerhard Herzberg, was awarded the Nobel Prize in 1971. Herzberg explored the energy content and properties of molecules using the new science of spectroscopy to study phenomena outside the visible region of light. Herzberg's pioneering interest was free radicals, and before winning the Nobel Prize, he had determined the properties of more than 30 free radicals, including methyl and methylene.

NRC designed protocols for testing loudspeakers, using an anechoic chamber. Floyd Toole, a psychoacoustics pioneer, worked with Canadian speaker makers in the 1970s to develop and refine tests for clarity, definition, fullness and exactness in sound reproduction, or fidelity. The Audio Engineering Society published Toole's research, which became a worldwide benchmark for audio evaluations.

Dr. Gerhard Herzberg, 1971 Nobel Laureate in Chemistry, analyzing spectrograms at his desk. Herzberg discovered the internal geometry and energy states in simple molecules. One important focus of Herzberg's was the study of methylene, or $CH_2$, a very unstable molecule known as a "free radical." (Circa 1990)

NRC began researching optical filters in 1956, and moved on to thin-film coatings. That work has been fundamental to technology for communication networks, semiconductor and electronics manufacturing, medical and research instruments based on fluorescence, anti-counterfeiting banknotes, space programs and more.

This was a period of accelerated change, where the various scientific disciplines' naming conventions no longer reflected NRC's growing ties to industry. The Physics Division was transformed into institutes, such as the Institute of Microstructural Sciences, created for solid state physics and optoelectronics to support the semiconductor industry.

By 1989, NRC brought together members from universities, government departments and industry to form the Solid State Optoelectronics Consortium (SSOC), which established wavelength de-multiplexing, a technology at the core of today's optical communications networks.

## NRC'S DAYS OF FUTURE PAST (1990-PRESENT)

At the beginning of this period, NRC experienced a heightened awareness of environmental, health and security issues—trumped only by the challenges Canadian industries faced in order to compete globally. NRC would adapt its existing technologies for broader application across industry sectors. For example, NRC developed 3D scanning technology for manufacturing, and honed it for aerospace engineering. An interesting secondary use of the technology enabled blockbuster creatures to come to life for

One of NRC's acoustic labs, an anechoic chamber built to absorb sound and eliminate echo, allowed NRC metrology experts to pioneer science-based methodologies still used today for measuring loudspeaker performance. (Circa 1980)

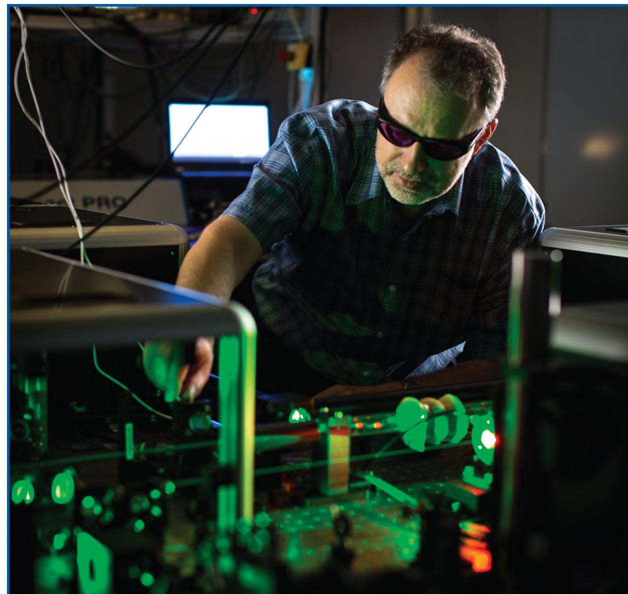
Peter Jackson's *Lord of the Rings* and *King Kong*. Recently, the scanner's microscopic 3D details have even appeared in video games and a U2 music video. These examples show the broad influence and applicability of the work NRC performs.

Members of a multi-year, international astronomy project called the Gemini Deep Deep Survey (GDDS) began peering into our universe's distant past. Working at the Gemini Observatories, NRC and its partners developed a technique that greatly improved long-range observation. What the GDDS team found as a result amazed them. Massive galaxies were discovered dating back from nine to 11 billion years. Until 2003, astronomers believed that only newly-forming galaxies existed during that epoch. GDDS raised fundamental questions about theoretical and cosmological models of the early universe.

In 2005, scientists at the National Institute for Nanotechnology (NINT), an NRC partnership with both the provincial government and the University of Alberta, found a way to create transistors on a molecular scale, which could pave the way for smaller, faster and cheaper microelectronics devices. Switching the current flowing through a single molecule on and off by changing the charge state of an adjacent atom, essentially turned a molecule into a transistor. A technology based on this concept would use much less energy, produce less heat, and run much faster than conventional technology.

Later, NRC researchers developed one of the world's most powerful adaptive-optics systems, known as Altair. Altair, and recent advances in image-processing technology, led an international team of astronomers to reach a milestone in the search for other worlds, capturing the first-ever images of planets circling a star other than the Sun in 2008.

In recent years, Paul Corkum and his team at NRC and the University of Ottawa have received worldwide honours for spectacular advances in probing atomic and molecular reactions. Researchers have created laser pulses as short as 150 attoseconds, or the time it takes an electron to make one orbit around a hydrogen atom. Dr. Corkum's work has opened a window to observe not just the motion of atoms, but the motion of electrons within atoms.



Dr. Andrei Naumov, NRC researcher at the NRC - University of Ottawa Joint Laboratory for Attosecond Science (JASLab), adjusts the calibration on ultrafast laser system that produces 80 million pulses of light every second. Each laser pulse is so precisely controlled it is accurate to 1 part in a trillion. (2007)

Nano-spintronics is a relatively new field in which an electron's spin is used to increase the capabilities of devices and circuits. NRC researchers have found a way to control and detect the spin states of a single electron, an advance that could make it possible for an electron's spin to act as the unit, or "bit", of information. The "single-spin transistor" could revolutionize how information is stored and processed. This research plays a fundamental role in quantum computing.

In Metrology, NRC succeeded in reducing the uncertainty of its watt balance—a device used in the determination of Planck's constant—to 15 ppb, making it the Kibble balance with the least uncertainty to date. That experiment, acknowledged by *Nature Magazine* as one of the hardest known to science, is part of a global, multi-decade effort. NRC's watt balance results pave the way for the kilogram's redefinition in 2018.

NRC has been a part of many of the greatest physical achievements over the last century. A cornerstone of the organization has been its support for science, experimentation and exploration, deeply rooted in social responsibility, to deliver the technologies of tomorrow—a foundational principle that has been true throughout NRC's 100-year history and will remain true tomorrow.

# QUANTIFYING OUR WORLD

BY DAVID J. LOCKWOOD AND NELSON L. ROWELL

Behind virtually everything that the public uses and consumes is the science of metrology, which is constantly evolving with society's needs. In this science, we measure physical quantities related to everyday experience. If you have ever been late for a meeting, had to run to work, go to the gym or turn on the air conditioning, you have experienced the results of the work of metrologists: time, distance, weight and temperature, are all studied.

Take time, for instance. Instead of being related to the size of the earth as it once was, the metre is now more accurately defined as how far light travels in a certain amount of time. Since the speed of light is a fundamental constant, it will not change based on environmental factors. A second of time—central to most aspects of life—is defined in terms of an atomic transition in cesium. However, as our measurement capabilities improve and are transformed, the methods of realizing the units also change. In some cases, the changes are revolutionary as they were for the Josephson volt and the quantum Hall standard for resistance. Normally, such changes in how the units are defined are not something that the general public would notice, but, ultimately, it does affect everyone.

Satellites sensing the environment, must accurately measure how much sunlight we catch to gauge its influence on global warming. Stock exchanges must time-stamp their trades with increasing accuracy. The Toronto Stock Exchange recently asked the National Research Council (NRC) for direct access to its detailed time signal—based on atomic clocks—so they can more precisely time-stamp their increasingly rapid transaction rates.

Perhaps the most visible example of the work metrologists perform is in the form of a 1965 request from then Prime Minister Lester Pearson, who entrusted NRC with the responsibility of establishing colour specifications for Canada's national flag. Today, Canada's red is a source of international pride that can withstand the tests of the elements.

**SUMMARY**

**The science of metrology is constantly evolving to meet the physical needs of society. Over the past century NRC has led the way in many areas of primary metrology, which have benefitted Canadian society considerably – and will continue to do so.**

Metrology is also critical to economic and industrial development. Impact studies indicate that it lowers transaction costs, contributes to energy conservation, increases research and development (R&D) efficiency and product quality, and enables new markets. Even though most never directly see the impact of this research directly, the financial return on the research investment is anywhere from 5 to 100 times. In other words, it literally pays to be precise!

NRC began expanding its metrology activities in the 1930s [1], and is now home to one of the world's most respected standards laboratories. Almost from its inception, NRC has played the role of Canada's highest-level metrology institution, and over the years has become one of the global leaders in measurement science. Most countries have their own National Metrology Institutes (NMIs), with the international coordinating body for such high-level metrology being at the Bureau International des Poids et Mesures (BIPM) in France.

At NRC, we ensure that Canada's measurements can be traced back to the International System of Units (SI), through our own independent realization of the units. This protocol is common to most countries and intercomparison establishes the level of equivalence among national measurement systems.

## RECALIBRATING MEASUREMENTS

The SI comprises seven base units (see Fig. 1a and Table 1): metre (m), kilogram (kg), second (s), ampere (A), kelvin (K), candela (cd) and mole (mol), all of which need to be stable and realizable everywhere. As long ago as 1900, Max Planck noted that, if based on fundamental constants of nature, the units would "necessarily retain their validity for all times and cultures, even extra-terrestrial and nonhuman." Although he could not have foreseen the changes that now drive the redefinition of some units, he was quite correct—prescient even—in his assertion.

It is now likely that in 2018, countries around the world will agree to changes in the definitions of the SI base units. It is proposed that the kilogram, ampere, kelvin and

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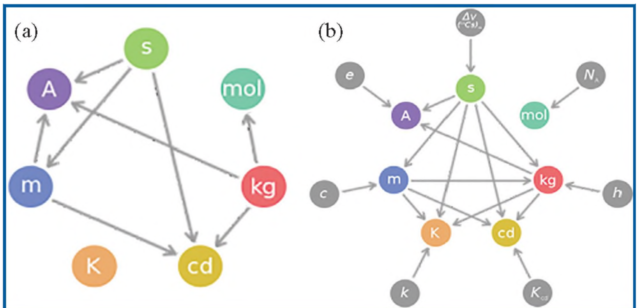


Fig. 1 (a) The diagram depicts the current SI in 2016. The arrows show the dependence of base unit definitions on other base units (for example, the metre is defined in terms of the distance travelled by light in a specific fraction of a second). For definition of units see Table 1. (b) Proposed SI for possible adoption in 2018. The dependence of base unit definitions is on physical constants with fixed numerical values and on other base units that are derived from the same set of constants.

mole be redefined by choosing exact numerical values for, respectively, the Planck constant, the elementary charge, the Boltzmann constant and the Avogadro constant (see Fig. 1b and Table 1). In this endeavour, NRC scientists provided significant contributions and/or leadership to the development of the new kilogram, kelvin and mole.

## NEW KILOGRAM

For 126 years, *Le Grand K*, a platinum and iridium cylinder housed at BIPM in Paris (see Fig. 2), has defined the kilogram, being the only SI unit remaining based on a physical object.

Since the cylinders were manufactured in 1889, mass differences as large as 50 micrograms have been detected between the *Le Grand K* and its six official copies. Such variations are certainly within present measurement resolution, and cast into doubt the stability of the mass of *Le Grand K*, and hence that of the international mass unit. As a result, it was proposed that the standard kilogram be defined not in terms of a physical artifact, but through a physical experiment, relating the kilogram to the value of the Planck constant. In this new definition, the kilogram will also be dependent on the second and the metre.

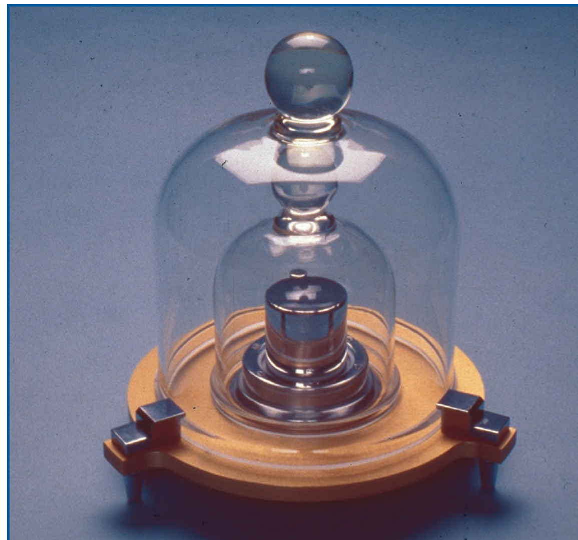

Fig. 2 Nested within several bell jars, rarely handled and stored in a controlled environment secure in a vault near Paris, *Le Grand K* is the artifact that presently defines the official SI unit of mass.

Counting atoms, as in the Avogadro Project [2], and weighing using watt balances [3] are the two distinct physical methods proposed to establish a mass unit that is not based on an artifact. It is required that both methods be so precise that their measurement uncertainties are less than 20 parts per billion (ppb).

In the international Avogadro Project, NRC has made a significant contribution by establishing the relative isotope ratios

**TABLE 1**

PHYSICAL CONSTANTS AND BASE UNITS EMPLOYED IN THE CURRENT AND PROPOSED SI.

| Physical constants | | Base units | | |
|---|---|---|---|---|
| Constant | Symbol | SI quantity | Unit | Symbol |
| Velocity of light | c | Length | metre | m |
| Planck constant | h | Mass | kilogram | kg |
| Hyperfine transition frequency in cesium | Δν (Cs) | Time | second | s |
| Elementary electric charge | e | Current | ampere | A |
| Boltzmann constant | k | Temperature | kelvin | K |
| Luminous efficacy | $K_{cd}$ | Light | candela | cd |
| Avogadro constant | $N_A$ | Molecular weight | mole | mol |

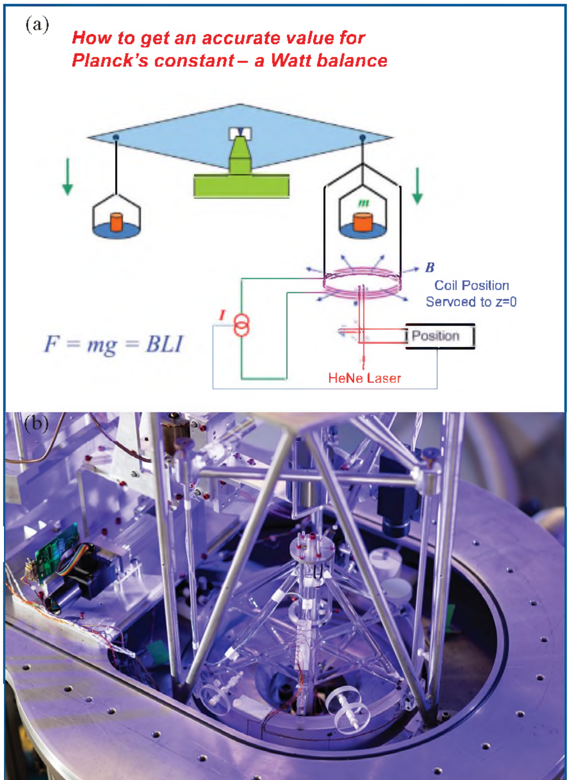


Fig. 3 NRC has recently completed a critical experiment – measuring the Planck constant to high accuracy using a watt balance, such that the measurement uncertainty is now below 14 ppb. The results are crucial to the redefinition of the SI kilogram. (a) In the upper panel, above, is a schematic of the watt balance in which the gravitational force due to the presence of a mass, $m$, is shown balanced by the electromagnetic force caused by the current through a coil. (b) In the lower panel, above, is a photograph of the NRC watt balance, with its vacuum cover removed.

in the silicon spheres nominally composed of a single isotope (mass 28), used in the atom-counting measurements of this project. Accurate knowledge of the trace amounts of the other isotopes provided by NRC allowed the Avogadro Project team to improve their value for Avogadro's constant, which they converted into a value for the Planck constant that was more accurate than their previous one.

A watt balance is used to produce a value for Planck's constant by weighing a test mass calibrated against an electromagnetic force (see Fig. 3a). NRC's metrology laboratory in Ottawa has the world-leading watt balance experiment (See Fig. 3b), presently providing values for the Planck constant with the lowest uncertainty ( $<$ 15 ppb) of any such experiments. The NRC team has continually reduced the uncertainties in their results by analyzing and lowering systematic uncertainties. Currently, and significantly, NRC's results have the lowest uncertainties.

In a 2014-15 evaluation of NRC's programs, the report stated that other NMIs recognized NRC as "having made a noteworthy contribution to key metrology research developments, specifically the redefinition of the kilogram. Using experiments based on the watt balance, NRC has been able to achieve the most precise determination of the Planck constant to date." As stated by one international NMI interviewee, "unequivocally, this has been a major contribution to fundamental metrology." In recognition of its expertise in metrology, NRC has recently been invited to join the Consultative Committee for Units.

While the idea of redefining the kilogram in terms of electrical quantities has been around for some time, the accuracy and stability of electrical measurements has improved tremendously over the years, taking advantage of quantum phenomena in the Josephson and von Klitzing effects. Because electrical quantities are now based on fundamental constants, we know they are very accurate and stable. Such advances in measurement science allow us to build a mass unit based on electrical quantities, so that we can retire the kilogram artifact [4].

## NEW KELVIN

Most practical temperature measurement around the world is based on a defined scale, the International Temperature Scale of 1990 (ITS-90), which relies on the best temperature values at fixed points (e.g., melting or freezing). This approach to evaluating temperature now has a number of issues. We know that, with better measurement methods now available, the temperature values derived using ITS-90 and the actual (thermodynamic) temperatures are not exactly the same. While these differences would not be noticed by—nor likely all that important to—the average person, some more specialized applications do need to use exceptionally accurate temperatures, more so than those afforded by ITS-90, especially away from the fixed points.

As an example of calibration accuracy and its significance to society, we know that climate-monitoring satellites are intended to provide us with actual (thermodynamic) temperature quite accurately in the environmental range between approximately $-70$ and 50 degrees Celsius. As the lower part of this range is one of the places where there are significant deviations between ITS-90 and thermodynamic temperature, measurements referenced to calibration devices internal to the satellites using ITS-90 have to be corrected before the results are used, for example, in physical models.

The definition of the kelvin is undergoing a fundamental change. Rather than using the triple point of water to fix the temperature scale, it will be based on a fixed value for the Boltzmann constant; however, the temperature at the triple point of water will remain the same [5]. NRC, through its mastery of primary thermometry, is now one of the world leaders in this area.

Another illustration of the importance of controlling calibration uncertainty was noted in radiometry and radiation thermometry several years ago with the controversy about the amount of sunlight (total solar irradiance) incident outside the atmosphere [6]. Over the years, beginning in the late 1970s, space-based measurements of solar irradiance were made on a continuous basis with a series of radiometric instruments. The results contained significant differences between the radiometers, generation to generation, due to a small but overlooked source of calibration uncertainty. This resulted in inter-instrument variances of a few watts per square metre, which, although only 0.3% of the total, were significant relative to the other radiation components that comprise the current global radiative energy imbalance. This particular calibration uncertainty was corrected with more accurate metrology, which will also be required to evaluate the reliability of the measurements in the long term.

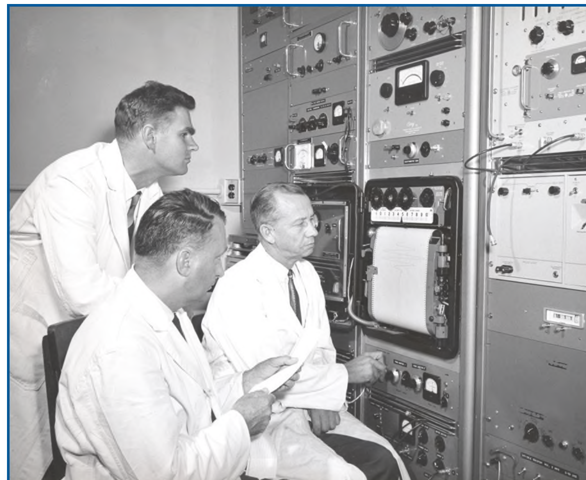

Fig. 4 In 1965, NRC employees Allan Mungall, Herman Daams and Ralph Bailey check out a chart recording of the Ramsay fringes originating from NRC's primary, atomic beam, cesium clock of the day.

## TIME (THE SECOND)

Time measurement, the most accurate metrology, has always been based on the idea of an oscillator, e.g., as in the pendulum. Even atomic clocks measure the natural microwave oscillation of an atomic transition in cesium. From the 1950s onward, NRC metrologists were early innovators (see Fig. 4) of this type of technology [7,8,9], building some of the first – and finest – cesium clocks with high-quality frequency and time-measurement capabilities [10].

Today, although the precision of cesium clocks has been somewhat surpassed by optical frequency standards, the unit of time is still based on cesium standards. Nonetheless, we should still be aware that the present cesium atomic clocks have extremely low uncertainties (less than one part in $10^{16}$). This amount is less than a nanosecond per century, so that if such a clock were running continuously, it would take about 100 million years to be out by a second. Further improvements in precision could, however, still be significant in various areas.

## CONCLUSION

Although its metrology programs are relatively small by international standards, NRC continues to be one of the world's top NMIs, and has contributed significantly to the developments leading toward the new SI. Over the past century NRC has led the way in many areas of primary metrology, which have benefitted Canadian society considerably—and will continue to do so. Perhaps, by that standard, we would need to revisit how we measure the size of metrology programs. If such a redefinition were to take place, NRC would no doubt be at the forefront, ready to tackle the challenge.

## REFERENCES


1. W.E.K. Middleton, "Physics at the National Research Council of Canada, 1929-1952", Wilfred Laurier Press, Waterloo, Ontario, Canada, (1979).
2. L. Yang, Z. Mester, R.E. Sturgeon and J. Meija, "Determination of the atomic weight of $^{28}$Si-enriched silicon for a revised estimate of the Avogadro Constant", *Analytical Chemistry*, **84**, 2321-2327 (2012).
3. C.A. Sanchez, B.M. Wood, R.G. Green, J.O. Liard and D. Inglis, "A determination of Planck's constant using the NRC watt balance", *Metrologia*, **51**, S5-S14 (2014).
4. R. Davis, "The SI unit of mass", *Metrologia*, **40**, 299-305 (2003).
5. J. Thomson, "A quantitative investigation of certain relations between the gaseous, the liquid, and the solid states of water-substance," *Proceedings of the Royal Society*, **22**, 27-36 (1873).
6. G. Kopp and J.L. Lean, "A new, lower value of total solar irradiance: Evidence and climate significance", *Geophys. Res. Lett.*, **38**, L01706 (2011).
7. S.N. Kalra, R. Bailey, and H. Daams, "Cesium Beam Standard of Frequency", *Canadian J. Phys.*, **34**, 1442-1443 (1958).
8. S.N. Kalra, R. Bailey, and H. Daams, "Canadian Cæsium-Beam Standard of Frequency", *Nature*, **183**, 575-576 (1959).
9. A. G. Mungall, R. Bailey and H. Daams, "The Canadian Cesium Beam Frequency Standard", *Metrologia*, **16**, 98-104 (1966).
10. P.A. Redhead, "The National Research Council's Impact on Canadian Physics", *Physics in Canada*, **56**, 109-121 (2000).

# THE GREAT LEAP FORWARD: NRC AND THE MICROSCOPIC STRUCTURES AND TRANSFORMATIONS OF MATTER

BY ALBERT STOLOW

While Physics deals with matter and energy, the world of physics research is human. Discovery and innovation emerge from individual creativity, collaboration, engineering advances and cultural receptivity—all of which influence the progress of science. As we revisit NRC's 100 years of contributions to physics, we celebrate our pioneers in chemical physics, epitomized by the 1971 Nobel laureate G. Herzberg.

As someone who has had the good fortune to be a part of NRC's chemical physics story, I am pleased to have the opportunity to share a few personal views on NRC's outstanding legacy.

## THE GREAT LEAP FORWARD: THE STRUCTURE OF MATTER

Classical physics describes the everyday world of projectiles, bridges and balls rolling down hills. It fails dramatically in the microscopic world of electrons and atoms – and especially for their interactions with light. In a sense, quantum mechanics was forced upon us by the need for an explanation of the light absorbed or emitted by atoms, or, for the case of black body radiation, matter in general.

One hundred years ago, physicists had little idea of the structure of atoms, molecules or solids. It is hard for us to imagine that, in 1900, even their existence was hotly debated, with L. Boltzmann taking the side of the Atomists and E. Mach the side of the Energists. Boltzmann was greatly depressed and, tragically, took his own life in 1906, seemingly unaware that Einstein had presented some of the most compelling support for the atomic theory just the year before. Quantum theory, in combination with the light-matter interactions of spectroscopy and diffraction, led to a great leap forward for humankind: an understanding of the microscopic structure of matter. It is hard to overstate the significance of this development. Quantum mechanics and spectroscopy gave us the detailed structure of molecules, solids, biomolecules, drugs, etc. It led to the development of things we take for granted today, such as computers, semiconductors, transistors, the atomic bomb and pharmaceuticals. In the field of molecular biology, it helped us understand the shape of DNA molecules and make predictions that opened doors to vast new fields, including genetic engineering.

**SUMMARY**

**As we revisit NRC's 100 years of contributions to physics, we celebrate our pioneers in chemical physics, such as the 1971 Nobel laureate, Gerhard Herzberg.**

## MOLECULAR SPECTROSCOPY—THE STUDY OF STRUCTURE

Spectroscopy, the study of the interactions between electromagnetic radiation and matter, was critical to the development of our fundamental theories, including quantum mechanics, relativity and quantum electrodynamics. To date, more Nobel prizes (currently 76) are related to light-matter interactions than any other discipline in physics.

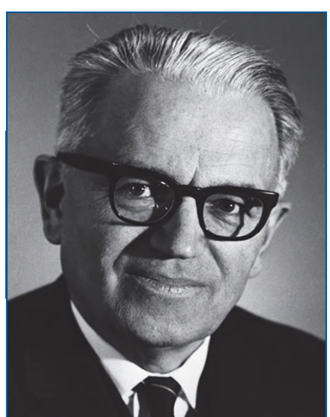

Fig. 1 Gerhard Herzberg, the Father of Molecular Spectroscopy, spent over 50 years at the NRC. Source: NRC Archives

In this domain, NRC played a pivotal—and Nobel Prize-winning—role thanks to Gerhard Herzberg (Fig. 1), the father of molecular spectroscopy, who was a member of NRC's Division of Physics for nearly 50 years. Herzberg's spectroscopy taught the world about the detailed structure of molecules, arguably one of the most significant contributions to our understanding of nature.

At the 1971 Nobel awards ceremony in Sweden, S. Claesson of Royal Academy of Sciences summed

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up Herzberg's immense stature in the field: "... 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." [1]

At Herzberg's birth in 1904, the concept of an electron was just catching on. When he attained his PhD in 1927, researchers had yet to discover how atoms combined to form molecules. Herzberg continued his studies at the University of Göttingen, Germany – the birthplace of quantum mechanics – working with Max Born and James Franck. After immigrating to Saskatoon in 1935, Herzberg joined NRC's Division of Physics in 1948, and remained active until 1994. In 1975, NRC established the Herzberg Institute of Astrophysics.

NRC became the world centre for molecular spectroscopy, receiving visitors and post-doctoral scientists from around the world. These included luminaries such as A. Dalgarno from Harvard, H.C. Longuet-Higgins from Cambridge and the future Nobel prizewinners D. Herschbach, R. Curl and H. Kroto.

Herzberg's legacy also includes his trilogy of books on molecular spectroscopy, nicknamed the "Spectroscopy Bible". According to Herzberg biographer and former NRC researcher Boris P. Stoicheff, he "... devoted Saturdays for fifteen years to the writing of this book, no matter whether he was in Ottawa or on travels to conferences or on other business. At the NRC we all understood we would not see him on Saturdays." [2]

Fig. 2 EWR (Ned) Steacie was a leading chemical kineticist who additionally became an NRC President and played a seminal role in developing science policy within Canada. Source: NRC Archives

Today, spectroscopy is in use everywhere, whether in quantum devices, chemical sensors, medical devices or an endless array of analytical equipment. In a very real sense, NRC's investment in molecular spectroscopy changed the world.

## CHEMICAL KINETICS AND DYNAMICS: THE STUDY OF CHANGE

Nature is seldom static. There is therefore a need to understand how molecular systems change and evolve: this is the field of chemical kinetics. A world leader in chemical kinetics was Montreal native E.W.R. (Ned) Steacie (Fig. 2), a successful professor and internationally-acclaimed research authority in free radical kinetics. Under Steacie, NRC became a centre for kinetics and chemical dynamics, attracting students and researchers from around the world, including future Nobel prize winners J. Polanyi and R. Marcus. Importantly, Steacie wrote the kineticist's "bible"–*Atomic and Free Radical Reactions* (1946)–that became the essential reference book for the field. At NRC, Steacie became Director of the Division of Chemistry and then NRC President, where his influence on science policy greatly increased Canada's scientific infrastructure and capabilities. He also created the NRC postdoctoral fellowship program that contributed greatly to the vitality of NRC laboratories.

Although Herzberg and Steacie stand out, NRC's legacy in chemical physics comprises other pioneering giants. These include F. Lossing for Mass Spectrometry, H.J. Bernstein for the Resonance Raman Effect, W.G. Schneider for High Resolution NMR and W. Siebrand for Theoretical Chemical Physics.

In a real sense, my own scientific career derives from the legacies of both Herzberg and Steacie. The Ultrafast Phenomena Group of NRC's Steacie Institute for Molecular Sciences (SIMS), founded in 1990 by P.B. Corkum, comprised elements from both legacies. Following my PhD studies in chemical dynamics under J. Polanyi (Toronto), I joined colleagues D.M. Villeneuve, M. Yu. Ivanov and Corkum in 1992 to work on another offshoot of spectroscopy, the ultrafast laser, and to develop new forms of ultrashort pulse (femtosecond, $10^{-15}$ s) laser spectroscopy.

We developed powerful new methods of ultrafast spectroscopy for making real-time "movies" of chemical reactions, trying to understand how atoms and electrons dynamically rearrange during a chemical reaction. This eventually led to my founding of NRC's Molecular Photonics Group, still very active today, and my ongoing interactions and collaborations with NRC. Ultrafast molecular spectroscopy has improved our understanding of fundamental processes, such as photosynthesis and vision, and has led to advances in molecular devices, photoactivated drugs, catalysts and other light-responsive materials. P.B. Corkum went on to pioneer a completely new branch of physics, namely attosecond ($10^{-18}$ s) science, which uses the world's shortest laser pulses to probe electronic processes in atoms, molecules and solids.

## BUILDING ON THE LEGACY

An interesting offshoot of ultrafast laser technology is the development of nonlinear optical microscopy, a field initiated by W. Webb at Cornell University. Normally at low power, light interacts with matter linearly, with the linear optical response containing the refractive index and the absorption coefficient. However, when an intense ultrashort pulse is applied to matter, a nonlinear optical response develops, leading to the possibility of many new forms of spectroscopy.

A recent example is a new kind of microscopy of live cells, materials and minerals. Combining femtosecond lasers, non-linear optics and quantum control with spectroscopy, we optimized a rapid label-free, chemical-specific imaging method based on a third order nonlinear response termed Coherent Anti-Stokes Raman Scattering (CARS). Importantly, the method allows for real-time imaging of live cells without adding any dyes or stains, as shown in Fig. 3. In 2009, NRC's femtosecond laser approach led to the first commercially available CARS microscope, developed in collaboration with Olympus Corp. The method has also been applied to imaging the distributions of specific compounds, such as hydrocarbons or valuable minerals, within ores and rocks, thus opening up a new field: "geophotonics".

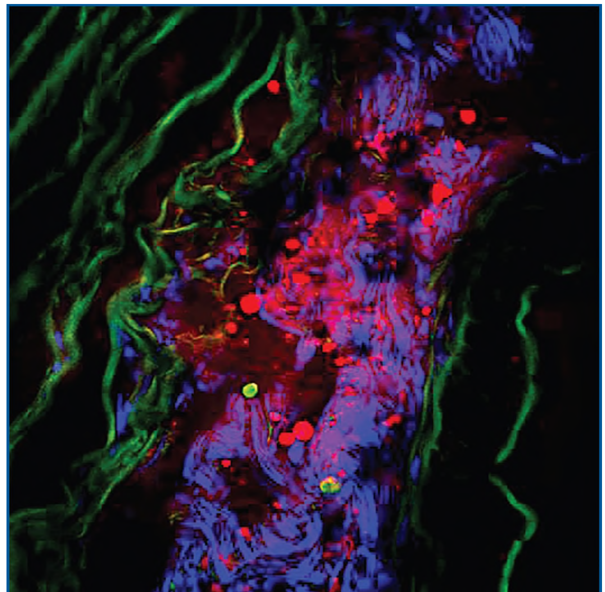

Fig. 3 A femtosecond ($10^{-15}$ s) laser method of Coherent Anti-Stokes Raman Scattering (CARS) was developed by NRC in 2007, allowing for rapid, label-free yet chemical-specific imaging of live cells, tissues, materials and minerals. The multi-modal CARS image shown above is an unstained sample of aorta from an atherosclerotic rabbit: the red shows telltale lipid droplets, the blue collagen and the green elastin. In 2009, NRC commercialized the world's first CARS microscope in collaboration with Olympus Corp. Source: Image courtesy of Albert Stolow

Underlying the NRC's 100 years of outstanding Physics research, there have always been individuals whose personal drive and curiosity led to puzzles and discoveries, dead ends and new fields, theories and innovations. This is certainly true for chemical physics and NRC's outstanding legacy in this field continues to serve Canada well. There may well be more Nobel prizes on Canada's scientific horizon, but such outcomes only reflect a sustained and serious creative effort. I would like to conclude with a quotation from a speech given by Gerhard Herzberg at a 1971 Rideau Hall banquet, celebrating the recent announcement of his Nobel Prize:

> *"... the Nobel foundation considers the Prizes in the Sciences to have the same purpose as the Prize in Literature, namely to reward contributions to the human spirit, i.e., to the cultural benefit of mankind. In science, of course, such contributions often lead to material benefits to mankind. Since one cannot predict discovery, these material benefits are usually quite unexpected and not foreseen by the scientists involved (nor of course by anyone else). The motivation of many scientists working in pure science is striving for knowledge for its own sake."*

## REFERENCES

1. http://www.nobelprize.org/nobel_prizes/chemistry/laureates/1971/press.html
2. *Gerhard Herzberg: An Illustrious Life in Science*, Boris P. Stoicheff, National Research Council Canada.

# GENERATIONS OF BIOPHYSICS: FROM NUCLEOTIDES TO NUCLEAR MAGNETIC RESONANCE

BY LINDA J. JOHNSTON

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Over the past century, biophysics has led to game-changing discoveries that are now part of mainstream vocabulary. Research in this field has led to the creation of diagnostic imaging tools that are in high demand today, although often taken for granted, such as the MRI, CT and PET scans. It is also the foundational science allowing the popular discussion of pros and cons of antioxidants.

An interdisciplinary science, biophysics has changed how people view the functioning of biological systems, and has helped gain a better understanding in health, disease-prevention and the creation of cures. It applies the principles of physics, chemistry, mathematics and computational modelling to studies of life at every level, from atoms and molecules to cells, organisms and environments [1]. The National Research Council of Canada (NRC) began recognizing biophysics' uniqueness as early as 1929, promoting the field and helping people understand its place among the established disciplines of physics, engineering, biology and medicine.

Perhaps one of the greatest and most known examples of biophysic's impact comes from the discovery of deoxyribonucleic acid (DNA), which we now understand as having an influence in countless areas of daily life. Beginning in the 1940s with experiments pointing out that genes are made of a simple chemical now called DNA, subsequent studies led to the identification of the now commonly-known double helix in 1953. Using X-ray crystallography, it is possible to obtain the structural identification of a complex biomolecule. From that point on, we understood that DNA was comprised of only four individual bases, whose pairing is responsible for who we are as biologically unique individuals. For the double helix finding, Francis Crick, James Watson—who had done virus research at NRC as a Merck Fellow—and Maurice Wilkins were awarded the Nobel Prize. The discovery of the DNA double helix laid the foundation for many DNA based technologies that are widely used today.

**SUMMARY**

**From DNA, to antioxidants, Biophysics discovers the biological cycles of heat, light, water, carbon, nitrogen, oxygen, and organisms throughout our planet, and has been recognized for its importance by NRC since 1929.**

In the 2000s, biophysical research, coupled with the vastly improved available technology, finally decoded all the genes in a human being. It was further possible to identify nearly 200 different complete species, and map a portion of the genetic material of over 100,000 others. DNA's discovery has been immensely significant, and has changed much of how we view the world. It is now taught in early education, almost as innocuously as algebra, a testament to its ubiquitous nature. It is used in paternity testing, forensic analysis, agriculture, and has obviously sparked a medical revolution in many circles.

## NRC'S COBALT-60 FIGHTS CANCER

In the mid-20th century, only a few highly trained physicists were undertaking radiological work. In general, they had been trained in medical sciences rather than in the fundamental physical laws necessary for the proper understanding of radiology. The NRC Associate Committee for Biophysics therefore recommended that NRC work on radium standards.

Since Marie Curie's 1898 radium discovery, radioactive sources have been used for multiple purposes, including the treatment of various forms of cancer. While these were promising for some localized cancers, they could not, at the time, reach deep tumours. In 1947, NRC opened NRX – the world's most powerful research reactor in Chalk River, Ontario, leading the way to improved treatment.

NRX was a heavy-water-moderated, light-water-cooled, multipurpose research reactor used to develop new isotopes, test materials and fuels, and produce neutron radiation beams that became an indispensable tool for condensed matter physics.

The nuclear physics design of NRX emerged from NRC's laboratory at the University of Montreal, where during World War II a team of Canadian, British and other European scientists had engaged in top-secret heavy-water reactor research. Among these were Canadian

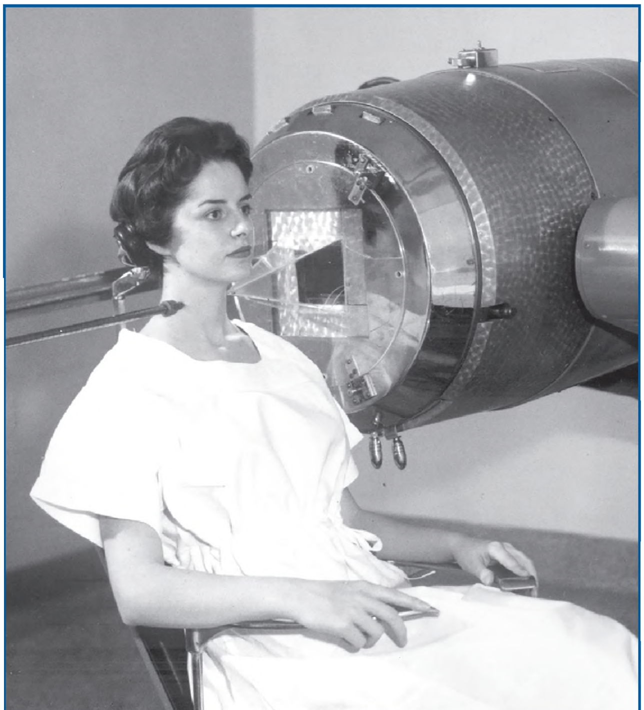

Fig. 1 Cobalt-60 and other isotopes used to combat cancer.

Bertram Brockhouse, whose work at NRX in the 1950s advanced the detection and analysis techniques used in the field of neutron scattering for condensed matter research. In 1994, he won the Nobel Prize in Physics, sharing it with American Clifford Shull.

In the 1950s, NRC began mass-producing Cobalt-60 and developed dozens of different isotopes at NRX. To ensure that radiation beams hit previously unreachable tumours, researchers increased Cobalt-60's (Fig. 1) strength and concentration by thousands of times. The "cobalt bomb" soon boosted patient 5-year survival rates by over 75 per cent in cancers that previously saw just one in five people pull through. Eventually, NRC medical physicists invented technology for targeting and destroying cancerous tissue only, and for many years Canada was a world leader in the area of medical isotopes, developing new uses and approaches to their production.

While NRC has licensed the technology to Nordion Canada Inc. for use at cancer clinics worldwide, Co-60 is still the main tool used in the Measurement Science and Standards division for calibrating radiation therapy instruments used at all cancer centres across Canada.

## NRC EXPLAINS NUCLEAR MAGNETIC RESONANCE (NMR) SPECTROSCOPY

A research technique that exploits the magnetic properties of certain atomic nuclei, NMR spectroscopy is used by chemists and biochemists to investigate the properties of organic molecules. While relatively standard today, it required a certain degree of explanation when it first emerged in the 1950s.

Addressing both theory and application, the first authoritative and comprehensive book, *High-resolution Nuclear Magnetic Resonance,* was published in 1959 by former NRC president William G. Schneider and two colleagues, John A. Pope and Harold J. Bernstein. The book remained the definitive reference for the following decade on matters relating to high-resolution NMR spectroscopy. In its function as a textbook in graduate and senior undergraduate courses, it instructed students in the intricacies of spectroscopy and illustrated the practical applications of quantum mechanics as applied to spin systems. By providing a far-reaching, comprehensive, and elegant overview of the field at a critical time, this treatise laid the groundwork for much of the impact that NMR spectroscopy now has on science, medicine and industry.

The NMR work pioneered at NRC influenced many researchers. Among these was chemist Ian Smith, who began his career as one of Schneider's summer students in the 1950s and went on to specialize in magnetic resonance spectroscopy. In 1987, he was appointed Director General of the NRC Institute for Biological Sciences in Ottawa, and in 1992 founded NRC's Institute for Biodiagnostics (NRC-IBD) in Winnipeg. One of NRC-IBD's most notable achievements was the development


Fig. 2 900 MHz spectrometer at NRC's W. G. Schneider Building.

of a movable MRI system that allows non-invasive scans of patients before, during and after surgery.

In 2006, the Government of Canada, in partnership with the University of Ottawa and the provinces of Quebec and Ontario, opened the NRC W.G. Schneider Building, which houses five spectrometers. Such spectrometers (e.g., Fig. 2) have helped scientists develop new battery composites, nano-materials for electronics, plastic polymers for vehicles, glasses for more sensitive sensors and faster computer processors, new materials for hydrogen storage and health-enhancing antibiotics.

## BIOPHYSICS MEETS CARBOHYDRATE CHEMISTRY

In the early 1970s, NRC chemist Harry Jennings devised a solution for successfully vaccinating children with meningococcal meningitis caused by three major strains of *Neisseria meningitidis*. At the time the vaccine – composed of purified sugars from the bacteria surface – was ineffective in children because the contents did not stimulate the immune system.

Jennings had heard about this problem from a chance encounter with a U.S. scientist working on meningitis who wanted to collaborate on NRC's NMR methods. As Jennings considered the problem, he realized it was possible to overcome the limitations of the existing vaccine by linking the polysaccharide to a protein to create a conjugate vaccine. Ian Smith was involved in the NMR work that laid the foundation for the meningitis vaccine.

While Jennings encountered a number of roadblocks in finding an industrial partner that would take the vaccine candidate forward, he persevered. However, it was not until 30 years after joining NRC that he found an industrial partner to commercialize it in 1996. The first major test of the vaccine against meningitis C was in 1999 against an outbreak among hundreds of British children.

This success led to a renaissance in vaccine research, opening up a number of possibilities for diseases that were not thought to be amenable to vaccines. Since the first conjugate vaccine patent for Meningitis C in 1982, the Institute for Biological Sciences has solidified a family of meningitis patents and continues to explore vaccines for a number of other diseases, including cancer.

## PIONEERING STUDIES OF FREE RADICALS AND ANTIOXIDANTS

Studies of free radicals and antioxidants was an area of extensive work at NRC for almost 60 years in the Division of Chemistry, and then the Steacie Institute for Molecular Science. Chemist Keith Ingold, who joined NRC in 1955, is a pioneer in understanding the role of oxidation in the aging process and the role of Vitamin E in medicine and health as an antioxidant. When he began his research, the chemistry of intermediates such as free radicals was unknown.

Ingold's mandate was to examine the degradation of engine oils and learn how to prevent it. This launched his lifelong love affair with free radical chemistry (Fig. 3). Applying the chemistry of free radicals to living organisms – specifically the human body, which produces about 10 kilograms of superoxides every year – is the area for which his research is best known. He also demonstrated the role of antioxidants in preventing degradation of a wide range of materials and helped to redefine the petroleum and plastics industry.

In the early 1980s, Ingold turned his attention to the role of oxidation in aging and the development of cancer and atherosclerosis – two leading causes of mortality in industrialized society. His team's pioneering work proved that vitamin E behaves as an antioxidant in living animals. NRC's game-changing findings on vitamin E led to a variety of medical breakthroughs, including improved treatments for patients awaiting heart surgery and a greater understanding of certain diseases involving vitamin E deficiency. However, vitamin E can actually promote oxidation in some cases, so there is still much to learn, and the field remains active.

The benefits of antioxidants in food and various products have been widely publicized, analyzed and debated, yet the general public believes they prevent the harmful effects of free radicals. Antioxidants are supposed to keep us healthy, allow us not to feel guilty for having that glass of wine in the evening and keep us from looking our age. However, a definitive review of the area of oxidants, published by Ingold and Derek A. Pratt in 2014, reports that while antioxidants are probably preventative, they are unlikely to be therapeutic.

Ingold continues to investigate the relationship between oxidation and atherosclerosis and cancer, the two leading causes of mortality in North America and Europe. In 2016, he was

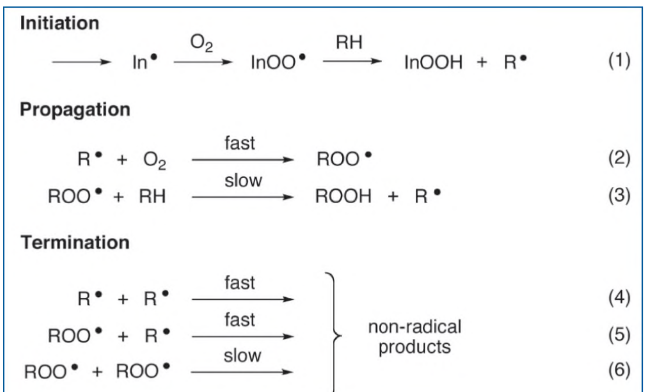


Fig. 3 Ingold was a leader in developing methods to study free radical reactions, among them quantitative measurement of reaction rates (ESR) [2].

awarded the Royal Society of Chemistry's Sir Derek Barton Gold Medal for his "fundamental contributions to the understanding of free radical chemistry."

## THE RISING IMPORTANCE OF BIOPHYSICS

The world is facing unprecedented physical and biological problems. Many aspects of daily life we tend to take for granted, such as energy, food and clean water, are in danger. Solving such crises requires scientific insight and innovation – and biophysics is an important key since it discovers the biological cycles of heat, light, water, carbon, nitrogen, oxygen, and organisms throughout our planet.

While there is much yet to be learned about the universe we inhabit, each new day brings us closer to understanding it. NRC researchers are at the forefront of biological sciences and physics, and continue their daily work towards discoveries that forever alter and enhance our lives.

## REFERENCES

1. http://www.biophysics.org/Education/WhatisBiophysics/tabid/2287/Default.aspx
2. K.U. Ingold and D.A. Pratt, "Advances in Radical-Trapping Antioxidant Chemistry in the 21st Century: A Kinetics and Mechanisms Perspective", *Chem. Rev.*, **114**, 9022–9046 (2014).

# LAB TO INDUSTRY: SCIENCE AT WORK FOR CANADA

**BY SYLVAIN CHARBONNEAU**

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For many physicists, the lab is their universe; it's a place where ideas take form, are advanced, and where they study everything from massive galaxies and cosmic nurseries, to tiny particles and hot droplets of matter and laser-cooled atoms. While some physicists focus on fundamental science, others choose to conduct applied research for the development and commercialization of new products and technology. At the National Research Council of Canada (NRC), our cosmos is all-encompassing, merging all the goals of research, and working to advance society. But just as the great expanse of the cosmos appears empty without its stars, so too would our universe be dimmer without the researchers who work tirelessly behind the scenes to advance NRC's mission.

Over the past century, NRC has put Canada on the science map with paradigm-shifting discoveries. Looking through those years, so much of the research has led to an expansion of industry in Canada, and beyond.

When NRC was formed in 1916, Canada had just over four dozen pure science researchers. NRC staff comprised eight academics including one physicist, three industrial members and, interestingly, one banker. By 1925, NRC had grown significantly. After NRC's first full-time president, physicist H.M. Tory, was appointed in 1928, Physics and Engineering was split into two distinct departments. The organization's permanent research laboratories opened in 1932 on Sussex Drive in Ottawa and became world-renowned for an immense range of research projects.

While the Great Depression of the 1930s took its toll on research budgets, the outbreak of World War II brought a reversal of fortune. NRC was well-positioned to mobilize national science expertise for war research and grew its staff significantly under the leadership of President General McNaughton, who dramatically increased military-related R&D. Canada's participation in the war and NRC's work led to the establishment of new industries along with tens of thousands of technology jobs.

**SUMMARY**

**NRC's research has been contributing to the everyday lives of Canadians for 100 years, and the results have created new industries, new technologies and the jobs of the future.**

By 1939 NRC had 300 paid staff, including 75 research professionals, in four laboratory divisions: Biology, Chemistry, Physics and Mechanical Engineering.

## ON THE RADAR IN WWII

In 1940, when Britain realized it needed help with the war effort, it sent Henry Tizard on a secret mission to enlist the help of Canada and the U.S. in developing and harnessing the power of radar. At the time, Britain's radar discoveries, such as the cavity magnetron, were state secrets. The partnership with North America meant they had to share their secret technology and their operational experience. As a result, the Tizard Mission brought new technology to Canada: the cavity magnetron and the basic plans for a radar system for anti-aircraft 'gun laying'. This launched radar research at NRC (where no one knew about magnetrons).

The Radio Branch of NRC expanded rapidly, attaining a total staff complement of nearly 300 by war's end. This contributed to the growth of NRC's laboratories to nearly 3000 staff by 1945. In 1941, radar research for the Canadian services and the British government had matured and was ready for commercialization. To manufacture the radar and optical equipment technologies NRC had developed, Research Enterprises Ltd. was created. Approximately 8300 radar sets destined for the Canadian, U.S. and British Forces were built in support of the war effort.

NRC also made history at this point, since for the first time it galvanized a large pool of engineers and physicists to support radar communications. The organization's investment in the war effort led to an ongoing influx of major communications companies from around the world, and Ottawa today is recognized globally for its strength in information and communications technology development.

## THE POST-WAR GOLDEN AGE

With NRC's capabilities and leadership status firmly established, resources began to flow inward. Political and university backing helped the organization develop nationally, train more researchers and expand into academia, government and industry with pure, applied and commercial research.

The 1950s and '60s saw progress into areas where none had gone before. For example, nuclear R&D performed in

With NRC's help, Canada installed the first operating radar system in North America – a coastal defence system near Halifax called the "Night Watchman." By 1945 NRC had developed about 30 different types of radar for various military purposes to help the Allies win the war. Source: http://www.nrc-cnrc.gc.ca/eng/about/centennial/achievements.html

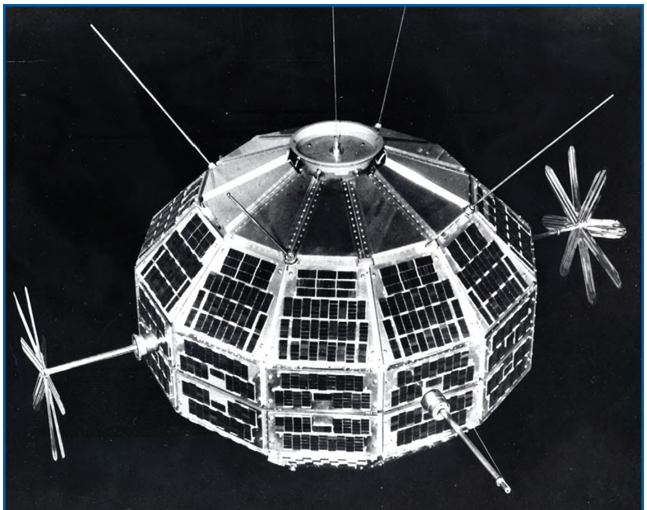
the early 1950s by NRC scientists in Chalk River enabled doctors in London and Saskatoon to create new treatments for cancer, using cobalt-60 gamma rays. NRC's development of the cobalt-60 isotope launched radiation therapy for cancer treatment and positioned Canada as a leader in the area of medical isotopes. Today, Canada produces about 75 percent of the world supply of cobalt-60.

The Sputnik 1 scare in 1957 provoked a significant spike in NRC funding for universities that by 1968 had amounted to nearly $30 million. With Sputnik, the first artificial Earth satellite, the Russians pre-empted the American effort, surprising the world with its success and triggered the international "Space Race."

In 1962, Canada's Alouette 1 – the first artificial satellite designed and built by a country other than the U.S. or Soviet Union – was launched. Built to study the ionosphere by bouncing radio signals back to earth, it featured a solution to a problem that, in 1951, had been solved by NRC researcher, engineer and inventor George Klein. The difficulty was that relaying the signals clearly from such a distance required a number of long, heavy antennas that would not only be cumbersome to transport but also use huge amounts of rocket fuel to launch into orbit. To address these challenges, Klein invented the lighter-weight Storable Tubular Extendible Member (STEM) antenna, which unrolls when the satellite arrives at its destination and remains stable during space operations. In September 1962, when Alouette took off, it was armed with STEM antennas —the first products of Spar Aerospace Ltd., the company now most famous for its Canadarm. The NRC antenna technology also became a standard on the American manned space missions Mercury, Apollo and Gemini.

## BACK TO THE FUTURE

NRC has played a strong role in developing myriad inventions over the years, and will continue to do so. Much of the R&D progress and commercialization has been due to the support, expertise and funding provided by the Industrial Research



The Alouette 1 was Canada's first satellite launched in 1962. It carried 4 STEM antennas (2 × 11 m and 2 × 22.5 m). Source: https://www.emaze.com/@AQFWCOW/STEM-antenna


On December 1, 1989 the Bank of Canada issued its $50 banknote that featured NRC's thin films anti-counterfeiting technology, designed with security features to counter the colour photocopiers of that era. Source: http://www.nrc-cnrc.gc.ca/eng/about/centennial/achievements.html

Assistance Program (NRC-IRAP), established in 1962. Among the inventions kick-started with NRC-IRAP assistance were the BlackBerry, UV-degradable plastics, and the Weevac-6 baby evacuation stretcher.

In partnership with industry, NRC-IRAP continues to stimulate wealth by helping small and medium-sized enterprises (SMEs) exploit emerging technologies and reduce their risk during critical start-up years. Today, some 240 Industrial Technology Advisors (ITAs) with access to expert technical and business advice, financial assistance, business information and contacts in national and international networks, provide customized solutions to about 10,000 SMEs annually. Respected globally as one of the best programs of its kind, NRC-IRAP is a vital component of NRC's innovation strategy and a cornerstone of Canada's innovation system.

### Optical thin films

A major discovery in the 1970s by NRC engineer Lloyd Pinkey led to a range of applications that are still used today for both research and industry. In response to a request from one of Canada's astronauts for "better vision in space," Pinkey applied the technology behind thin film target dots to develop a space vision system. Commercialized by Neptec, the system was first used on mission STS-74 to begin building the International Space Station.

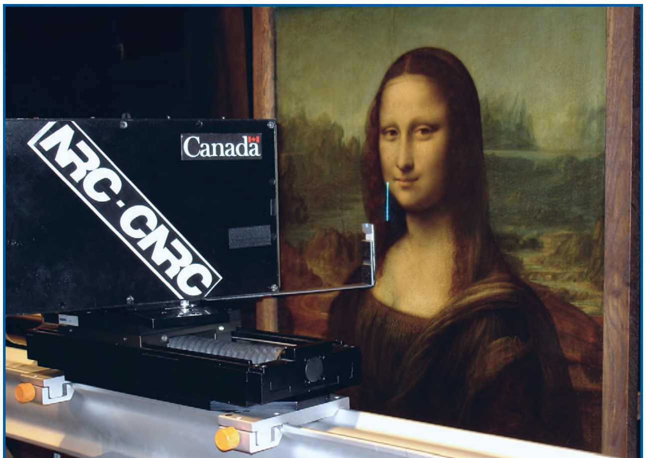
Growing the optical thin film industry in Canada was the lifelong work of NRC physicist George Dobrowolski, who adapted thin film products as a security technology to protect banknotes, passports and other important documents – and was awarded more than 30 patents. In 1968, the Bank of Canada (BOC) approached his group to develop a security solution for high-value banknotes. Dr. Dobrowolki and his colleagues quickly envisioned a way to embed an optical security device strip in the banknotes that made it almost impossible for counterfeiters to duplicate bills. This relationship between BOC and NRC continues today, with the familiar holograms and foils visible on every modern Canadian banknote, including the highly secure polymer banknotes in circulation today.

### Solid State Optoelectronics Consortium (SSOC)

Dr. R. Normandin, a lead NRC researcher in optoelectronics, created the Solid State Optoelectronic Consortium (SSOC) in 1988. This five-year research initiative's underlying idea was to choose an area of evolving technology of economic significance, which could be developed to the benefit of Canada. With the participation of Bell Northern Research, Litton Canada and several SMEs, the consortium developed photonic technologies for wavelength division multiplexing (WDM) on a single semiconductor chip. This was the foundation of the optical communications revolution of the mid-1990s that led to unprecedented commercialization of a NRC discovery. By 2000, Canadian companies had captured 40 percent of the components market. Ottawa alone saw 70 start-ups generating more than $1 billion in sales and creating 7000 high-tech jobs. NRC spinoffs included: Iridian Spectral Technologies, BTI Photonics, Metrophotonics and Optenia – all exploiting innovative photonic technology solutions invented and developed by NRC researchers.

### 3D imaging

In the 1990s, Marc Rioux's fascination with imaging gave birth to the 3D imaging strength still housed at NRC. Characterizing the variations of the human body shape is fundamentally important in many applications ranging from animation to product design. Some of the better-known industrial uses




In 2004, NRC used its 3D imaging technology to perform scans of the Mona Lisa in the basement of the Louvre. This revealed the painting's state of preservation, and provided more information about da Vinci's *sfumato* technique used to create the corners of Mona Lisa's famous smile. Source: http://www.nrc-cnrc.gc.ca/eng/about/centennial/achievements.html

are special effects in films such as *The Matrix* and *The Lord of the Rings*.

Taking its 3D imaging technology into new realms in 2004, NRC used it to perform scans of the Mona Lisa in the basement of the Louvre. This revealed the painting's state of preservation and has shed light onto the *sfumato* technique da Vinci used to create the corners of Mona Lisa's famous smile. The same year, NRC researchers recreated the head of the Sulman mummy using a combination of scanning technologies to determine its shape, texture and colour prior to mummification. This proved that the mummy was a female – something earlier x-rays had been unable to do.

**Canadian Photonic Fabrication Centre (CPFC)**

In 1998, NRC President Arthur Carty sent me on a "mission" to develop a national photonic technology cluster strategy for integrating industry, government and university resources. It employed new partnership models to create technological and entrepreneurial advantages that would enable Canadian businesses to innovate and compete in the global marketplace. In 2001, the business plan for the NRC-Ontario cluster initiative – the Canadian Photonic Fabrication Centre – was approved for funding by the Treasury Board.

This pure-play photonic fabrication facility, established primarily to serve industry, was unique in North America. However, it also supports academic research and helps bridge the often financially risky gap between idea and commercialization that start-up companies have dubbed "the valley of death." Today, the CPFC provides a one-stop shop for world-class engineering and manufacturing services, commercial-grade prototyping and pilot-run production facilities for photonics-based components, from discrete components to highly sophisticated photonics integrated circuits used by the information and communication technology industry. These photonics circuits are the basis of today's high-end optical communication systems that fuel the Internet revolution.

**Printable electronics (PE)**

Printable electronics add intelligence to printed media that allow everyday objects to interact with customers in ways that were not even conceived five years ago. Using conventional, low-cost printing devices for processes such as screen printing, offset lithography or inkjet, PE adds electronic inks, the *optical* component of a film used in *Electronic* Paper Displays (EPD), to create active or passive applications for countless products. New goods include smart labels that reduce shipping costs, smart drug packaging that improves healthcare delivery, anti-counterfeiting measures that increase banknote security, and broadband printed antennas that harvest radio frequency energy.

The fusion of Information Communications Technologies (ICT) and printing is revolutionizing not only the manufacturing of high-volume, low-cost interactive consumer products and security documents, but also industries and markets worldwide.

Building on long-standing expertise in organic photonics and electronics in Canada (NRC, academia and industry), NRC launched a Printable Electronics Flagship Program in 2011 and tasked me with its strategic development. The business delivery model for addressing these needs was through a consortium involving the entire supply chain – from functional materials development to printable devices – in market segments that are important to growing our economy. Now fully established, the program has a multidisciplinary team addressing challenges related to next-generation printable functional materials, printable devices and imprinting.

During the past century, NRC has evolved greatly despite pressures from many directions. But it has always remained true to the values established when it was first created: Science at work for Canada. As NRC's work gained traction over the years, the research has paid off in supporting innovation for the country and led to start-ups that have created jobs, revenues and taxes reinvested in the economy.

Through reflecting on all this history, I am reminded of one of George Dobrowolski's famous sayings, which I feel captures the spirit of NRC: "Let us always remember that we are building on the efforts of other people and let's be humble about what we do." And by working together and sharing our results with the world, we continue to solve tomorrow's problems today.

# REPORT ON CANADA'S PARTICIPATION IN THE 47TH INTERNATIONAL PHYSICS OLYMPIAD IN ZURICH, SWITZERLAND

BY ANDRZEJ KOTLICKI

The 47th International Physics Olympiad (IPhO) was held from July $11^{th}$-$17^{th}$, 2016 in Zurich, Switzerland. Due to the generosity of our sponsors, in particular one who requested anonymity, we were able to organize the Canadian Olympiad Finals in Vancouver. The students who were invited to the finals at our cost were the top scorers of the Canadian Association of Physicists (CAP) High School Exam. 846 students from 163 Canadian schools wrote the exam this year (an almost 6% increase compared to last year), and the top 15 students were invited to the National Finals in Vancouver. Only the student who placed $3^{rd}$ in the CAP exam decided not to come. After 6 days of lectures, 2 theoretical exams, and 2 experimental exams, the Canadian Team for the International Physics Olympiad was selected. The National Final was organized with great help from UBC profs Mona Berciu and Bill Unruh, Canadian Physics Olympiad alumni Tout Wang, Brett Teeple, and Wilson Wu, a UBC TA Koosha Rezaiezadeh (a former IPhO gold medalist from Iran), and UBC COOP student Sophie Ebsary. The limited funding did not allow for any additional training for the full team before the trip to Switzerland, however, Dr Natalia Krasnopolskaia and Wilson Wu organized a daylong training session at UofT for the 4 students living in the Toronto area. It is worth mentioning that teams from other countries are given anywhere from 2 weeks to 2 years of additional training for this competition.

This year we were able to pay for the trip to the IPhO for all of the students but the two leaders had to pay their own way to Switzerland (about $1700 per person). Many thanks to Run Ze Cao for committing his time and money to act as a co-leader. The Canadian Physics Olympiad (CPO) Program also paid the IPhO participation fee (3000 EU).

**SUMMARY**

**This year, due to the generosity of our sponsors, the Canadian Physics Olympiad could organize the National Camp and have a proper selection process for a team of 5 students who represented Canada during the 47th International Physics Olympiad held in Zurich in July 2016. Our students won 5 bronze medals.**

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The members of the Canadian team this year were:

**Yiqun Zhang**, a grade 12 student of Henri Van Bemmel from Marc Garneau C. I.

**Stephen Liu**, a grade 12 student of Bogdan Brkic from Bayview Secondary School

**Noel Loo**, a grade 12 student of David Karbashewski from Western Canada High School

**Steven Mai**, a grade 9 student of Shawn Brook from UofT Schools

**Yuheng (Jack) Xu**, a grade 9 student of Raymond Fung from Unionville High School

It was amazing to see the advanced knowledge and problem solving skills in the grade 9 students!

The team leaders were Dr. Andrzej Kotlicki (UBC), Director for the Canadian Physics Olympiad Program, and Run Ze Cao, an ex-participant of Canadian Physics Olympiad, who just graduated from the University of Pennsylvania.

This year's IPhO was hosted by the University of Zurich with its Department of Physics, Office for Education of the Principality of Liechtenstein, Association of Swiss Scientific Olympiads with its member and the Association of Swiss Physics Olympiad. The opening ceremony took place at the university and was accompanied by music from 6m long mountain horns. The closing ceremony took place at the famous Zürich Concert Hall: the Tonhalle and had amazing organ music between the speeches and the awarding of the medals.

Eighty-six countries participated from all continents except Antarctica in this year's Olympiad. According to the IPhO's rules, roughly 67% of the participants were awarded Olympic medals or honorable mentions.

As usual, the competition had both theoretical and experimental parts that were meant to challenge students at a level more advanced than typical high school or even first year university physics exams. The competition consisted of 3 theoretical and 2 experimental problems which required some of the same equipment. All the problems were

The Canadian Team with medals after the Closing Ceremony. From the left: The Swiss guide Laurissa, Run Ze Cao, Yiqun Zhang, Yuheng (Jack) Xu, Noel Loo, Stephen Liu, Steven Mai, Dr Andrzej Kotlicki.

excellent, at a very appropriate level, and not only interesting to solve but also very educational for the students. One theoretical and one experimental problem in particular required students not only to apply known principles and do complex calculations but also to be able to analyze and figure out unknown processes.

The first theoretical problem was about the stability of a wooden cylinder with a metal disc hidden inside and about gravity in the space station. The second problem, in my view the most interesting and challenging problem, was about a linear model of a thyristor. The students were given explanations and a linear approximation of a voltage-current characteristic of this device and they had to find out how the system including such an element can oscillate or form a one shot univibrator. Only a few students completely solved this problem and it was nice to see that one of our students was included in this group. The third problem required students to analyze the principles governing the acceleration of the particle beams in Cern's Large Hadron Collider.

In experimental problem 1, students had to perform four probe resistance measurements of a silicon wafer coated with a thin chromium film and graphite coated conductive paper. They had to find out experimentally how the measured

Our team during the mountain excursion.

quantities related to the resistivity and determine the sheet resistivity of the material and how the size of the sample affects this relationship.

The second experiment, using some of the same equipment, required students to investigate a very clever model of a second order phase transition. This experiment can be used as a great demonstration for a high level thermodynamics course.

As usual to ensure the fairness and consistency of the marking, grading was done separately by organizers and team leaders and then moderated. Overall, marking was excellent. There were only a few minor changes resulting from the moderation for our students.

Our team did reasonably well in the competition considering the limited training. Everyone on the team received a bronze medal.

In between and after the exams, the students enjoyed interesting excursions to Cern, Lichtenstein, and a local mountain (accessed by a cog railway and hiking). There was also a lot of socializing including a "midterm" party with a lot of typical Swiss competitions like mountain horn blowing, nail driving and artificial cow milking. There was even a set of enormous catapults to test the students' ability to apply the theory of projectile motion with drag to the rubber chicken trajectory.

Next year, Indonesia will host the IPhO in Bali. Canada looks forward to participating in 2017.

# SCIENCE POLICY UPDATE

## BY AIMEE GUNTHER, CAP SCIENCE POLICY COMMITTEE MEMBER

In Budget 2016, the Canadian Government called for an independent review of national fundamental science funding mechanisms by a panel of experts. This Panel invited comments from researchers, institutions, students and postdocs, facilities, and funders to address issues related to fundamental science in Canada, and received more than 1250 responses.

The CAP, compiling feedback from the membership and science policy committee, submitted a response on September 30, 2016, on behalf of Canadian physics researchers. This submission generally lauded the NSERC Discovery Grant model, with recommendations for increased funding and unbiased grant peer review across institution size and researcher career stage. Recognizing the vastness of Canada's diverse fundamental science infrastructure demands, CAP encouraged the development of a more unified and flexible approach to funding small equipment to very large international research facilities over the entire infrastructure lifecycle. In addition, as fundamental science funding encompasses more than just money for fancy research tools and funding highly qualified personnel, CAP's submission also recommended that there be flexible funding streams applicable for science education and associated research as well as for use in multidisciplinary and international collaborations.

The fundamental science review is one element of a broader Innovation Agenda review being undertaken by Industry Canada. In light of this, the CAP submitted a separate brief to the Innovation Agenda on August 31, 2016.

The CAP's submissions to the Innovation Agenda and the Review of Fundamental Science Panel can be found at http://www.cap.ca/en/activities/science-policy.

The report and recommendations of the Fundamental Science Review should be released in early 2017. More information is available online at www.sciencereview.ca.

# *LE POINT SUR LA POLITIQUE SCIENTIFIQUE*

## *PAR AIMEE GUNTHER, MEMBRE DU COMITÉ DE LA POLITIQUE SCIENTIFIQUE DE L'ACP*

Dans le Budget 2016, le gouvernement du Canada a préconisé un examen indépendant par un groupe d'experts des mécanismes de financement fédéral des sciences fondamentales. Ce groupe a invité les chercheurs, institutions, étudiants postdoctoraux et autres, établissements et sources de financement à faire des observations au sujet des questions entourant les sciences fondamentales au Canada, et il a reçu plus de 1250 réponses.

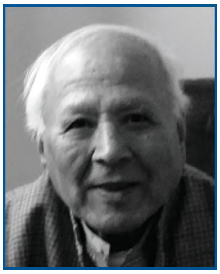
Après avoir compilé les réactions de ses membres et de ceux du Comité de la politique scientifique, l'ACP a présenté une réponse, le 30 septembre 2016, au nom des chercheurs canadiens en physique. Elle y a louangé le modèle de subventions à la découverte du CRNSG, formulant des recommandations pour un financement accru et un examen impartial par les pairs des demandes de subventions destinés aux établissements de toutes tailles et aux diverses phases de carrière des chercheurs. Reconnaissant l'étendue des diverses exigences du Canada quant à l'infrastructure des sciences fondamentales, l'ACP a incité à instaurer une approche plus unifiée et souple au financement des petits équipements destinés aux très grands établissements internationaux de recherche pour l'ensemble du cycle de vie des infrastructures. De plus, comme le financement des sciences fondamentales déborde les sommes destinées aux instruments de recherche sophistiqués et au financement du personnel hautement qualifié, l'ACP a aussi recommandé dans son mémoire qu'il y ait des sources de financement souples pour l'éducation en science et pour la recherche associée, ainsi que pour les collaborations multidisciplinaires et internationales.

L'examen des sciences fondamentales est un élément d'une vaste étude du Programme d'innovation, entreprise par Industrie Canada. Dans cette optique, l'ACP a présenté un mémoire distinct du Programme d'innovation le 31 août 2016.

On peut consulter les mémoires de l'ACP concernant le Programme d'innovation et l'examen du Conseil consultatif sur la recherche fondamentale à http://www.cap.ca/fr/activites/politique-scientifique.

Le rapport et les recommandations concernant l'examen des sciences fondamentales devraient être rendus publics au début de 2017. On peut trouver d'autres renseignements en ligne à http://www.examenscience.ca/eic/site/059.nsf/fra/accueil.

# VIRESHWAR VISHWANATH PARANJAPE (1930-2016)



Vireshwar Vishwanath Paranjape, longtime professor of physics at Lakehead University, passed away after a short and courageous battle with biliary cancer on April 22nd, 2016. 'VV', as he was known to colleagues and friends, was born on May 10th, 1930 in Saoner, Maharashtra, India and spent his childhood and primary schooling in Saoner. The family moved to Nagpur after his mother died when he was still a boy, and 'VV' completed his secondary and high school at the New English High School. 'VV' went on to complete his B.Sc. and M.Sc. degrees in Mathematics at the University of Nagpur in 1953 and 1956, respectively. In 1956, he went to Liverpool, England to start a Ph.D degree in Physics under the supervision of Herbert S. Frölich, where his elder brother [1] was already doing the same. He completed his Ph.D in 1963 and was then appointed Fellow of the University of Liverpool. During his time in Liverpool, he married Neela in December 1960, his devoted and steadfast companion for 56 years, and his son Makarand was born in 1962.

In late 1964, he was appointed Assistant Professor at the Indian Institute of Technology Kanpur, in Kanpur, India. However, he found the atmosphere too politically charged, which was certainly not a work environment suitable to his taste. He returned back to Liverpool to continue his work with Professor Frölich, and also continued to apply to other places seeking a permanent position. He obtained offers from St. Andrew's University in St. Andrew's, Scotland; University of Manitoba, Winnipeg, Manitoba; Brock University, St. Catharines, Ontario and Lakehead University, in Port Arthur (at the time, now Thunder Bay), Ontario. He accepted the position at the University of Manitoba, but stayed only for one year (1966-1967) before accepting an appointment, at the Associate Professor level, in Lakehead University. He was promoted to Full Professor at Lakehead in 1971.

'VV' was an active researcher in condensed matter physics throughout his life and even in his final year, was working on a paper on Dirac semi-metals. He continuously held an NSERC Discovery Grant for 46 years. He had ongoing collaborations with his local colleagues and with international colleagues. In recognition of his research accomplishments, Lakehead University awarded him the Distinguished Researcher prize in 1993. Similarly, during the university's 40th anniversary celebration in 2005 he was identified as one of Lakehead's 40 Research Stars. Although he officially retired in 1995, he would keep up with his research and continue going to the Physics Department essentially every day, successfully publishing journal articles every year, to the end. He supervised 16 Ph.D/M.Sc. students during his career, several of whom have gone on to obtain faculty positions in Physics in Canada and abroad. He is the author of 100 scientific papers in condensed matter physics, ranging on the topics: atom-surface interactions, polarons, electrons in quantum systems and high field conduction in semi-conductors, among others.

His main interest and great expertise was in the area of polaron dynamics and dispersion forces. However, he had a very deep understanding of statistical mechanics and the general area of condensed matter. In the early years of his career, he was the first to perform the analysis of the dispersion of electrons due to optical phonons and the acoustic-electric effect on electrons. In his later career, he studied many subjects that included properties of clusters of atoms, forces on atoms in waveguides, electron states in crossed wire geometries, Bose-Einstein condensates, and the formation of bi-polarons.

'VV' was also active in the administration of his university. He served as Chair of the Physics Department on four separate occasions for a total of 12 years. 'VV' played an important role in the development of research, graduate and undergraduate programs in the Department. At the University level he served as the first Director of Graduate Studies and Research. He also served on three different Senate committees, where he was the Chair each time.

'VV' maintained an active lifestyle, walking 5 km to the department and swimming almost every day. In 2009, in his 80th year, he taught undergraduate Relativity and Quantum Mechanics at Georgetown University in Washington D.C. where his son is an Associate Professor in the Physics Department. 'VV' was recently interested in health conscious eating and the science behind it, and he was in the process of writing a book on the subject. He has also published short stories in the Marathi language, his mother tongue. He was known for his cheerful disposition, a non-confrontational attitude and his sage advice. He epitomized how to live a simple, comfortable, and meaningful life, without compromising on principles. He was like a father figure to many people in the Physics Departments at both Lakehead and at Pune University, where he frequently visited.

A colleague wrote, « A very fine physicist, ready to help anyone, with a deep understanding of a wide range of physics...very thorough and classical style of work, practical but not compromising in physics. . .polite but firm. . .will tolerate no nonsense »

He will be missed by many.

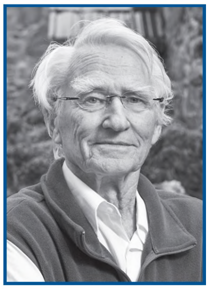
Manu Paranjape
Université de Montréal

**REFERENCE**

1. Bhalachandra Vishwanath Paranjape (1922-2014), *Physics in Canada*, **70**, 3, 194-195 (2014).

IN MEMORIAM

# Tudor Wyatt Johnston (1932-2016)



Tudor Wyatt Johnston passed away in the morning of August 24th, 2016, aged 84. He was surrounded by family members and friends. On that day we lost an outstanding colleague, a dedicated collaborator, a superb mentor and a dear friend.

Trained in engineering (B.Eng. McGill, 1953; PhD Cambridge, 1958) Tudor was an outstanding physicist who made extensive original contributions to the theory of plasmas. After working in a private laboratory (RCA) in Montreal and then for a few years at the University of Houston, Tudor joined the Centre for Energy of Institut National de la Recherche Scientifique (INRS) in 1973 and thus became one of its pioneers, founding the group "interaction laser-matiere" and contributing his energy and passion to its activities for over three decades. His experience, notoriety and superior skills in writing grant proposals greatly enhanced the group's activities. In addition to his own remarkable theoretical contributions on laser-matter interaction and his crucial interpretation of experimental results, Tudor has incessantly encouraged, supported and participated in all the multifold efforts pursued by the laser-matter interaction team. He played a fundamental role within this group and by extension at INRS as a whole.

Tudor also collaborated with other colleagues both at INRS and elsewhere on a number of different projects, consistently with his broad scientific interests and resulting in the acclaimed book "Particle Kinetics of Plasmas" (which is still highly regarded today) and over 160 journal articles, including 23 in the greatly coveted Physical Review Letters. He was instrumental in bringing the book "Survival Skills for Scientists" to the level of a best-selling text on professional development. He remained active until a few years ago and after officially retiring in 2010, he became Emeritus Professor at INRS in 2012.

Due to his original contributions to physics and his penetrating insights, Tudor was a plasma scientist whose stature was widely recognized internationally. He was in high demand as a consultant in numerous US laboratories, associate divisional editor for major journals as well as a collaborator who was able to interpret complex experimental results and develop imaginative models with predictive properties. His work received ample peer recognition; among various honours we mention the election to Fellow of the American Physical Society in 1968.

Tudor had an incredibly lively (and loud) personality. He could talk for hours about almost anything, yet he was also a very good listener. He was always full of ideas, eager to help, extremely generous with his time and provided constant stimuli to so many of us. Mentoring and helping others, especially younger colleagues and students in writing better papers and projects, was his second nature. His interests were broad well beyond science and his presence could fill a room with energy and enthusiasm, making his absence all the much harder to bear. Tudor Johnston was a great scientist, teacher, sailor, mentor and friend. He leaves behind a memorable scientific and human legacy.

Mohamed Chaker, Henri Pepin, Federico Rosei and Francois Vidal

Centre for Energy, Materials and Telecommunications, Institut National de la Recherche Scientifique

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**(as at 2016 September 30 / au 30 septembre 2016)**

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Books may be requested from the Book Review Editor, Richard Marchand, by using the online book request form at http://www.cap.ca.

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The Book Review Editor reserves the right to limit the number of books provided to reviewers each year. He also reserves the right to modify any submitted review for style and clarity. When rewording is required, the Book Review Editor will endeavour to preserve the intended meaning and, in so doing, may find it necessary to consult the reviewer. Reviewers submit a 300-500 word review for publication in PiC and posting on the website; however, they can choose to submit a longer review for the website together with the shorter one for PiC.

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# Books Received / *Livres reçus*

The following titles are a sampling of books that have recently been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Unless otherwise indicated, all prices are in Canadian dollars.

Lists of all books available for review, books out for review and book reviews published since 2000 are available on-line at www.cap.ca (Publications).

In addition to books listed here, readers are invited to consider writing reviews of recent publications, or comparative reviews on books in topics of interest to the physics community. This could include for example, books used for teaching and learning physics, or technical references aimed at professional researchers.

*Les titres suivants sont une sélection des livres reçus récemment aux fins de critique. Nous invitons nos lecteurs à nous soumettre une critique en anglais ou en français, sur les sujets de leur choix. Sauf indication contraire, tous les prix sont en dollars canadiens.*

*Les listes de tous les livres disponibles pour critique, ceux en voie de révision, ainsi que des critiques publiées depuis 2000 sont disponibles sur : www.cap.ca (Publications).*

*En plus des titres mentionnés ci-dessous, les lecteurs sont invités à soumettre des revues sur des ouvrages récents, ou des revues thématiques comparées sur des sujets particuliers. Celles-ci pourraient par exemple porter sur des ouvrages de nature pédagogique, ou des textes de référence destinés à des professionnels.*

### GENERAL INTEREST

**Communicating Science: A Practical Guide for Engineers and Physical Scientists**, Raymond Boxman, Edith Boxman, World Scientific, 2016; pp. 261; ISBN: 978-981-3144-23-1; Price: 44.50.

**Fashion, Faith, and Fantasy in the New Physics of the Universe [v]**, Roger Penrose, Princeton University Press, 2016; pp. 520; ISBN: 9780691119793; Price: 34.16.

**I am the Smartest Man I know**, Ivar Giaever, World Scientific, 2016; pp. 276; ISBN: 978-981-3109-18-6; Price: 38.95.

**Plows, Plagues, and Petroleum: How Humans Took Control of Climate [v]**, William F. Ruddiman, Princeton University Press, 2016; pp. 240; ISBN: 9780691173214; Price: 21.95.

### UNDERGRADUATE TEXTS

**Principles of Magnetostatics**, Richard C. Fernow, Cambridge University Press, 2016; pp. 218; ISBN: 978-1107161122; Price: 184.24.

### GRADUATE TEXTS AND PROCEEDINGS

**Cosmic Rays and Particle Physics**, Thomas K. Gaisser, Ralph Engel, Elisa Resconi, Cambridge University Press, 2016; pp. 478; ISBN: 978-0521016469; Price: 83.53.

**Data Analysis for Scientists and Engineers (V)**, Edward L. Robinson, Princeton University Press, 2016; pp. 408; ISBN: 978-0691169927; Price: 93.95.

**MEMORIAL VOLUME FOR Y. NAMBU,** Editors: Lay Nam Chang, Moo-Young Han & Kok Khoo Phua, World Scientific Publishing, 2016; pp. 168; ISBN: World Scientific Publishing; Price: 38.95.

**QUANTUM MONTE CARLO METHODS: ALGORITHMS FOR LATTICE MODELS,** James Gubernatis, Naoki Kawashima & Philipp Werner, Cambridge University Press, 2016; pp. 536; ISBN: 978-1107006423; Price: 78.89.

**SPIN PHYSICS - SELECTED PAPERS FROM THE 21ST INTERNATIONAL SYMPOSIUM,** Editors: Bo-Qiang Ma & Haiyan Gao, World Scientific Publishing, 2016; pp. 200; ISBN: 978-9813142701; Price: 107.95.

**THE THERMODYNAMICS OF QUANTUM YANG-MILLS THEORY: THEORY AND APPLICATIONS (2ND EDITION),** Ralf Hofmann, World Scientific Publishing, 2016; pp. 544; ISBN: 978-9813100480; Price: 93.95.

# BOOK REVIEWS / *CRITIQUE DE LIVRES*

Book reviews for the following books have been received and posted to the Physics in Canada section of the CAP's website: http://www.cap.ca. When available, the url to longer versions are listed with the book details.

*Des revues critiques ont été reçues pour les livres suivants et ont été affichées dans la section "La Physique au Canada" de la page web de l'ACP: http://www.cap.ca. Quand disponible, un lien url à une critique plus longue est indiqué avec les détails du livre.*

**EVERYDAY CALCULUS: DISCOVERING THE HIDDEN MATH ALL AROUND US** by Oscar E. Fernandez, Princeton University Press, 2014, pp: 150, ISBN 9781400850082, price 31.95.

I sadly often hear people say that mathematics are not useful in their everyday life, even coming from people who know a good deal of it. From now on I will happily be able to prove them wrong by quoting examples from the book "Everyday Calculus", or having them read it. Indeed, the author Oscar E. Fernandez, an assistant professor of mathematics at Wellesley College, tries to answer in this nice book the question that every calculus student asked himself at least once: "Where am I ever going to use this?". He does it by "mathematizing" situations that everyone experiences daily, not just scientists, and that are rarely discussed.

To reach that objective, the whole book follows a regular day at the office, from waking up in the morning to looking at the stars at night, during which the author points out very naturally the objects and phenomena where mathematics are hidden. The applications are from a varied range of subjects, like biology (propagation of colds, blood flow), physics (cooling of coffee, age of the universe) and economy (employment rate, retirement income), and that makes the book interesting for everyone. The mathematics are focused on calculus and the chapters follow the usual order: functions, limits, derivatives, optimization, differential equations and integrals. Each chapter introduces the concepts by using real world applications and the full calculations are left in appendices at the end of the book to make the narrative flow very fluid.

This book is clearly made for complementing the knowledge of someone who knows calculus and it does so perfectly. On the other hand, the author claims that his book is aimed at everyone, but I feel like someone who doesn't already know calculus will not gain everything the book has to offer, even though the main message is easy to grasp. The high number of equations, which are actually often restated in words, can scare some people off. From my point of view, the physics applications are classic but the applications to other fields are sometimes surprising. For instance, I learned how sleep cycles work and I was impressed by the uses of the mean value theorem by traffic cameras.

On the negative side, I believe the author makes a mistake when he discusses the terminal velocity for rain. The concept is mathematically introduced by using a mass increasing with time in Newton's second law and the terminal velocity is supposedly due to the increase of friction with mass, but there is actually no friction considered in the equation, just a time varying mass. There are also some small errors that need to be skipped over, like a wrong value for the speed of light.

To sum up, this book goes over an impressive amount of uses of calculus in the real world while making them totally understandable and by focussing on the intuition instead of the rigorous details. It is a must read for students learning calculus to consolidate their understanding and any other reader can still gain something from the book, going from people unfamiliar with calculus to real scientists. Note that this is not a book to learn calculus.

Yan Gobeil
McGill University

**EVERYDAY CALCULUS: DISCOVERING THE HIDDEN MATH ALL AROUND US** by Oscar E. Fernandez, Princeton University Press, 2014, pp: 150, ISBN 9781400850082, price 31.95.

J'entends malheureusement souvent des gens dire que les mathématiques ne leur servent à rien dans la vie de tous les jours. Avec bonheur, je vais à partir de maintenant pouvoir les corriger en mentionnant des exemples tirés du livre « Everyday Calculus » ou même en leur faisant lire l'ouvrage. En effet, Oscar E. Fernandez, un professeur assistant au Wellesley College, essaie de répondre dans son livre à la question que tous les étudiants de calcul se sont posées un jour : « Où est-ce que ça va m'être utile? » Il le fait cependant en « mathématisant » des situations que j'ai rarement vu discutées et que tout le monde vit à chaque jour, pas seulement des scientifiques.

Pour atteindre cet objectif, l'auteur raconte une journée typique au bureau, qui commence par le réveil et qui se termine en contemplant les étoiles le soir, pendant laquelle il fait remarquer de façon très naturelle les objets et phénomènes où se cachent les mathématiques. Tout le monde devrait y trouver son compte puisque les sujets explorés sont nombreux : biologie (propagation des grippes, circulation sanguine), physique (refroidissement du café, âge de l'univers) et économie (taux d'emploi, épargnes retraite) entre autres. Les mathématiques sont centrées sur le calcul et les chapitres suivent l'ordre habituel : fonctions, limites, dérivées, optimisation, équations différentielles et intégrales. Chaque chapitre introduit les concepts à travers des exemples de la vie de tous les jours et les calculs sont dans des appendices afin que le livre se lise de façon fluide.

Le livre a clairement pour objectif d'enrichir les connaissances de quelqu'un qui connaît le calcul et il accomplit ceci à merveille. Par contre, l'auteur affirme que son ouvrage vise un public plus général alors que j'ai l'impression que quelqu'un qui n'est pas familier avec les outils du calcul ne peut pas accéder à tout ce que le livre a à offrir, même si le message principal est clair. Le grand nombre d'équations présentes, quoique généralement vulgarisées, peut aussi effrayer certains lecteurs potentiels. De mon point de vue, les exemples de physique me semblent assez classiques, mais j'ai trouvé les applications à d'autres sujets surprenantes. Par exemple, j'ai appris comment fonctionnent les cycles du sommeil et comment les caméras de circulation utilisent le théorème de la valeur moyenne.

Pour ce qui est du négatif, je crois que l'auteur a fait une erreur lors de sa présentation de la vitesse terminale des gouttes de pluie. En effet, ce concept est expliqué mathématiquement en considérant la deuxième loi de Newton avec une masse qui augmente dans le temps, ce qui fait supposément augmenter la friction. Cette explication me semble cependant erronée puisque le frottement est absent de cette situation. Il y a de plus quelques petites erreurs dans le texte, par exemple une mauvaise valeur pour la vitesse de la lumière.

Pour résumer, ce livre couvre de façon claire un nombre impressionnant d'applications du calcul à la vie de tous les jours et les explique très intuitivement, en évitant les détails inutiles. Ce livre est donc un incontournable pour les étudiants de calcul afin de parfaire leurs connaissances et n'importe quel autre lecteur peut bénéficier de cet ouvrage, que le calcul lui soit inconnu ou qu'il soit un expert. Il est à noter que ce n'est pas un livre pour apprendre le calcul.

Yan Gobeil
McGill University

**Extreme Physics** by Jeff Colvin and Jon Larsen, Cambridge University Press, 2014, pp xii+405, ISBN 978-1-107-01967-6, Price 215.19.

"Extreme physics" aims at providing an overview of physical processes governing matter under conditions of relevance to laboratory plasmas, with a particular emphasis on computational methods. The book starts with general definitions of the "extreme" conditions of matter, followed by a very brief review of plasma physics in which kinetic theory, Coulomb collisions, Debye shielding and the electron plasma wave are presented in only 28 pages. Then follow chapters on the interaction between laser light and plasma, hydrodynamics, shocks, equations of state, atomic physics, thermal and radiative energy transport, and magnetohydrodynamics. The physics described in these initial ten chapters is often short shrift, and the topics presented range in scope from elementary, to more advanced. Omitting exercises at the end of every chapter, the number of pages per chapter ranges from 21 to 34. This brief summary provides an interesting reminder of the many processes of relevance to plasma physics, but I suspect that it would be insufficient for a reader unfamiliar with the subject. The preface states "Focusing on computational modeling, the book discusses topics such as . . .". This "focus just on theory and computation" is also mentioned in the first chapter (p. 3 last paragraph before 1.1.2). With only the two last chapters on computational approaches totaling 61 pages however, it is not clear that the focus really is on computational modelling. The last two chapters do present some interesting general guidelines for developing computer models, but several aspects, such as finite difference approximations of derivatives, or the solution of a tridiagonal system of equations, are too elementary to appeal or be useful to students already appraised of computational methods. The book also contains a number of inaccuracies or typos as for example, ". . . these are shielded out in a distance short compared to the Debye length, . . ." (p. 52 middle of last paragraph). This is incorrect because shielding of small potential perturbations takes place over a distance of order of the Debye length, and shielding of large perturbations takes place over larger distances. On page 135 second to last line, "Kronecker delta function" should read "Dirac delta function". On page 277 line 12 from the top, the inequality sign is wrong following "at very low frequencies", and Delta is missing in front of x (p. 332, second to last line). Those are but a few examples, and severa; more can be found.

When I started reading this book I was intrigued and eager to find out more about the properties of matter under "extreme" conditions. I did not find what I expected, and I remain largely on my apetite. Perhaps the main criticism that can be made is that the authors attempted to do too much in too short a book. Considering the plethora of books on introductory plasma physics and numerical methods, this book could have been more relevant and useful if it had assumed an adequate background in basic plasma physics and electromagnetism, and concentrated on the more advanced topics in matter under extreme conditions of density, temperature or magnetic fields. Advanced computational methods applicable to these conditions could then have been treated in more depth, by considering 2D and 3D modelling techniques under realistic conditions. Despite these shortcomings, I can see that "Extreme Physics" could be used as a reference in a course in which lectures would complement the material presented in the text.

Richard Marchand
University of Alberta

**How Do You Find an Exoplanet?** by John Asher Johnson, Princeton University Press 2016, pp: xv +178, ISBN 978-0-691-15681-1, price 43.95.

La découverte de planètes gravitant autour d'autres étoiles que le Soleil, qu'on appelle *exoplanètes*, s'est véritablement amorcée en 1996. Vingt ans plus tard, on a confirmé l'existence de plus de 2000 de ces corps célestes, et au moins autant d'autres candidats attendent leur confirmation. Rien n'indique que l'essor fulgurant que connaît ce champ de recherches soit sur le point de s'essouffler.

John Asher Johnson a rédigé ce petit livre en ayant d'abord en tête les étudiants de premier cycle qui désirent réaliser un court projet de recherche sur les exoplanètes et peut-être, plus tard, s'engager plus résolument dans leur étude. Mais l'ouvrage intéressera un public beaucoup plus étendu, allant des astronomes amateurs aux scientifiques curieux de savoir jusqu'à quel point notre système solaire, et la vie qu'il abrite, sont uniques. Quelques erreurs d'inattention (comme la remarque à la page 13 selon laquelle l'énergie potentielle gravitationnelle est inversement proportionnelle au carré de la distance) n'enlèvent rien à la valeur de l'ouvrage.

Quatre des six chapitres du livre se consacrent chacun à une méthode spécifique de détection d'exoplanètes: (i) le changement périodique de la vitesse radiale d'une étoile produit par l'attraction d'une planète et révélé par l'effet Doppler; (ii) la diminution de la luminosité apparente d'une étoile due à un transit planétaire; (iii) la microlentille gravitationnelle d'une planète se superposant à celle de son étoile; et (iv) l'observation directe d'une image d'exoplanète.

Dans chaque cas, Johnson explique clairement les principes physiques sur lesquels se base la méthode de détection, préférant les situations simples (par exemple des orbites circulaires) à des configurations plus générales où l'on pourrait se perdre dans la complexité des calculs. De cette manière, le lecteur arrive fréquemment à déduire directement d'un graphique certains paramètres importants d'une exoplanète et de son étoile.

Tirant parti de son expérience d'observation, Johnson décrit soigneusement les techniques et les appareils utilisés pour la détection d'exoplanètes. L'ingéniosité déployée surprendra le lecteur non spécialiste. Pour mettre en contexte les difficultés de détection, signalons que le transit de la Terre devant le Soleil réduit sa luminosité de moins d'une partie dans dix mille, et que l'attraction de la Terre fait osciller la vitesse radiale du Soleil avec une amplitude de 9 centimètres par seconde. Eh bien, on arrive présentement à détecter des effets de cet ordre dans d'autres systèmes stellaires.

L'ouvrage s'amorce sur un rappel de l'astronomie copernicienne et du changement de perspective qu'elle a apportée. De même que la Révolution scientifique a détrôné la Terre de sa position centrale, la découverte d'exoplanètes a montré que notre système solaire n'est pas unique, ni même typique. Par exemple, les planètes de la taille des géantes gazeuses sont nettement moins nombreuses que celles de taille comparable à la Terre ou à Vénus, et les grosses planètes qu'on observe se trouvent souvent près de leur étoile. Une révision importante de nos modèles de formation planétaire s'impose.

Johnson conclut en indiquant comment les quatre méthodes de détection décrites auparavant vont se développer dans les années à venir. De nouveaux appareils et télescopes spécialement dédiés à la recherche planétaire vont voir le jour. L'un des principaux objectifs consistera à détecter des planètes plus ou moins semblables à la Terre, traçant des orbites se situant dans ce qu'on appelle la zone habitable, c'est-à-dire à une distance de l'étoile qui permet la présence d'eau liquide. Des techniques se développent pour détecter l'atmosphère de telles planètes, et voir s'il porte la trace de phénomènes biologiques. Les vingt prochaines années pourraient bien apporter des réponses à ces interrogations.

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**An Introduction to the Global Circulation of the Atmosphere** by David Randall, 2015, pp 442, Princeton University Press, ISBN 0-691-14896-1, price $113.00.
http://www.cap.ca/brms/reviews/Rev1456_854.pdf

La compréhension de la circulation globale de l'atmosphère a fait d'énorme progrès lors des dernières années et le sujet et devenu plus étendu et plus complet. A l'aide des coordonnées isentropiques (surface d'égale température potentielle) il est possible à la fois de faire l'étude des concepts d'énergie et des processus à plus petite échelle, tel que la turbulence et le rôle des systèmes nuageux. Le prérequis pour apprécier cet ouvrage est que le lecteur soit familier avec les notions d'équation du mouvement, les balances géostrophique et hydrostatique, la température potentielle, tourbillon, coordonnées de pression et ondes planétaires. Ce livre est basé sur les cours enseignés par l'auteur lors des 26 dernières années au Colorado State University. L'auteur est intéressé à faire comprendre le comment et le pourquoi de la circulation globale de l'atmosphère.

Après un bref tour d'horizon du contenu du livre, l'auteur, au chapitre 2, présente les flux d'énergie au sommet de l'atmosphère, à la surface de la Terre, et à travers l'atmosphère. Le chapitre 3 est un aperçu des phénomènes saisonniers observés de la circulation globale de l'atmosphère tel les circulations de Hadley et Walker, les moussons, les ondes planétaires et des aspects du cycle hydrologique. Les graphiques sont créés à l'aide des réanalyses provenant du European Centre for Medium Range Weather Forecasts (ECMWF) et représentent un avantage substantiel à la visualisation de ces circulations. Le chapitre 4 couvre les principes de conservation de mouvement, d'humidité, d'énergie sous ses diverses formes, de tourbillon potentiel ainsi que les approximations quasi-hydrostatique et quasi-géostrophique, toujours en coordonnées isentropiques lorsque nécessaire.

Le chapitre 5 porte sur la circulation atmosphérique entre les régions sources et puits d'énergie statique, d'humidité totale, du mouvement angulaire au sommet et à la base de la troposphère. Le chapitre 6 introduit les sources et puits de l'énergie convective en débutant par une revue de la convection dans une atmosphère humide ou sèche. Ici, des modèles conceptuels auraient été utiles pour la visualisation de ces mécanismes. Le chapitre 7 présente les énergétiques de la circulation globale, en débutant avec l'énergie potentielle disponible et le concept de stabilité statique brute (gross). Le chapitre suivant, l'un des plus intéressants, introduit divers types de tourbillon; en commençant par une brève discussion de l'équation tidale de Laplace, suivie par la théorie des ondes de Rossby créée par un écoulement forcé au-dessus d'une topographie et la théorie des ondes équatoriales de Matsuno.

Le chapitre 9 examine les interactions des tourbillons pour un écoulement zonal moyenné en commençant par le théorème de non interaction. Le chapitre 10 discute de la nature de la turbulence à grande échelle en commençant par présenter la nature de la turbulence et la différence d'un écoulement, dépendant qu'il soit en trois ou deux dimensions. Enfin, le dernier chapitre fait un bref sommaire des courants actuels et futurs de la circulation atmosphérique en période de changement climatique. Le lecteur qui veut approfondir ce sujet se réfèrera au IPCC (Intergouvernmental Panel on Climate Change) ou au chapitre '*Changes in the Atmospheric Circulation as Indicator of Climate Change*' de Thomas Reichler que l'on retrouve sur le Web.

Chaque chapitre comporte une série d'exercices, et le volume se termine avec plusieurs annexes. Une bibliographie de près de 800 références et un index viennent mettre fin à cet ouvrage fabuleux. Ce livre, qui se présente comme une introduction, peut être considéré, selon moi, comme un indispensable pour la préparation d'une recherche dans le domaine; par sa structure englobante et ses dérivations mathématiques et physiques du sujet.

André April
Environnement et Changements climatiques Canada

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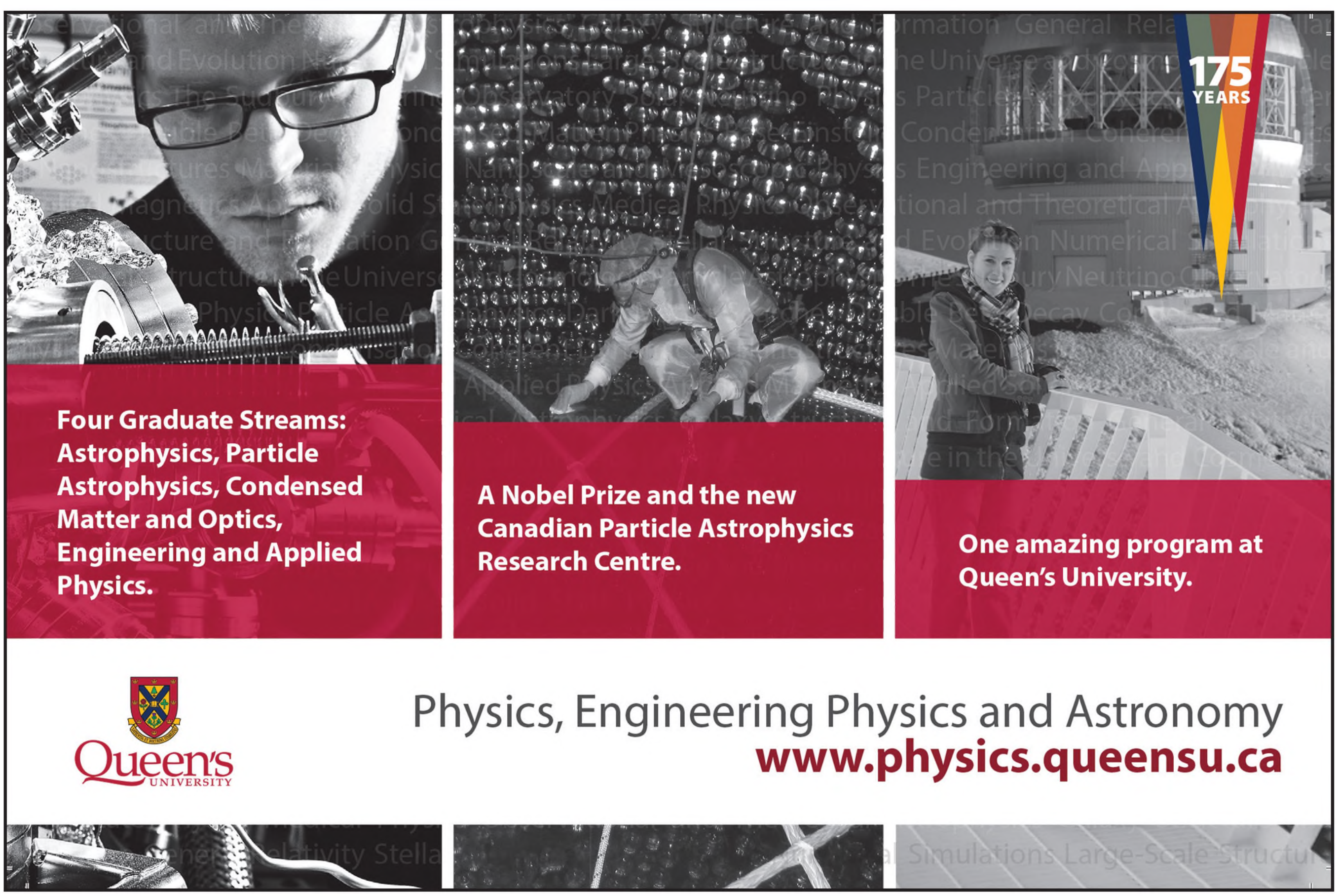

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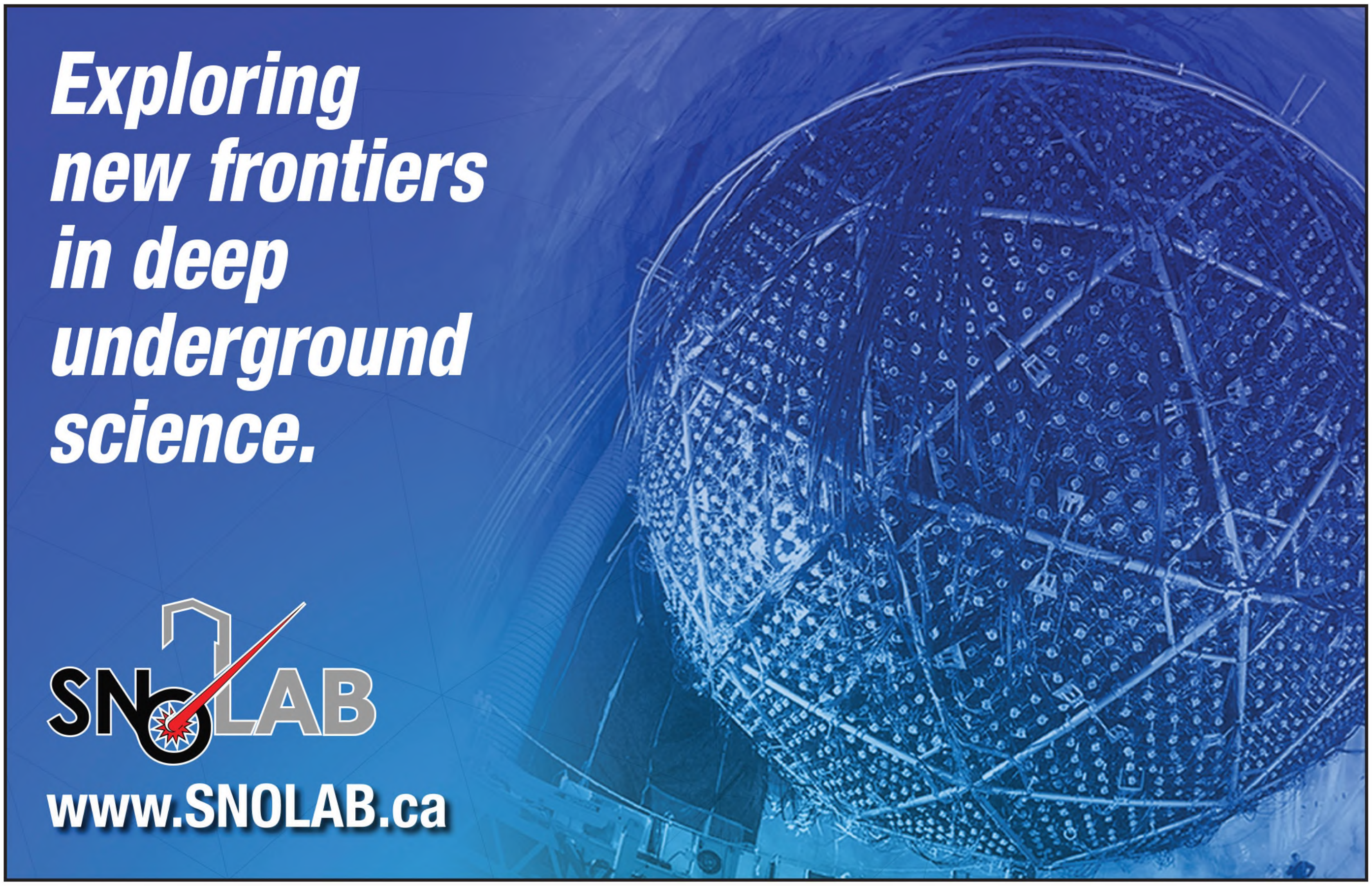
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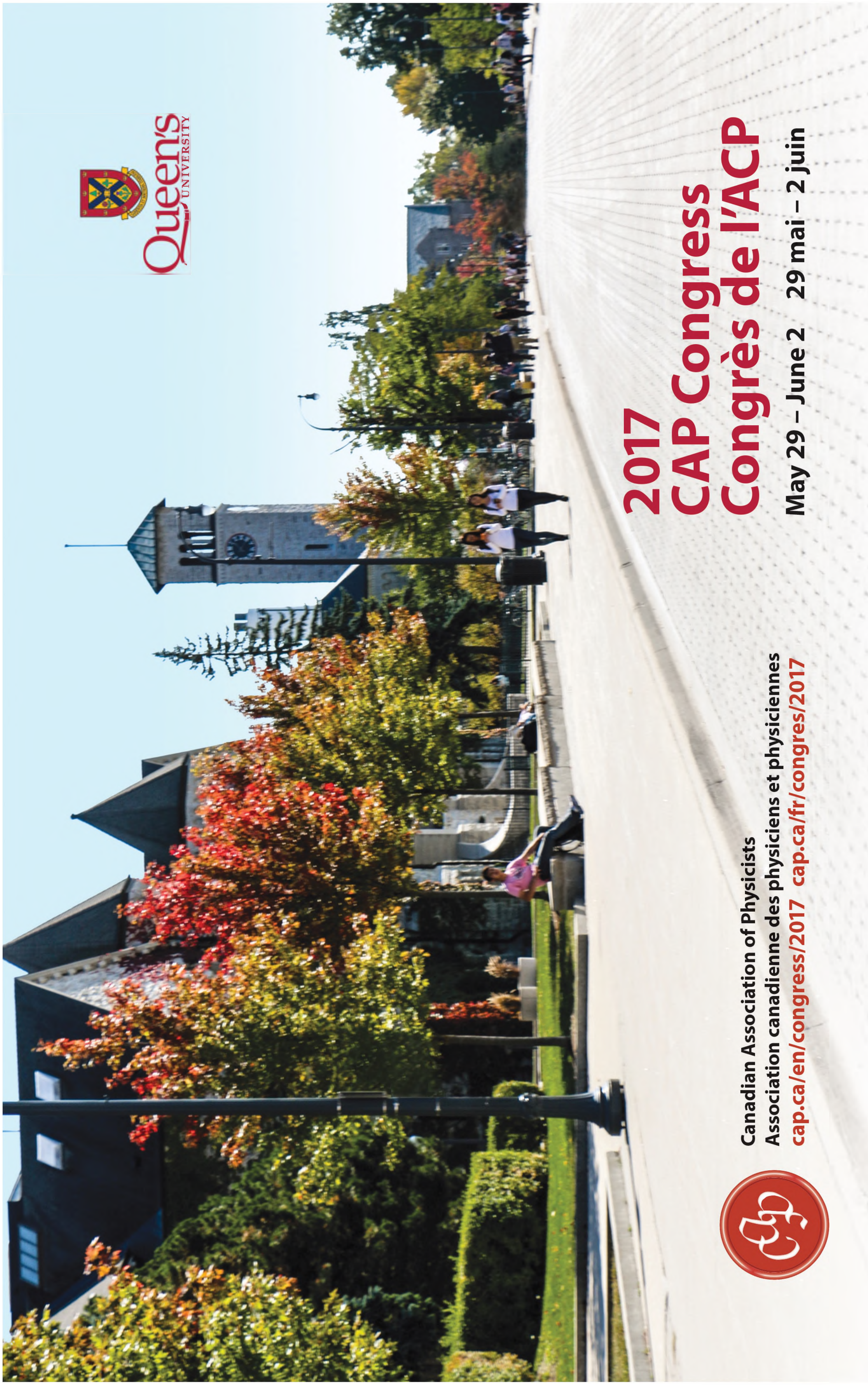


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