
PHYSICS AT THE
UNIVERSITY OF TORONTO

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DEPARTMENT OF PHYSICS / UNIVERSITY OF TORONTO
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DATES OF INTEREST

- 1843 Professorship in Mathematics and Natural Philosophy established
- 1878 Laboratory for undergraduates set up
- 1881 Position of Demonstrator in Physics established
- 1882 Fourth year of the honour course in Mathematics and Physics divided into Division I-Mathematics and Division II-Physics
- 1887 Professorship in Physics established
- 1904 Provision made for the erection of a building for Physics, Division III-Astronomy and Physics added in fourth year, Astrophysics made a sub-department
- 1905 Sod turned for the Physics Building
- 1907 Official opening of the Physics Building
- 1918 Astronomy separates from Physics
- 1923 Completion of the helium liquefaction plant
- 1933 Engineering Physics course introduced, M.A. course in meteorology established
- 1943 Geophysics made a sub-department
- 1947 Computation Centre set up by the University
- 1949 Official opening of the Burton Wing
- 1964 Sod turned for the new McLennan Laboratories
- 1966 Official opening of the Linac Laboratory, Scarborough College opened
- 1967 Official opening of the new McLennan Laboratories, Erindale College opened
- 1970 Undergraduate Department of Computer Science established

FOREWORD

An attempt will be made to follow the development of the Department of Physics in the University of Toronto from its beginning to approximately 1980. This period divides naturally into five parts. The first extends from the appointment of the first Professor of Mathematics and Natural Philosophy in 1843 to the opening of the first Physics Building in 1907, the second from 1907 to 1932, the third from 1932 to 1948, the fourth from 1948 to 1969 and the fifth from 1969 to 1980.

The years from 1907 to 1948 will be treated in greater detail than others. Particular attention will be paid to the growth in scientific stature of the Department, i.e., to the scientific interests of, and the research projects initiated by, the academic staff. Personal references to staff members will necessarily be brief. Changes in the undergraduate courses will not be followed in detail. It will be possible to refer personally to only a few of the non-academic staff, although their importance to the work of the Department throughout its history has been very great.

The author's background for this narrative is more than fifty years spent as student and staff member in the Department of Physics in Toronto. Many of the details such as numbers and dates were taken from the President's Reports covering 1901 - 1902 and subsequent years, and from the calendars of University College in the earlier period and of the University of Toronto in the later period. Information about the opening ceremonies for the first Physics Building was found in the University Monthly for 1907 and in the daily press of that time.

The story of the work with helium during the First World War was recorded in Mines Branch Information Circular 1G105 by Professor Satterly, and some description of the research carried on by staff members during the Second World War is given in "Operational Research in the Canadian Armed Forces" by J.W. Mayne.

Two accounts proved most helpful: one entitled "A short history of Engineering Science at the University" and published in 1970, the author being Don Ball, and the other telling the history of the Toronto Linear Accelerator Project written by J.S. Hewitt and K.G. McNeill. Information about the research activities of the period before the Second World War is contained in the volumes of reprints of papers published by staff members, which are to be found in the Physics Library. Research activities of more recent years are described in the Graduate Studies Reference Booklets issued by the Department since 1967.

The lists of graduate students who have obtained Ph.D.'s were compiled from Departmental records. The thesis titles were also available and provided additional details of the type of problem being studied.

Present members of the staff have been most helpful; K.G. McNeill, G.M. Graham, G.D. Garland, C.C. Gotlieb and R.L. Armstrong deserve special mention. H.L. Welsh has read the manuscript as it was being written, and has given invaluable criticism and advice to the author as well as supplementing the author's recollections with his own.

INTRODUCTION

The Royal Charter for King's College was granted in 1827 but its terms aroused much opposition and not until 1843 did academic work begin. At that time professors of classics, belles lettres, divinity, law, mathematics, chemistry and anatomy were appointed. It appears that those responsible for the character of the new university thought of an institution with a staff only of professors. In the future new subjects of learning would be taken care of by the appointment of new professors. Physics or natural philosophy was regarded as closely related to mathematics and within the purview of that chair, the first appointees to which were designated as Professor of Mathematics and Natural Philosophy.

Such a concept of the university was valid only if it continued to have a small body of students and if the material to be covered within a given subject remained limited. It proved untenable because of the proliferation of all knowledge and particularly of experimental science in the latter half of the nineteenth century. The number of lecture courses required to adequately treat a given field and the number of students desiring these courses multiplied and undergraduate laboratories were introduced.

Not many years elapsed before positions other than that of professor were established. A mathematics tutor was appointed in 1864 and a demonstrator in physics in 1881. In 1887 the professorship in mathematics and natural philosophy was divided and physics recognized as an important branch of learning by the creation of a professorship in physics. The rank of associate professor of physics first appears in staff lists in 1902 and that of assistant professor in 1916.

The appointment of the first Professor of Physics in 1887 can be taken as marking the creation of the Department of Physics. The concept of one professor controlling instruction in a given field persisted for many years. Even after he came to have a number of assistants,

he could act virtually without consultation. When in the twenties and later, more than one person in a given field was promoted to the rank of professor one of these was designated as Professor and Director of the Laboratory or as Professor and Head of the Department with powers which were essentially those given the original professors.

For most of the period covered in the following historical account, the Department consisted of a Head who determined its policies and planned its future and a number of staff members who assisted him in carrying out these policies and who were assigned definite duties in the instruction of undergraduate students. They were free to engage in research of their own choice and in the training of graduate students. As physical knowledge broadened and the number of senior staff members increased the role of each in the determination of the undergraduate teaching programme and in planning the future of the department became more important. In 1962 the title Head was discontinued and that of Chairman substituted.

An important factor in its growth was that the formative years of the Department in Toronto were years in which exciting developments took place in physical science. It was in 1843 that James Joule, on the basis of his observations, stated his conviction that a given amount of mechanical work, if completely transformed into heat, always produced the same amount of heat; the development of the science of thermodynamics followed. The atomic theory had taken on a quantitative character at the beginning of the nineteenth century, but only in the last decade of that century was the electron shown to be a constituent of all atoms. The nuclear atom and the science of spectroscopy which assumes the reality of the structured atom belong to the twentieth century. Electromagnetic waves were unknown until 1888 and the quantum hypothesis and the theory of relativity both were born in the early years of the twentieth century. The realization that many discoveries were the result of experimental observations won for the scientific laboratory a recognized place in the universities. Physics laboratories for research and for undergraduate students were first established in European and British universities. Their creation in Toronto led to a need for enlarged accommodation for the Department.

Undergraduate instruction was and remains a primary responsibility of the Department. The number of undergraduates seeking courses in physics steadily increased over the years. The sharp increases which followed the first and second world wars were succeeded by sharp decreases which, however, did not reduce the numbers to their pre-war levels. The general trend was up and in the early fifties the number of students registered in physics courses was about double that before

the first world war. The sharp increase in the late fifties and the sixties sparked a rapid expansion of the Department. It did not continue far into the seventies but it was followed by a levelling off and not by a sharp decrease in the numbers. The Department was by this time large and diverse and was entering upon a new phase in its life in which the staff and student body would remain relatively unchanged in numbers. Henceforth the effort would be directed almost entirely to the maintenance and improvement of the quality of the teaching and research. The proximity of this period to the present is the reason so little space has been devoted to it.

Research and graduate studies have assumed a gradually increasing role in the Department since its inception in 1887. The first Professor of Physics, James Loudon, was one of those who urged the University to draw up a programme for the graduate degree of Ph.D. The requirements for the degree were laid down in 1897 and the first two degrees were granted in 1900. One of these was in physics. Until 1907 research was restricted by the space and facilities available, but this limitation was removed by the opening of the first physics building in that year.

During the years in which he was Head of the Department, J.C. McLennan dominated its research activities. Most of the graduate students worked under his supervision and the projects in which he was interested received greatest support. His retirement took place near the beginning of the great depression and for some years afterwards money for research was difficult to obtain. The feasibility of a new project depended to a considerable extent on outside support from an interested sponsor. In the war years which followed the depression academic research was phased out, only defence-related problems being pursued. After the war research had to be quickly reinstated and expanded as many young men wished to begin or to continue graduate work on their return from war service. All staff members now could obtain support for projects which they wished to undertake and all became responsible for the supervision of graduate students. During the expansion of the fifties and sixties, research groups, each made up of several staff members of closely related interests, were created. All major fields of classical and modern physics were covered and the groups contained both experimental and theoretical physicists.

I / THE EARLY YEARS, 1843-1907

The first professorships in King's College were established in 1843; there was no provision for one in physics. Natural Philosophy, as physics was known in some universities, consisted largely in the application of Newtonian mechanics in the explanation of natural phenomena and was predominantly mathematical in character. There were plans for a professorship in mathematics and the first appointment to that post was called professor of mathematics and natural philosophy. The "Department of Instruction" was also named Mathematics and Natural Philosophy. The majority of the lecture courses offered by this department were in mathematics but it also provided lectures in Newton's Principia, statics, dynamics, hydrostatics, geometrical optics, acoustics, and astronomy. As late as 1857 - 58 no lectures in the theory of heat or in electricity were listed, any instruction in these fields being given by the Department of Chemistry as chemical physics.

Specialization was not in mathematics or in physics but in mathematics and physics. The first distinction between students primarily interested in mathematics and those primarily interested in physics was made in 1882 when the fourth year of the prescribed specialist course was divided into two options. Five years later separate professorships were set up in mathematics and in physics and the responsibility for instruction in the two subjects was divided. The Department of Instruction remained Mathematics and Physics and was administered jointly.

The first incumbent of the chair of Mathematics and Natural Philosophy was Richard Potter who, at the time of his appointment, was Professor of Natural Philosophy and Astronomy at University College, London, England. He was a man of some scientific achievement but remained in Toronto only about a year. The professors of classics and of divinity received a salary of £500. It seems that when the salaries of other professors in the Faculty of Arts were set at £450, Potter

resigned and returned to his former position in London.* Because of his short sojourn he cannot have left any considerable impression on the teaching of mathematics and physics in Toronto. He was succeeded by Robert Murray about whose tenure little seems to have been recorded. Murray was at one time a Presbyterian minister in Oakville, Ontario, and at the time of his appointment to King's College was acting as Superintendent of Education for Ontario. The desire to replace him in that position appears to have been the motivation for his appointment as professor since no record of his scientific achievements was found. He retained the professorship until his death in 1853.

During a part of Murray's tenure J.B. Cherriman, a fellow of St John's College, Cambridge, was his assistant and established himself as a teacher of exceptional merit. He was also the author of textbooks on statics, dynamics and hydrostatics. It seems likely that for some time before Murray's death Cherriman had been carrying most of the responsibility, and when Murray died Cherriman was appointed Professor of Natural Philosophy. Writing in the *University of Toronto Monthly* for January, 1908 under the title "Some Recollections of an Old Boy", George Kennedy, M.A. makes the following statement: "Professor Cherriman was not much admired by his pass men but it was with his Honour men that his good qualities shone out."

It is interesting to note that the British physicist John Tyndall also was an applicant for the professorship at this time. He had completed his Ph.D. studies at Marburg, Germany, and been elected a Fellow of the Royal Society of London in 1852. His stature as a scientist far exceeded that of Cherriman but it does not follow that the wrong choice was made. The new University had been established primarily to provide post-secondary education in the province and the appointment of one who, working under the conditions then existing, had had outstanding success as a teacher need not be severely criticized.

In 1850 King's College became the University of Toronto. This was a degree-granting institution and all teaching was carried on in University College which was created for the purpose. The scope of the physics taught at this time is indicated by a list, given in the calendar of University College for 1857 - 58, of instruments used to illustrate the lectures in natural philosophy, viz: 39 illustrative of statics, 14 of dynamics, 50 of hydrostatics, 10 of acoustics, 20 of optics and 16 of geodesy and astronomy. All lectures offered by the Department of Mathematics and Natural Philosophy to the first year and at least half of those offered to the second, third and fourth year students were in mathematics. In the second year curriculum statics and dynamics,

* The University of Toronto and its Colleges, 1827 - 1906. The University Library, published by the Librarian, 1906.

in the third year hydrostatics and geometrical optics, and in the fourth year astronomy and acoustics appear in addition to mathematics. Lectures listed by the Department of Chemistry include electricity, electromagnetism, thermoelectricity and heat. The lists of lectures remain almost unchanged in succeeding years; however, changes in the recommended text-books and in the distribution of subjects among first, second, third and fourth years suggest upgrading of the material treated. No major re-structuring of the curriculum seems to have taken place during the next twenty years.

Cherriman did not resign his professorship until 1875. However the number of students was increasing and a new position of Mathematics Tutor was created. James Loudon, an honours mathematics graduate of 1862, was appointed to this new position in 1864. His subsequent service to the University extended over a period of more than forty years. In 1865 he was made Dean of Residence and in 1873 he became one of the first elected members of the University Senate. He was appointed Professor of Mathematics and Physics in 1876 and when, on the passage of the Federation Act in 1887, the University became a teaching body with mathematics and physics listed as separate "university" subjects he became Professor of Physics. He retained this chair when, in 1892, he was appointed President of the University and did not sever his connection with the Department until 1906. His influence on the growth of the University was felt in many ways but particularly in the teaching not only of physics but of all the sciences.

Many of the scientific discoveries of the nineteenth century were made not as the result of theoretical prediction but as the result of observation and experimentation. Practical demonstrations had therefore become a feature of university teaching. Loudon was one of those who believed that it was of great importance that the student in science, himself, be able to carry out demonstrations of natural phenomena and to test natural laws. Laboratories for these purposes had been created in some universities but were not in 1876 available to him in Toronto. It was largely due to Loudon's efforts that in 1878 the first laboratory in Canada for the use of undergraduate students in physics was established in Toronto. Laboratories were set up at the same time for students in chemistry, in biology, and in mineralogy and geology.

The creation of the undergraduate laboratory played an important role in the growth of physics teaching in Toronto. In 1882 the fourth year of the prescribed honours course was divided into two options; it then became possible for students who had a special interest in physics to devote a greater part of their time to physics than to mathematics during their final undergraduate year. This made it feasible for them

to spend more time in the laboratory and, in some cases, to participate in research projects. Certificates for laboratory work were required of honours students in 1885, and in that same year the calendar stated that there are "special laboratories which offer unusual facilities for the conduct of experiments in the various branches of physics". The division of the fourth year also made it possible to introduce additional fields of study in physics. Physical optics and electrostatics appeared as lecture courses only after 1882, although a place had been found for thermodynamics and heat as early as 1880.

Only in 1887 did a department of physics separate from that of mathematics become a reality. Before this, in 1881, a new staff position of Demonstrator in Physics was created, the title of which reflected the added importance given practical work. In 1887 when James Loudon became Professor of Physics, W.J. Loudon his nephew, retained the position of Demonstrator, which he had held since 1881, and a new appointment of Fellow in physics was made. The new department thus had a staff of three. This number was not increased until 1892 when C.A. Chant was added as Lecturer and J.C. McLennan became Assistant Demonstrator. All three of those named above served the University for many years. W.J. Loudon became Professor of Mechanics, C.A. Chant Professor of Astrophysics and J.C. McLennan Professor of Physics.

The space initially occupied by the new undergraduate physics laboratory when it was set up in 1878 consisted of a number of rooms in the University College building, known then and for many years afterwards as the Main Building. As told by Loudon in an address printed in the University Monthly for 1907, it had been arranged that the new undergraduate laboratories for all the sciences be located in the new building known as the School of Practical Science. He went to Europe to buy apparatus and on his return found that all space in the new building had been taken and there was none left for physics. He therefore accepted space, previously occupied by the Chemistry Department, in the Main Building. In succeeding years the space was gradually expanded to include additional rooms not well suited to laboratory purposes. Loudon became President of the University in 1892. In his report for the academic year 1902 - 03 he stated that the floor space available to physics was 9285 square feet whereas that available to chemistry was 31,332 square feet and to biology 26,694 square feet. Two years before he had stated that a new building for the purposes of the Department of Physics was a necessity. To make this building a reality the support of the newly-formed Alumni Association was enlisted.

One of the considerations which made provision of more suitable accommodation for physics necessary at this time was the large number of students, both in Arts and in the professional faculties, whose primary interest was not physics, but for whom instruction in physics was regarded as essential. The number of students from faculties other than Arts changed widely from year to year. During the academic year 1903 - 04, in which provision was made by the Government of Ontario for the construction of a building for physics, there were approximately one hundred and fifty students from the Faculty of Arts and four hundred from Medicine and Engineering who were taking courses in physics. On the other hand a factor which made it difficult to obtain laboratory facilities within the University was the strongly-held belief of some prominent members of the faculty and of influential persons outside the University that such laboratories served only for technical training and had no place within a university. The expansion of post-graduate education in experimental science and the part it would play in the contribution the University could make to the community was not foreseen by the non-scientist.

In concluding the first chapter in the development of the Department of Physics, it may be of interest to look at the financial aspect of operating the Department. Science departments, especially physics departments, are expensive to operate when compared to other departments in the Faculty of Arts. Beginning in 1901 the three Departments of Chemistry, Physics, and Mineralogy and Geology were financed for a number of years directly by the Government of Ontario. Their financial statements are so designated in the President's reports. In 1901 - 02 the cost of maintaining the Physics Department is detailed as follows:

Salaries	\$10,350
Supplies, Apparatus etc.	\$1800
Fuel, water, light, cleaning, etc.	\$1725
Physics share of physics and chemistry examination expenses	\$305.

The staff at this time is listed as:

JAMES LOUDON, M.A., LL.D.	Professor
W.J. LOUDON, B.A.	Demonstrator
C.A. CHANT, M.A., Ph.D.	Lecturer
J.C. McLENNAN, M.A., Ph.D.	Demonstrator
J.S. PLASKETT, B.A.	Mechanical Assistant
G.R. ANDERSON, M.A.	Assistant

By the session 1904 - 05 the salaries account had increased by \$1950 to \$12,300. With this added expenditure two assistant demonstrators and six class assistants had been added to the staff and W.J. Loudon and J.C. McLennan had been promoted from demonstrator to associate professor. During the same interval the money spent on apparatus and supplies had increased by slightly more than \$2300.

In the above list of staff for 1901 - 02 the presence of a mechanical assistant is worthy of special comment. Soon after the laboratory was established Loudon felt the need for a workshop in which apparatus could be constructed and repaired and found that, while mechanical skill was indispensable, it could not be easily secured. In the first workshop which he set up, he himself worked in his spare time with some instruction from a student in mechanical engineering. In 1889 he applied for a mechanical assistant and was fortunate to secure J.S. Plaskett, who had had considerable experience in industry. While retaining his position as foreman of the workshop, Plaskett registered as a student and graduated with honours in mathematics and physics in 1899. In 1903 he went to Ottawa to the Astronomical Branch of the Department of the Interior, and thereafter had a brilliant career as an astrophysicist. The workshop in Toronto continued to be of great service to the physicists and by 1906 provided full-time employment for two skilled mechanics.

The contract for the construction of a building for physics was let in June 1906, and at the end of that month James Loudon severed his connection with the University. J.C. McLennan became Associate Professor of Physics and Director of the Physical Laboratory. He was promoted to Professor the following year and in a very real sense directed the laboratory for the next twenty-five years.

II / THE MCLENNAN YEARS, 1907-1932

September the twenty-sixth and September the twenty-seventh, nineteen hundred and seven, were significant dates in the life of the University of Toronto. On the twenty-sixth Robert (afterwards Sir Robert) Falconer was inaugurated as President and on the twenty-seventh the new Physics Building was officially opened. The proceedings associated with the opening were held in Convocation Hall with the new President in the chair. They began with an address by Dr. Loudon, the former President and Professor of Physics, in which he described the difficulties he had encountered, first in having science, especially experimental science, accepted as a study suitable to a university curriculum and later in obtaining adequate accommodation for the Department of Physics. The new building was evidence that he had successfully overcome these difficulties.

At the conclusion of Loudon's address, McLennan was asked to explain the plan of the new building. He also gave his hearers some idea of the facilities which would be available in it when the task of equipping it had been completed and declared himself satisfied that anyone desirous of doing scientific research would find it suitable.

Dr. Pritchett of the Carnegie Foundation for the Advancement of Teaching Standards, who had brought greetings to President Falconer at his inauguration the previous day, then spoke on "The Progress of Science in the Last Century". He was followed by Professor Cox of the Department of Physics at McGill University, who offered congratulations on behalf of that university and praised the new building for its spaciousness and the provisions made in it for the convenience and efficiency of those working there. The Physics Building at McGill was already seventeen years old and had been a source of pride to them during that period.

At the conclusion of the addresses the Lieutenant Governor of Ontario declared the Building open, and following this a reception

was held there by President and Mrs. Falconer. Afterwards those present were given an opportunity to inspect the Building.

McLennan was proud of the Physics Building and convinced that it was the best for its purpose that could have been built for the money available. He may or may not have felt that it was the equal of any on the continent as it had been described by one of the speakers at the opening ceremonies. He had supported Loudon in his efforts to obtain the building, had taken part in its planning and had watched over its construction on a day to day basis. He was a wise choice as leader of the department which was to be housed in it, having great physical energy and an enthusiasm which he could impart to others.

Born in Ingersoll, Ontario, of Scottish-Canadian parents on April 14, 1867, John Cunningham McLennan was, like his predecessor, a graduate of the University of Toronto. On matriculating from Clinton High School in 1883, he had been unable for financial reasons to proceed directly to university and had spent five years teaching in elementary schools and studying mathematics. In 1892 he graduated in the physics option of honours mathematics and physics and joined the staff as an assistant demonstrator in physics. He had been able to spend the year 1898 - 99 at the Cavendish Laboratory and under the influence of Sir. J.J. Thomson and Sir Oliver Lodge had become enthusiastic about the possibilities for new discoveries inherent in experimental research and had decided to devote his life to it. On his return to Toronto he completed in 1900 the requirements for the Ph.D. degree and received the first such conferred by a Canadian university on a student of the physical sciences. With the completion of the Physics Building he envisioned a department of physics in Toronto which would train men and women to staff physics departments in the newer universities yet to be established, particularly in Western Canada.

In 1906 - 07, at the time the move to the new building was made, the staff consisted of: J.C. McLennan, W.J. Loudon, C.A. Chant, E.F. Burton, L. Gilchrist, three assistant demonstrators and a lecture assistant. W.J. Loudon, a nephew of James Loudon, had been a member of the staff since 1881 when he became the first to occupy the position of Demonstrator in Physics. However, being primarily interested in theoretical mechanics rather than experimental physics, he severed his connection with the Department of Physics when it moved to the new building. As Associate Professor of Mechanics he remained in the University College building with the Department of Mathematics.

C.A. Chant graduated in mathematics and physics at Toronto in 1890, was awarded a teaching fellowship in physics in 1891, and in 1892 was appointed a lecturer in physics. In 1900 he obtained his

Ph.D. in physics from Harvard University, having been given leave of absence from Toronto to do so. He became increasingly interested in astronomy and, when in 1904 a fourth year option of astronomy and physics was instituted in M and P, he headed the new sub-department of Astrophysics. He remained a member of the staff in physics and moved to the new building. When in 1918 Astronomy became a department separate from Physics he became its first Head.

E.F. Burton had graduated in 1901, become a lecture assistant in 1902 and an assistant demonstrator the following year. Awarded an 1851 Exhibition scholarship in 1904, he went to the Cavendish where he worked under Sir J.J. Thomson for two years. On returning to Toronto in 1906 he re-joined the staff as a demonstrator. He remained on the staff and became Head of the Department when McLennan retired in 1932.

Lachlan Gilchrist also was a demonstrator in 1906. As an undergraduate he had chosen to specialize in physics and chemistry, which had been added as a honours course in 1896, rather than in mathematics and physics. A great admirer of A.A. Michelson, he decided on graduating in 1904 to go to the University of Chicago for post-graduate work. Much of this he did in the summers while serving as a demonstrator in Toronto during the winter term, obtaining the degree of Ph.D. in 1913. He, too, helped to organize the work in the new building, was appointed to the rank of Assistant Professor in 1916 and remained in Toronto for a lifetime.

It was quite common, both at this time and later, for persons graduating with a high standing to join the staff as a class assistant or assistant demonstrator and continue their studies to qualify for a more advanced degree. Many stayed for one or two years only before going to another university for further study or taking a position in a research laboratory or in industry. Others remained permanently. Among those who stayed for only a year or so were some persons whose names later became very well-known. As examples mention may be made of J.K. Robertson (M.A. 1908) who became Head of the Physics Department in Queen's University; A.J. Dempster (B.A. 1910) whose work on isotopes made him famous; Andrew Thomson (M.A. 1916), Director of the Meteorological Service of Canada 1946 - 59; D.A. Keys (M.A. 1917) who was Macdonald Professor of Physics at McGill from 1941 to 1947.

Among those who, starting as assistant demonstrators, remained in Toronto, in addition to McLennan himself, Burton and Gilchrist, was H.A. McTaggart who became an assistant demonstrator in 1907, on graduation in M and P. Born in Kemptville, Ontario in 1876, he spent

his early life in British Columbia and had taught for several years in elementary schools before coming to Toronto to enter university in 1903. Except for two years at the Cavendish and the war years he spent his life up to an early death in 1941 as a member of the staff of the Department.

Another among those who joined the Department as a class assistant and remained for a lifetime was Annie T. Reed. A graduate of M and P in 1897 she became a class assistant in 1910 but did not follow an academic career. Rather she became secretary, although not until 1924 was her appointment changed to be Class Assistant and Secretary to the Department. For many years she typed all letters, examination papers and other confidential material, kept the accounts and issued purchasing orders. Her first loyalty was to the Department and she participated in all its activities until her retirement in 1946.

The four persons mentioned above, McLennan, Burton, Gilchrist and McTaggart, with the single addition of John Satterly, who came from England in 1912 to assume a position as lecturer, formed the senior staff not only in the first years in the new building but also throughout the twenties. Satterly already on coming here had a D.Sc. degree from the University of London. He became best known for his lectures to junior students. He did not retire until 1949 and throughout the years lectured to students in first year honours physics. His lectures to students in the upper years were sometimes dull but he showed great ingenuity in devising demonstration experiments for lectures to first year students. One lecture each year on phenomena which occur at liquid air temperature and the properties of materials at that temperature was so enjoyed that students in other courses skipped their regular classes to attend, and the large lecture theatre would be filled to capacity well before the time scheduled for the lecture to begin.

In 1915 there were as just noted five members of the staff of the Department who held on-going appointments. Early in 1915 the two junior members, Gilchrist and McTaggart, were granted leave of absence to join the Medical Corps as x-ray specialists. It should be remembered that x-rays had been discovered only in 1895 and that their use in medicine was still in the experimental stage. Gilchrist joined the Ontario Military Hospital in Orpington, England, as x-ray expert on the development of the application of radiology for the armed services. McTaggart became Captain in charge of the x-ray department of No. 4 Canadian General Hospital, Salonika. After this hospital was moved to England in 1916, he was transferred to war research and put in charge of an Admiralty Research Laboratory in West Kensington.

Although the remaining members of the senior staff now carried the whole responsibility for teaching undergraduates, they became involved in a new research activity. Late in 1915 McLennan was asked by the Department of Inventions and Research, London, to make a survey of natural gas wells in the British Empire to determine the helium content of the gas with a view to deciding whether large scale production and purification of helium for use in lighter-than-air craft was feasible. All three, McLennan, Burton and Satterly, became involved but in 1917 McLennan went to England as Scientific Advisor to the Admiralty. Although his principal responsibility there was related to submarine and mine detection and destruction, he continued his interest in the helium project and established a small laboratory in London for helium research. Here he gathered a group of young Canadians, mostly graduates in physics from Toronto.

With the departure of McLennan, the direction of the Department demanded more of Burton's attention and the helium research devolved largely on Satterly who now had associated with him Dawes of McMaster, R.J. Lang later of the University of Alberta, and John Patterson on leave from the meteorological service. The first plant for the extraction of helium and its purification was built on Hamilton Mountain and used gas from south-western Ontario. Later this was closed and one built on Bow Island near Calgary, where a more plentiful supply of gas of slightly higher helium content was available. Although no important production of helium was achieved before the United States entered the war and made available a much more abundant supply, the work with helium had most important consequences in the future of the Department.

Towards the end of the war for the first time women are found occupying the position of demonstrator. Women as staff members were not an innovation but previously they had held the rank of assistant demonstrator or class assistant only. Two who joined the staff at this time remained permanently with the Department. Kathleen M. Crossley will be remembered by many generations of first year students, and Florence M. Quinlan, particularly by those who were students in the honour course of Household Economics.

After the war all five, McLennan, Burton, Satterly, Gilchrist and McTaggart, resumed their duties on the regular teaching staff. Burton had been made Associate Professor in 1911. Satterly and Gilchrist had been promoted to Assistant Professor in 1916 and McTaggart in 1919. Throughout the twenties they were the only staff members of professional rank. All others remained lecturers, demonstrators or sessional appointees.

In the 1920's there were three large undergraduate laboratories

each dealing with experimental phenomena in one field of physics and each was developed and supervised by one professorial staff member. That for heat and properties of matter was the responsibility of Satterly; that for optics of McTaggart and that for electricity and magnetism of Gilchrist. The three taken together were designed to provide instruction in the basic concepts and laws of all of what is now known as classical physics. For honours students the work was spread over two years; others such as pre-professional students completed the required work of all three laboratories in a single year. For honours students in the third and fourth years more specialized training was provided in smaller laboratories often associated with the research activities of the Department. McLennan and Burton were involved in these and the other three professors to a lesser extent. Since the lectures were also the responsibility of the same five men they carried very heavy teaching loads.

These teaching duties were reduced somewhat when in 1930, shortly before McLennan's retirement, D.S. Ainslie was appointed to the professorial staff. A graduate of M and P in 1915, he had spent some time in Britain on anti-mine research. Near the end of the war he had returned to Canada and joined the helium project in Calgary. After a year spent as instructor at the University of Saskatchewan, he completed work for his Ph.D. in Toronto in 1925 and joined the Department of Physics in the University of Western Ontario.

RESEARCH

Hand in hand with the development of first class teaching laboratories went the development of research facilities. Apparatus acquired primarily for research could often be used for teaching when not in use for research, and when research projects were changed some instruments might be released permanently to the undergraduate laboratories. Conversely instruments from the teaching laboratories could sometimes be spared for research. Honours physics students in their fourth and occasionally in their third year were encouraged to devote part of their laboratory time to research and were assigned projects.

If one judges from his publications during the period before 1910 McLennan had two main research interests. One of these was the apparent natural radioactivity of many substances and the activity induced in substances when bombarded by cathode rays. The other was the electrical conductivity of the atmosphere. Stemming from the first of these interests was an investigation of the radiation emitted by certain salts when bombarded by cathode rays. This is chosen for

mention since, carried out before 1902, it dealt with an effect which aroused considerable interest when rediscovered fifty years later. It has been explained as due to thermally stimulated electron emission. His interest in atmospheric conductivity resulted in his discovery in 1903, in collaboration with Burton, of the penetrating radiation later identified by Hess as of cosmic origin. This discovery was made at about the same time, quite independently, by Rutherford and Cooke at McGill. Measurements of atmospheric conductivity were continued for a number of years and in a variety of locations. Many of the anecdotes of earlier times current in the Department in the twenties concerned mishaps occurring when these experiments involved the use of small boats on Toronto Bay or were carried out on the ice once the Bay was frozen over.

Sometime before 1910 both McLennan and Burton developed new interests to rival those mentioned above. Research in radioactivity and gaseous conduction decreased, to be replaced in the case of McLennan by spectroscopic investigations and in the case of Burton by studies in colloid physics.

Beginning about 1905 McLennan made a habit of visiting England and the continent each summer. In this way he kept in touch with other physicists and learned of new discoveries and new lines of investigation. The analysis of atomic spectra and their interpretation in terms of the energy states of the atoms became an exciting endeavour in the second decade of the twentieth century. McLennan was one of those who became convinced early that it offered great possibilities for the further understanding of the structure of matter. In 1911 when he was President of section III of the Royal Society of Canada he devoted his presidential address to this subject. As Director of the Laboratory, McLennan supervised most of the graduate students and increasingly the research projects pursued in the laboratory became spectroscopic in character. Burton did not become greatly interested in spectroscopy but while at the Cavendish had become involved in colloid physics. He continued to work in this field with a small group of graduate students and he, too, gradually withdrew from radioactivity investigations.

The wartime involvement of members of the Department with helium led to a new research activity which in the years after the war rivalled spectroscopy but did not replace it. The plant near Calgary for the production of helium, to which reference has been made, became operational late in the summer of 1919 and before it was shut down in April 1920 produced about 60,000 cubic feet of helium of 60% to 90% purity. This gas was later released to McLennan by the

Admiralty for the purpose of establishing a cryogenic laboratory in Toronto. At this time the only laboratory in the world in which helium had been liquefied was in Leiden, Holland. Since he had helium and a number of persons to work with it whose wartime experience had made them familiar with its properties as well as with low temperature experimentation, McLennan planned, with his characteristic enthusiasm, to set up a helium liquefaction plant. Kammerlingh Onnes, the Director of the Leiden laboratory, assisted him with the design and working details of the apparatus. Early in January 1923 in Toronto helium was first liquefied in quantity outside the laboratory in Leiden and on January 24, 1923 the cryogenic laboratory in Toronto was officially opened. Thenceforth investigations into the properties of liquid helium and of other substances at the temperature of liquid helium formed an important part of the research carried on in the Department. During the twenties many of these studies were concerned with changes in the electrical conductivity of metals at very low temperatures and the newly discovered phenomenon of superconductivity.

Spectroscopy remained the field in which the greater number of McLennan's graduate students carried on their investigations. Spectra of different atoms were observed in the infrared, the visible, the ultraviolet and the short-wavelength ultraviolet, each of these regions requiring a distinctive technique. The wavelengths of the lines were determined and an effort made to assign each line to a transition between identified energy states of the atom. This often involved additional information obtained from absorption spectra, under water spark spectra, or spectra produced by the use of carefully controlled excitation energies. High resolution observations of the structures of lines or of line splittings in a magnetic field (Zeeman effect) were made to verify the assignments and later to determine nuclear moments. In 1928 soon after its discovery the Raman effect, too, became a subject of investigation.

Perhaps the most widely remembered spectroscopic experiment of this period were those by which it was established that the strong green line in the spectrum of the Aurora Borealis, and also present in the spectrum of light from the night sky, was due to atomic oxygen and not to nitrogen as had been claimed previously. Another important spectroscopic first was the recording of the Raman spectrum of liquid hydrogen which showed that the molecules behaved as if rotating freely and also verified that hydrogen is a mixture of two almost non-interacting gases, parahydrogen and orthohydrogen.

At this time most of the post-graduate students worked with McLennan. This was partly because of his position as Director of the

Laboratory, and partly because his enthusiasm for his projects created in others the desire to participate in them. However, each of the other professors pursued their own research interests. Burton maintained a colloid physics laboratory in which working with him were several students and research assistants. Also he continued to be interested in electrical phenomena and to carry out measurements of the electrical conductivity and dielectric constants of various substances under various conditions. Arnold Pitt who came to work with him in 1927 was probably the first in the Department to make extensive use of electronic devices.

After the war Gilchrist continued to work on problems connected with x-rays and the applications of physics in medicine. Later he saw the possibilities in the use of physical methods in prospecting for minerals and in 1928 began work in that field. As the scope of these investigations and the number of students associated with him increased, interest was generated in other aspects of geophysics. It became an important subject of teaching and research within the Department and in 1943 was given the status of a sub-department with Gilchrist as Professor of Geophysics.

The research projects initiated by Satterly and McTaggart were not as attractive to students. Satterly usually had one or two working with him on problems in mechanics or on the measurement of gas viscosities or the surface tension of liquids and the change in these quantities with temperature and pressure. McTaggart while at the Cavendish had developed an interest in the electrification existing at the boundary between a liquid and a gas, as for example on the surface of a liquid or of small gas bubbles in a liquid. These were exacting experiments but there was always at least one student who chose to assist in these investigations.

Of the students who participated in the above mentioned and other research projects some remained in Toronto as faculty members but most left to take positions in other Canadian universities or in research laboratories. From the list given in Appendix 3, it can be learned that twenty-seven Ph.D. degrees in physics were granted in the period 1918 - 1933 inclusive. Two were awarded to students, B.M.R. Deacon and M. Annetts, who worked in the colloid physics laboratory with Burton. The research of all the other recipients was supervised by McLennan and of them the majority became professors in the department of physics in a Canadian university. Their names, the year in which they obtained the degree and the universities in which they served are given below.

H.F. Dawes (1918) - McMaster; R.C. Dearle (1919) - Western Ontario;

H.A. McTaggart (1922) - Toronto; R.J. Lang (1923) - Alberta; G.M. Shrum (1923) - British Columbia; J.F.T. Young (1923) - Manitoba; D.S. Ainslie (1925) - Western Ontario and Toronto; H.G. Smith (1926) - British Columbia, Toronto and Alberta; A.B. McLay (1927) - McMaster; E.J. Allin (1931) - Toronto; A.M.I.A.W. Durnford (1931) - Western Ontario; C. Barnes (1932) - Toronto; A.C. Burton (1932) - Western Ontario (Biophysics); F.M. Quinlan (1932) - Toronto; J.M. Anderson (1933) - Toronto; J.F. Allen (1933) who was supervised by McLennan up to his retirement became professor of physics in St. Andrew's, Scotland.

Elizabeth Cohen (1929) spent several years as a member of the faculty of Mount Holyoke College and later returned to Toronto to become a member of the teaching staff in the optics laboratory. Mattie Rotenberg (1926) (née Levi) and Beatrice Deacon (1929) (née Reid) left physics for some years but returned during the war, the former to a teaching position in the first year laboratory and the latter as a research assistant and lecturer. May Annetts (Mrs. C. E. Smith) on her marriage gave up research but not her involvement in university teaching.

Of those who chose a career in research, K.H. Kingdon (1920) went to the General Electric Research Laboratories in Schenectady, New York; W.W. Shaver (1923) went to the research laboratories of the Corning Glass Company; J.H. McLeod (1929) to the research laboratories of the Eastman Kodak Company, Rochester, New York. G.D. Niven (1928) joined the research laboratories of the National Research Council, Ottawa, and H.D. Smith (1933) became Director of the Nova Scotia Research Council.

M.F. Crawford (1936) was also a graduate student of McLennan's having worked with him for more than five years and completed all the requirements for the Ph.D. except that of the thesis before McLennan's retirement. Crawford delayed the submission of his thesis until he had accomplished a large body of research and already was recognized as an authority in the field of atomic spectroscopy. He remained in Toronto.

The cost of developing research facilities could not be met from the operating funds of the University. Additional support from private and public sources was required. The excellence of the work done in the laboratory was not in itself enough to obtain this and the fact that the staff members were well-known in the business and professional communities was most important. When the Alumni Association was formed, McLennan was its first secretary and visited many local centres to stimulate interest in it and so became known to graduates of all

faculties. As early as 1904 he addressed a standing committee of the House of Commons on the metric system of weights and measures pointing out its advantages. He was a very fine public speaker and his lectures to the Royal Canadian Institute which were carefully prepared and illustrated by many experiments attracted large audiences. He was a strong advocate of the value of research to industry and when an Advisory Council on Industrial and Scientific Research was set up late in 1915 he was one of the original members. Gilchrist too was well-known outside the University. Before the first world war the use of x-rays in medicine was limited. When Gilchrist first joined the staff in Toronto he began a study of the applications of x-rays working with the staffs of St. Michael's and Toronto General Hospitals. On his return from active service he placed the knowledge gained from his experience as an x-ray expert with the medical corps at the disposal of the hospitals. The above are only some examples of the involvement of the physics staff at this time in national and community affairs. This involvement resulted in the Department being widely known and favourably regarded.

An important consequence of the reputation which the laboratory gained in the wider scientific community and of the fact that the staff members were known in England, Western Europe and the United States was the willingness of leaders of physical thought to visit Toronto. Such visits are a commonplace to-day and play an important role in scientific life. They were even more significant in the years before travel became so swift and easy. Toronto was still relatively isolated academically and these visitors were important to the education of senior students and junior staff. When possible it was arranged that visits of two or more persons would coincide and a colloquium would be arranged with invitations to attend sent to other Canadian and American universities. In 1921 a conference at which the lecturers were Dr. L. Silberstein of the Eastman Research Laboratories, Rochester, and Dr. I. Langmuir of the General Electric Research Laboratories, Schenectady, reported attendance from nearly every university in Canada. In the academic year 1923 - 24 a series of lectures on "Applications of Modern Physics to Astronomy" was given by Professor H.N. Russell of Princeton and three lectures on the "Theory of Atomic Structure" by Professor Niels Bohr of Copenhagen. The British Association for the Advancement of Science and the International Mathematical Congress met in Toronto in August 1924.

Spectroscopic work in Toronto had concentrated on observations of, and the analysis of, atomic spectra. Two lectures by Professor James Franck of Göttingen, Germany, in 1927 - 28 on molecular

spectra were therefore of particular interest. Between April 23 and May 9, 1928, Professor H.A. Kramers, head of the physical laboratory at the University of Utrecht, Holland gave a course of lectures on the new mathematical and physical concepts involved in the de Broglie wave theory of matter, the Schrödinger wave equation and matrix mechanics. These lectures were attended by a number of physicists from McGill, Western Ontario and the United States. The opportunity to learn from one regarded as an authority on these theoretical developments was of great value to students and staff alike.

Special mention may also be made of a symposium on "Theoretical Physics" held in January and February 1930. Five physicists from Europe and the United States took part.

A list of those who lectured in the Department between the end of the war and the retirement of McLennan is given below. It may not be complete although it is hoped that it is nearly so.

- 1920-21 L. Silberstein, *Eastman Research Laboratories*
I. Langmuir, *General Electric Research Laboratories*
- 1923-24 L. Silberstein, *Eastman Research Laboratories*
H.N. Russell, *Princeton University*
Niels Bohr, *Copenhagen*
- 1924-25 L. Silberstein, *Eastman Research Laboratories*
- 1927-28 J. Franck, *Göttingen*
H.A. Kramers, *Utrecht*
- 1928-29 R.S. Mulliken, *Chicago*
F. Hund, *Leipzig*
L.S. Ornstein, *Utrecht*
- 1929-30 W.F.G. Swann, *Bartol Research Foundation*
J.H. VanVleck, *University of Wisconsin*
O. Oldenberg, *Göttingen*
S. Rosseland, *Oslo*
E.S. Akeley, *Recent Student of Einstein*
A.E. Ruark, *Mellon Institute*
J. Cabannes, *Montpellier*
S. Goudsmit, *University of Michigan*
- 1930-31 A. Haas, *Vienna*
H.A. Kramers, *Utrecht*
R.H. Fowler, *Cambridge*
- 1931-32 P.A.M. Dirac, *Cambridge*
P. Debye, *Leipzig*
G. Dèjardin, *Lyons*
G.L. Clarke, *Illinois*

LIFE AS A GRADUATE STUDENT

To give a more complete picture of the Department at this time the insertion of some reminiscences of life as a graduate student during the late 1920's and early 1930's would seem to be useful. This period includes McLennan's retirement which created changes in the supervision of research projects but did not immediately greatly alter other aspects of the activities of the Department. During the depression period the majority of the graduate students remained unmarried and, because of financial limitations, satisfied with simple pleasures. The students were all more or less the same age and everyone in the research laboratory knew everyone else very well.

There were about twenty graduate students in this period of whom roughly two-thirds were working towards the Ph.D. degree. The majority had probably taken their undergraduate training in Toronto, but there were always a number from other Canadian universities and one or more from Great Britain. While in Britain during the summer, McLennan would interest one or more recent graduates of a British university in coming to Toronto. They quite often stayed for a year only, obtained an M.A. and returned to Britain. Among those who stayed were C.D. Niven from Aberdeen and A.C. Burton from London, both of whom have been mentioned above.

During the daytime hours attendance in the laboratory was expected unless lectures or seminars or demonstrating duties required one's presence elsewhere. Except when the nature of the experiment required it, evening work was little done especially by junior students. These hours were used for reading on subjects outside one's immediate research interests and, of course, for recreation. Sunday and to a lesser extent Saturday afternoon were times when attendance in the laboratory was not normally expected. There was no question of remaining away to cram for examinations. Attendance was expected as usual except for the actual period during which the examination was being written. This could be almost a whole day. No time limit was set and the questions required lengthy answers. If McLennan had left for England before a paper for him was to be written, the practice was to write with lead pencil and to make a carbon copy lest the original be lost in its journey overseas.

Each morning McLennan accompanied by the head of the workshop, the glassblower, and often a junior staff member visited the site of the experiment of each of his graduate students, to enquire what, if any, progress had been made, what difficulties had been encountered and how it was proposed to overcome these. The initial query was:

"What's new". It was unwise to have nothing to discuss since this was regarded as evidence of lack of endeavour.

There was at this time little possibility of a graduate student working twelve months of the year with a holiday only two weeks or a month in length. Scholarships, whether from the Research Council or other sources, provided only for the nine months from October the first to June the thirtieth and no support was available for the other three months. Added to this the laboratories were thoroughly house-cleaned during the summer. The floors were of wood and were scrubbed and oiled. When this had been done the rooms were locked and a sign put on the door which read: "Wet oil. Do not enter".

The workshop took advantage of the absence of students to repair old and construct new apparatus for the teaching laboratories. Research apparatus took second place. The research students tidied their work areas so as not to interfere too much with the house-cleaning and left the laboratory, often to prepare for publication the results of the past year's work, or to attend summer school elsewhere, but often too to find work in order to support themselves. There was not much long distance travel at that time partly because of the expense and partly because of the time involved since air travel was not yet readily available.

Those graduate students who did not hold scholarships and were dependent on assistant demonstrators were required to report on September the fifteenth although the academic session did not begin until about a week later. The greater part of the apparatus in the teaching laboratories had been stored in cupboards for the summer. The assistant demonstrator removed it from the cupboard, arranged it in the laboratory and tested it, to make sure it would be ready for the first class. In the spring at the conclusion of the session, he examined the apparatus, cleaned and put in cupboards that which did not require repair, and collected that which did in a designated area where it was readily available to the workshop. Payment was for the period September the fifteenth to May the fifteenth and was on a term rather than an hourly basis. Each assistant demonstrator was responsible for three laboratory classes a week. This responsibility included ensuring in advance that the laboratory was ready for the class, assisting the students during the class and checking the apparatus at the end of the period to make provision for necessary repairs or substitutions. Those serving a given class were also responsible for correcting and marking the reports submitted by the members of that class. In the 1920's the stipend was \$750 for the eight month period designated above. During the later depression years it was reduced to as little as \$500.

A departmental seminar was held regularly at 4 p.m. on every second Thursday, the alternate Thursdays being given over to meetings of the Mathematics and Physics Society. The first item on the seminar programme was normally a report by McLennan on a subject which he considered important, with references to papers which had recently been published. This was followed by two or three reports on other papers in current periodicals, given by other members of the staff, graduate or undergraduate students. Graduate students and undergraduate students in their third and fourth years in honours physics were expected to attend the seminars. Because of its nature the seminar was an occasion when all staff and senior students met together. Some persons who were no longer students but remained interested in physics also attended. Tea was served before the presentation of the papers began and Mrs. McLennan, and in later years Mrs. Burton, usually came to pour and meet those present. The meeting did not conclude until 6 p.m. or somewhat later.

But it was not all work and no play. At five o'clock each afternoon, when the laboratory classes were officially at an end tea was served. For some years the tea table was in the apparatus room, a large room across the hall from the large lecture theatre in which apparatus for lecture use was stored in museum cases. Later tea was served in a small area at the south end of the library, closed off from the main section by book cases. Those who came to tea paid a fee to cover the cost of tea, biscuits and the washing of the cups and saucers. The kettle was put on the gas ring by Mrs. Vigar, a long time member of the cleaning staff, when she left for the day and the rest of the preparations were made by the women graduate students, although the men would on occasion lend a hand if all the women were otherwise engaged. McLennan came to tea only rarely but a cup of tea was taken to his room. Burton liked to attend although he was not always able to do so. Gilchrist and McTaggart never came and Satterly only very occasionally. Most of the graduate students were unmarried and had little reason to hurry home to dinner. A very pleasant half-hour or so was spent in relaxed conversation.

Each winter the McLennans gave a party with dancing in the physics building to which all staff and students were invited. The library and the laboratories near it were cleared and decorated.

Later at the end of the academic year there was the Crossley picnic in June. Kathleen Crossley, a staff member, lived with her family in Oakville. Each spring the Department was invited to hold a Saturday afternoon picnic there. The forenoon was spent in the physics building in the preparation of food and arrangements were made so that transportation was available to all staff and graduate students and

their families. There were large grounds with a tennis court and, even more important, a croquet lawn. Did you ever continue to play croquet after it became necessary to pick out the hoops and balls with a flashlight? This sometimes happened when the competition was keen. These were most enjoyable occasions and everyone attended.

Then there were the evenings when a group of graduate students would attend the theatre together, sitting in the "gods" where for fifty cents or a dollar one could get a seat for the best shows. Everyone paid his or her own way but a block of tickets would be purchased in advance by one of the group.

Life in the laboratory did have its moments of crisis when the apparatus broke down, or proved inadequate to the task set it, or when no results were forthcoming and it was thought that this was because the effort made had been inadequate. McLennan had a quick temper and was impatient to push each project to a successful conclusion as quickly as possible. However all his students knew that they could depend on his support when applying for a scholarship or a job. Whatever their shortcomings he was certain his students were as good as or better than those from other laboratories.

The workshop staff and the glassblower were essential to the success of both research and undergraduate laboratories. Much apparatus was designed and built in the laboratory and repairs both to it and to that purchased commercially were frequently required at short notice. Mention has been made in an earlier chapter of the first foreman of the mechanical workshop, J.S. Plaskett, who became a well-known astrophysicist. The foreman in the twenties was T.S. Plaskett, his younger brother, who was a skilled technician and the friend of every graduate student. The men under him were always helpful but only he had the patience and skill to produce a perfect edge on a spectrograph slit.

Much of the apparatus for spectroscopy was made of glass or fused quartz or required windows or other parts of these materials. The cryostats for low temperature research were also often made of glass. A highly skilled glassblower was therefore essential. R.H. Chappell came to Toronto from England in 1920 and continued to work in the Department until his retirement in 1964. In the earlier years he used to spend a part of his holidays to attend the school for glassblowers at the University of Leiden in Holland and earned a Master Glassblower's Diploma. Of this he was very proud as he was the only British person to hold this award at that time. He would attempt to make almost anything requested of him and the graduate students came to think that it was impossible to conceive of glass apparatus which he could not make.

The graduate student might acquire a limited skill in the operation of the workshop lathes or in the use of a blow torch but without expert assistance his apparatus would often have failed. The men in the workshop and the glassblower were friends in need.

III / THE BURTON YEARS, 1932-1948

The period during which Professor Burton was Head of the Department has three natural divisions, viz: the period before the 1939 - 45 war, the war years and the years immediately following the war. The first was a time of economic depression; the second made unusual demands on the staff and the facilities of the Department; the beginning of the third was marked by an influx of eager, serious students, both undergraduate and graduate, whose expectations had to be met as fully as possible. Each of these periods will be treated separately.

1932 - 1940

When McLennan retired in 1932 his successor was Eli Franklin Burton, already a member of the staff when the move to the new building was made in 1907. For many years he had administered the Department when McLennan was absent, and no major re-orientation of either the research or teaching programme followed his appointment as Head of the Department and Director of the Laboratory. Some changes were inevitable.

The number of professorial staff was five as it had been since 1920. The only new appointment since that time had been that of D.S. Ainslie in 1931. This had raised the number to six but on McLennan's retirement it had reverted to five. With this exception the personnel, too, were the same. A considerable number of other staff members held positions designated variously as lecturer, research assistant or associate, demonstrator or sometimes even as a combination of these. All such positions were yearly appointments, although in quite a few cases they were renewed year after year. Some were for twelve months but many for nine months only, in which case the person was ineligible for pension rights. These junior staff members made an important contribution to the Department but could not be expected to share equally the responsibilities of administration and planning.

The situation with regard to the instruction of graduate students and the supervision of research required review after McLennan's retirement. The two largest and best-equipped research laboratories were the low-temperature and the spectroscopic. Detailed supervision of all students working in these laboratories had been given by McLennan. It was apparent that the appointment of additional senior staff accompanied by a redistribution of responsibilities among staff members was required.

Expansion of the staff was difficult because these were years during the great depression. At one point all university staff members were asked to accept a reduction in salary, and married women in all departments were under pressure to resign. However, promotion need be accompanied by only a small, if any, increase in salary.

As time went on Burton had the status of a number of those in junior positions raised. H.J.C. Ireton, who had been overseas with the navy during the war and had been a member of the staff since 1918, was promoted to Assistant Professor in 1932, and more and more assisted in the details of administration and in contacts with outside organizations and individuals. C. Barnes and H. Grayson Smith were promoted to Assistant Professor in 1935. Barnes had come to Toronto in 1923 from Leeds, England and had become most valuable as a lecturer in the more theoretical aspects of physics. Grayson Smith had returned in 1932 from the University of British Columbia where he had been Assistant Professor. He was involved in both teaching and research. In 1937 M.F. Crawford, J.O. Wilhelm and A. Pitt were all promoted. Crawford had assumed leadership of spectroscopic research and was also a successful teacher. He had come to the Department as a graduate student in 1926 after graduation from the University of Western Ontario, and had held an appointment as Lecturer since 1930. Arnold Pitt was a Canadian who had spent some years in the United States and had graduated from Houghton College. Wishing to return to Canada he in 1927 accepted a position as Research Assistant to Burton. His first interest was in research but he was also engaged in the modernization of the advanced electricity laboratory, to provide teaching facilities for the physics of higher frequency techniques. He had held the rank of Lecturer since 1933. J.O. Wilhelm had come to Toronto from Saskatchewan as a graduate student and was involved in the operation of the cryogenic laboratory. He, too, had held the rank of Lecturer since 1933. Thus the number of staff members of professorial rank which had remained at five throughout the twenties had increased to eleven in 1937. The total number of persons on staff had not increased correspondingly but the responsibilities for research, teaching and administration could be much more widely spread.

Greater effectiveness both in undergraduate teaching and in research resulted from these changes.

1932 - 1940, Undergraduate Studies

During this period much thought was given to the organization of the undergraduate teaching programme. Courses were offered to both pass and honours students in the Faculty of Arts as well as to students in the faculties of Medicine, Dentistry, Forestry, Household Science and the School of Optometry. Students from these outside faculties were, in general, offered a one year course covering the fundamental principles of all branches of physics. The basic course for honours Arts students extended over two years with more specialized work prescribed for them in the third and fourth years. The programme for the pass Arts students was similar but less demanding.

Burton took a special interest in those students whose primary interest lay outside physics. For a number of years he, himself, gave the physics portion of "General Science" a lecture course provided for pass Arts students who were taking no other instruction in science. He was instrumental in having an honours course, Biology and Physics, replace the course, Physics, which for many years had been one of the honours courses in the Natural Science group. He was one of those whose efforts resulted in the introduction into Mathematics and Physics of an option designed especially for those who did not plan to go on for graduate studies in either mathematics or physics. Neither this new alternative nor the Biology and Physics course proved attractive to students and both were discontinued after a few years.

Of more lasting value was the effort Burton and Gilchrist put into the setting up of a course in the Faculty of Applied Science and Engineering, similar to Mathematics and Physics in the Faculty of Arts but designed with the needs of the engineer in mind. Such a course came into being in 1933 - 34. Known as Engineering Physics it was broadened gradually and is now Engineering Science.

Burton's interest in the non-specialist spilled over into the teaching of physics in the secondary schools. In the 1930's the Ontario Educational Association each spring held an Easter meeting on the University of Toronto campus. A feature of these meetings was a lecture given, usually by a senior member of the physics staff, to the members of the mathematics and physics and natural science sections. To encourage the teachers to visit the laboratories Burton arranged to have set up and demonstrated on the day of the lecture, experiments which might be useful in a school classroom or would assist the teacher to more

fully comprehend some recently observed physical phenomenon. This was done for several years. The teachers could visit the experiments in the afternoon and spend time with them. In the evening all interested persons were invited to the laboratory and tours organized. A program for such an evening shows it began at 7.30 p.m. and concluded at 10.30 p.m. with refreshments after that hour in the physics library.

In the academic year 1934 - 35 a series of Friday evening lectures was arranged in co-operation with the Department of University Extension. Given by members of the staff in physics, the lectures were intended to serve advanced science students in departments other than physics and science teachers in secondary schools within a convenient radius of Toronto. The average attendance of approximately three hundred and fifty indicates the interest taken by these groups and others.

1932 - 1940: Research

The emphasis on teaching did not imply a reduced interest in research. It has been noted in an earlier chapter that Burton in the twenties had research students working not only in colloid physics but also on the electrical properties of dielectrics. Because of his interest in electrical phenomena he had kept in touch with the studies of superconductivity in the low temperature laboratory. On McLennan's retirement he became closely associated with Grayson Smith and Wilhelm in the direction of the research there. Studies of superconductivity and of the properties of substances at very low temperatures were continued. In the later thirties graduate students in Toronto were among the first to observe and study the extraordinary properties of liquid helium when cooled below 2.1 K.

Since Burton had never become greatly interested in spectroscopy, leadership in that field fell to Crawford who was already widely known as an atomic spectroscopist. Interest in the determination of nuclear moments was replacing the earlier interest in the determination of atomic extranuclear states. More and more of the experiments being done were designed for the study of the hyperfine structure of lines in the spectra of neutral and ionized atoms. A new field of study was introduced by H.L. Welsh on his return from Göttingen, Germany, in 1934, that of resonance and sensitized fluorescence. Some experiments in Raman effect were being done but it had not yet become a major interest.

Burton's interest in colloids and in the measurement of dielectric

constants persisted. Studies in this period looked into the coagulation of metal colloids and the possible application of such solutions in medicine. Measurements of dielectric constants were made at high frequencies as well as low.

A research project which deserves special mention is that of the design and construction of an electron microscope. As a result of his work in colloids, Burton had been interested for some years in the "ultramicroscope". He visited Europe in 1935 and, having heard that research was in progress in Germany to develop a high resolution microscope using an electron beam, visited the laboratories where the work was being done. He became enthusiastic about the possibilities of such an instrument and on his return persuaded a graduate student, C.E. Hall, to adopt electron optics as his special subject for his M.A. thesis. This was the beginning of a series of projects which culminated in the construction by Hillier and Prebus in 1939 of the first transmission electron microscope built in North America. It was also the first built anywhere which was capable of immediate practical use, a feature of some importance since it was completed near the beginning of the war. Prebus completed his Ph.D. in 1940 and went to Ohio State University. Hillier completed his degree in 1941 and had a successful career at R.C.A. where he became a vice-president. The development of the microscope is given in some detail in: *Electron Microscopy*, Vol. III 1978.

The geophysicists at this time had as their chief interest the application of physics in prospecting for minerals. Professor Gilchrist was on occasion seen by members of the public making observations in farmers' fields, and was once called upon to write an explanation of his work for Professor Burton to forward to the Board of Governors.

As always there were one or two students working on problems outside the fields in which most were active. The study of the structure of materials using x-ray diffraction and of the diffusion of gases through solids may be mentioned as examples. When all projects are counted thirty-seven students completed the requirements for the Ph.D. in the years 1932 - 1941, inclusive.

The times were such that money to carry the electron microscope project to a successful conclusion was obtained only through the cooperation of the Banting Institute. Other research projects requiring the application of physical principles to problems outside physics were being directed by members of the physics staff and obtained funding through interested groups. The analysis of mine dust by x-ray diffraction provided a graduate student in physics with experience in the application of the theory of x-ray diffraction, and workers in the Banting Institute with data on the composition of the dust. The

problem of dust prevention in industry was studied in the colloid laboratory at the instigation of the Ontario Department of Health. The same department helped to finance the construction of an apparatus for the production of radon seeds for cancer treatment which was set up in the basement of the physics building. The plant remained the property of the Department of Health but was operated by the Physics Department. After about ten years it was moved to the laboratories of the Department of Health.

Before concluding the discussion of the thirties mention should be made of the course in meteorology for M.A. students, introduced in the academic year 1933 - 34. Early in the history of the University there had been a Professor of Meteorology and instruction in that subject was given as a part of the Arts curriculum from 1859 to 1879. The M.A. course introduced in 1933 was designed in consultation with the Director of the Meteorological Service. The basic physics instruction was given by the staff in physics and the practical experience was provided by the staff of the meteorological observatory.

From what has been said above it will have become apparent that in this period of financial difficulty support for pure physics depended to a considerable extent on an accompanying programme in applied physics. In the war years it was seen that advances in pure physics provided the basis for rapid developments in new technology. During the prosperous years which followed the war, pure science received unquestioned support and departments of physics enjoyed several years of unprecedented prosperity. In the case of the Department of Physics in Toronto these years of growth came only after an interval when the staff voluntarily gave up all research in pure physics in order to take part in defence research or in the instruction of enlisted men being trained for special duties.

THE WAR YEARS

From 1939 to 1950 the activities of the Department were influenced greatly by the war and its aftermath. As time went on a number of staff members asked for and were granted leave of absence to enable them to perform services for which they had special qualifications. Some joined research teams of the National Research Council, while others became members of one or another of the Operational Research Organizations set up by the three armed services. Additionally some of those staff members who remained in Toronto undertook research designed to assist the defence effort. The net result was that at the conclusion of the academic year 1940 - 1941 the Department reported

that many of its previously on-going research programmes had been discontinued temporarily.

As was to be expected the number of graduate students decreased rapidly and in the academic years 1943 - 44 and 1944 - 45 there were no students registered as candidates for the Ph.D. The number of regular undergraduates did not decrease as rapidly because of the emphasis being placed on the need for some scientific training in the technical branches of the services. The teaching load of those members of the staff who were not on leave of absence or engaged in war-related research became very heavy. During the regular academic session the regular undergraduate programme was maintained and, in addition, throughout the calendar year instruction was given to large numbers of men training for special service with the armed forces.

In 1940 Ainslie, who had worked on anti-mine devices in 1918 and 1919, was given leave of absence to work in Halifax on the "degaussing" of ships. This problem as well as related problems of magnetic mine sweeping, defence against magnetic and acoustic torpedoes, and acoustic minesweeping were being attacked there by a group under the direction of Professors J.H.L. Johnstone and G.H. Henderson of Dalhousie University. All were at that time on the staff of the National Research Council.

Pitt, too, became involved in defence research early in the war although he remained in Toronto. In 1940 he was asked to assume responsibility for the Canadian part of a British-Canadian-American joint programme for the design of a proximity fuse which would give anti-aircraft missiles greater efficiency against high-speed targets. Associated with him was R.W. McKay who came to the Department at this time from the Ontario Research Foundation where he had been since completing his Ph.D. in 1934. Their contribution to the success of the project was a radically new idea for providing power to the fuse.

Grayson Smith, while also remaining in Toronto, investigated devices for the provision of oxygen in high-altitude flying.

Young graduates as well as staff members took part in wartime research. Three such, P.E. Pashler, M. Rubinoff and G.C. Gottlieb, were able to use their research for their Ph.D. theses. Having completed their degrees Pashler and Gottlieb joined the staff. Pashler remained only until 1950 when he went to the General Electric Corporate Research and Development Centre in Schenectady, N.Y. Gottlieb remained in Toronto and became Director of the Institute of Computer Science in 1962.

Other staff members became active in one or other of the operational research groups set up by the three armed services. The work of these groups was largely statistical in nature. Data on various oper-

ational activities and factors were assembled and analysed with the Staff Officers concerned.

The first Canadian office for operational research was established by the air force. Two members of the Department of Physics in Toronto were involved. In August 1942 Wilhelm was chosen to head the Operational Research Office at Airforce Headquarters and held the appointment of Associate Director General, Research and Development. He remained there until November, 1944. In addition to the central office two field sections were set up. That with Eastern Air Command was organized by Barnes who remained with it until August, 1944. Later Barnes spent time in France with the Office of Strategic Services.

After about a year the research group in Halifax, mentioned previously, severed its connection with N.R.C. In July, 1943 Dr. Johnstone was appointed Director of Operational Research and charged with organizing an operational research group for the navy, the work of the former N.R.C. group being incorporated in that of the new organization. As examples of its activities, the collection and analysis of data on anti-U-boat operations in Canadian waters and on various phases of convoy protection may be mentioned. Close liaison with the United States Navy and with the Admiralty in London was required. Welsh was asked to join the new group as a research advisor. He was ordinarily stationed in Ottawa but visited Washington frequently and spent January and February, 1945 at the Admiralty in London. Later in 1945 he left the Navy and returned to Toronto, where much later he became Chairman of the Department.

The last of the services to set up an organization for operational research was the army. Colonel J. Tuzo Wilson was appointed Director in December, 1943 and remained in charge until January, 1946 when he retired from the army and was appointed Professor of Geophysics in Toronto. The most widely-publicized activity undertaken by C.A.O.R.G. under Wilson's direction was Exercise Musk Ox. It was staged near the end of the war and was designed to find out more about the Canadian Arctic and operating conditions there.

A member of C.A.O.R.G. from its early days in 1944 was McKay who had participated with Pitt in the proximity fuse project and who at the conclusion of the war re-joined the Department and remained there until his retirement in 1973.

The Wars Years: Courses for Service Personnel

The first of a number of courses for the scientific training of men designated to perform special duties in the armed services was given

in 1940. Instruction was given to a group of graduates in mathematics and physics, engineering physics, and electrical engineering who were to serve as naval radar officers. Even graduates in the above courses had had very little instruction in electronics, particularly in high frequency techniques. When in 1940 the Admiralty (London) asked Canada for a number of scientists for special radio service it was impossible to find as many as requested with an adequate background. The Canadian Navy agreed to enlist such persons as officers and loan them to the Royal Navy. Burton realized that if the additional men were to be obtained it would be necessary to give special instruction to graduates in physics and engineering. He was able to offer to provide this because of the presence on the staff of Pitt and Anderson, the latter of whom had joined the staff in 1937 and had been working with Pitt in the advanced electricity laboratory. For several years a small number of honours physics students had been given some instruction in the principles underlying the operation of high frequency oscillators, amplifiers and detectors, and some laboratory equipment was available. Since the men were not yet trained there was some difficulty in obtaining money for the first course but it was eventually provided by the Kiwanis Club of Riverdale, Toronto. A group of eleven graduates was assembled and given instruction during the period June 15 to August 15, 1940. On the conclusion of the course the men were enlisted in the navy as sub-lieutenants and sent overseas. It was also arranged within the University that in subsequent academic sessions members of the graduating class in honours physics and in engineering physics could substitute for a part of their regular laboratory work, work similar to that given to the radar officers. The first group proved so valuable when sent overseas that in January 1941 the Canadian Navy agreed to take on strength additional men from those graduating the following spring. These men were given a special course in March and April 1941. This course led to a request for others and in all five were provided. The story is told in a small book entitled: "Canadian Naval Radar Officers" prepared by Burton and printed by the University of Toronto Press.

On being sent overseas these men were given further training in the Admiralty Radio Direction Finding School in Portsmouth, and then assigned to duty with the Royal Navy. Most became Radar Officers on ships which were on active duty escorting convoys, enforcing blockades etc. Three, all from Toronto, were lost when the ships on which they were serving were torpedoed. At other times these men acted as training officers for radar courses, supervised the fitting of ships with radar equipment, and took charge of the maintenance and development of radar equipment.

Most of the young men applying to enter these courses were recent graduates. There were a number from Toronto in each group but many came from other Canadian universities. A few had already begun graduate studies or even completed the requirements for the Ph.D. G.D. Scott was beginning work in 1939. When the Department began the classes for service personnel he became an instructor. In 1943 he enlisted and went to England as a Radar Officer and after training at the school in Portsmouth, was assigned to a Landing Craft Flotilla and was present on D-day. Later he was with a Motor Torpedo Boat flotilla in the Adriatic. Just at the end of the war he returned to Canada as a member of the naval operational research group and after leaving the Navy at the end of the war he completed his graduate work in 1946 and joined the staff of the Department.

John Convey went overseas with the first group in 1940, just after he had completed his Ph.D. working with the spectroscopy research group in Toronto. He was transferred to the Admiralty Metallurgical Research Laboratory in Sheffield where he worked until he returned to Canada in 1946. L.B. Leppard, a member of the 1940 course, had obtained his Ph.D. in 1936. He remained a Radar Officer throughout the war. Returning to Toronto he later became Physicist with the Ontario Department of Health.

As a part of its regular graduate programme the Faculty of Medicine had for some years offered a course leading to a diploma in radiology. The instruction in x-ray and radiation physics was given by the Department of Physics and the clinical experience in one of the hospitals. To provide radiologists for the services a similar course was given in each of the years 1942 and 1943 to doctors from the navy, army and airforce medical corps.

At the instance of the Canadian navy a class of naval ratings was taken on February the first 1941 for a three-month course in fundamental physics connected with anti-submarine work. This was followed by a second group in May and June and still others (five in all) later in 1941 and in 1942.

In February 1941 the Defence Department asked the Canadian universities to put on a three-month course for the training of twenty-five hundred radio technicians during the summer of that year. Of these Toronto took five hundred, all of whom were enlisted in the R.C.A.F. The course began on May the twenty-sixth and lasted for fourteen weeks. This too was the first of a number of similar courses following hard on the heels of one another in 1941, 1942 and 1943.

In 1942 - 43 for the first time the army sent a group of enlisted men for training in basic physics and in 1943 - 44 a second group was sent for the same purpose. In total over four thousand men received

training in the Department during the war. The instruction varied from the advanced specialized training given the radar officers and the radiologists, through the less advanced but as specialized training of the radio technicians, to the classical physics taught the naval ratings and the army recruits. All these were additional to the regular undergraduate classes which were continued through the normal academic sessions. There was some decrease in the number of regular students toward the end of the war but the number in physics remained high.

Before 1939 the total registration in the Department stood at approximately one thousand. In 1941 - 42 when the service classes were included the number receiving instruction in physics had risen to twenty-nine hundred. In view of the fact that several senior staff members were on leave of absence, the promotion of junior members was used to provide for the increased number of students. In 1940 - 41 Arthur Brant, a geophysicist, and in 1941 - 42 Kathleen M. Crossley, Florence M. Quinlan, Elizabeth J. Allin and John M. Anderson were promoted to Assistant Professor. All were involved in teaching both regular and service classes. Anderson, who had held the rank of Lecturer since 1938, deserves special mention for the leadership he gave in setting up the radar officer's and radio technician's courses. Miss Crossley and Miss Quinlan had held junior positions since about 1920 and Miss Allin since 1930. Harry L. Welsh and Richard R. Richmond were promoted in 1942, and A. Donald Misener in 1946.

THE IMMEDIATE POST-WAR YEARS

In the summer of 1944, after the conclusion of the last of the special courses for service personnel, the level of activity in the Department decreased but only briefly. Although registration in the regular undergraduate classes had dropped near the end of the war, both it and the number of graduate students increased sharply as young men returning from active service took up postponed or interrupted studies. The undergraduate numbers reached a maximum in 1945 - 47 and 1947 - 48 and then dropped rapidly. The graduate student enrolment did not peak until 1950 - 51 and decreased only slowly thereafter.

During the late forties changes in faculty personnel were fairly numerous. Wilhelm resigned in 1947 to join the Ontario Research Foundation. Convey, who had assumed professorial rank on his return in 1945, left in 1948 to become Chief, Physical Metallurgy Division, Mines Branch, Department of Mines and Technical Surveys, Ottawa. Arnold Pitt resigned in 1946 to become director of research for the Massey-Harris Company and his place was taken by R.W. McKay who had re-joined the staff at the end of the war.

On the retirement of Gilchrist in 1945, J. Tuzo Wilson was appointed Professor of Geophysics. A graduate of Toronto in Physics and Geology in 1930, he had obtained his Ph.D. at Princeton in 1936, and was already well-known as a geologist when he enlisted in the Royal Canadian Engineers in 1939. As noted in an earlier section he had first served as Technical Liaison Officer at CMHQ, London and then had become Director of Operational Research for the army. On his retirement from the army he joined the University, in which he has had a distinguished career.

Burton's health had been deteriorating. He was forced to take leave-of-absence in 1946 - 47 and died on July the sixth, 1948. During the period of his illness Ireton, who had carried much of the responsibility for the administrative arrangements for the wartime service classes, served as Acting Head.

RESEARCH IN THE POST-WAR PERIOD

The need to provide for a sudden large increase in the number of graduate students created many problems. It was felt that all those who on graduation had postponed further study, and all those who had interrupted their graduate work, should be accepted if possible. In 1944 - 45 there were four students registered for the M.A. and none for the Ph.D. In 1945 - 46 there were twenty-two registered for the M.A. and four for the Ph.D. and in 1947 - 48 there were twenty-eight for the M.A. and thirty-seven for the Ph.D. When it is recalled that the research programmes which were on-going in 1939 had almost all been in abeyance for several years, the effort demanded of the staff by this sudden increase in Ph.D. registrations can be appreciated.

Several factors were important in making it possible to provide the necessary facilities. The most important was undoubtedly the eagerness of staff members to return to their research projects. Of considerable importance too was a decision taken during the war by those who had given up all research activities to instruct the service classes. They had asked that a part of the money received from the government to pay instructors for these classes should not be paid them in salaries but should be set aside in a fund ear-marked to assist in the re-establishment of research after the war. Even though the immediate post-war years were a far cry from the pre-war depression years, the immediate availability of money for the acquisition and repair of apparatus was most valuable in providing quickly facilities for a large number of students.

When research in spectroscopy was taken up again there was a considerable broadening of the fields studied since both graduate students

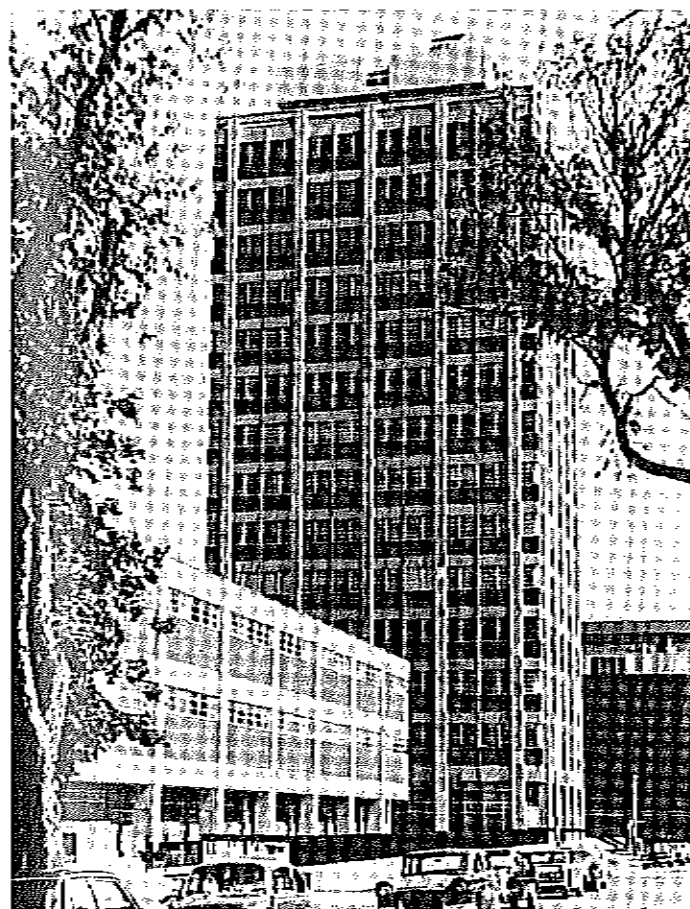
and research funds were readily available. Crawford continued his work on the hyperfine structure of atomic spectral lines, with increased success since he developed an atomic beam source which greatly reduced the Doppler broadening. A fruitful collaboration of Welsh, and Crawford was about to begin. This was principally in the field of molecular spectroscopy, particularly infrared absorption and Raman scattering. In 1948 a new phenomenon, collision-induced infrared absorption, was discovered by one of their students, J.L. Locke, now Director of the Herzberg Institute of Astrophysics of the National Research Council. This new effect was to be the subject of many Ph.D. theses in the coming decades. Welsh also instituted, at first along with P.E. Pashler, work in the general field of the spectroscopy of gases under high pressures. Although Pashler left for the General Electric Company in 1950, this work was continued as a main field of endeavour.

It was not possible to re-activate the cryogenic research as quickly since replacement of the helium liquefier and other apparatus was necessary. Several students did, however, find it possible to carry on low temperature investigations during this period and three students completed Ph.D. theses in 1949.

The electron microscope had been completed just at the beginning of the war and had found application in war research. It could now be used as a tool by graduate students. What had been the colloid physics research group joined that using the electron microscope. When in 1948 G.D. Scott joined the group its activities were extended to the study of the properties of thin films and very small crystals.

Burton's pre-war research on the measurement of dielectric constants and electrical conductivities was superseded by research in physical electronics supervised by Anderson and McKay. Facilities which had been provided for the courses given to the Radar Officers formed the basis of the equipment needed to accommodate a number of interested students.

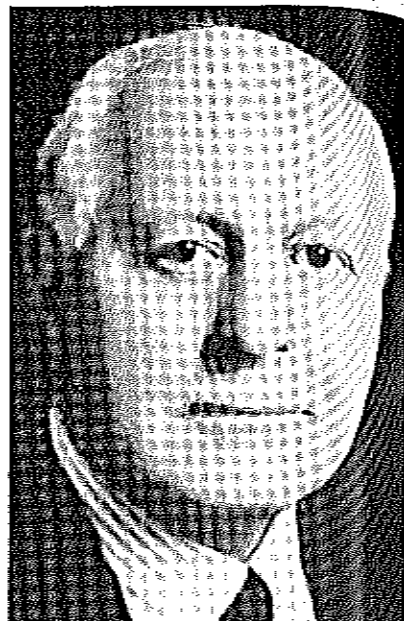
Geophysics had been made a sub-department in 1933 - 34. With the encouragement of Burton, Arthur Brant, a 1932 graduate in Mathematics and Physics, went to the University of Berlin then a leading centre in applied geophysics, obtained his Ph.D. there in 1936, and returned to join the staff of the Department. The group later included N.B. Keevil, working in geochronology, and J.H. Hodgson, a seismologist. When in 1945, after the retirement of Gilchrist, J. Turo Wilson was appointed Professor of Geophysics, his interest in the origin of continents and his enthusiasm enhanced the attractiveness of research in geophysics for the graduate. Much of the interest of the geophysicists still centred on the study of methods for magnetic or



*McLennan Physical Laboratories
Showing
The Burton Tower and North Wing*



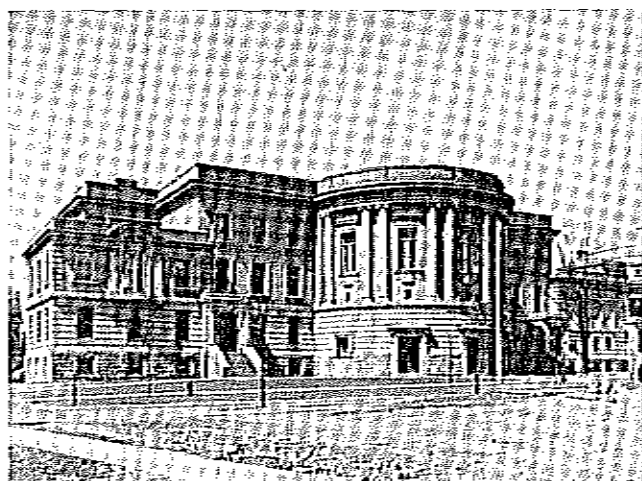
*James Loudon
First Professor of Physics*



*J.C. McLennan
First Director of the
Physical Laboratory*



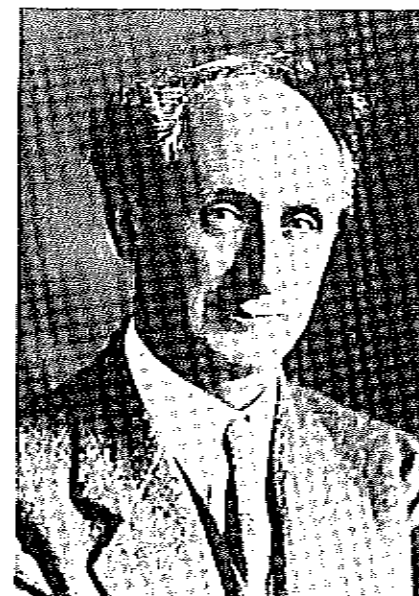
*E.F. Burton
Professor and Director of the Physical Laboratory
1931 — 1948*



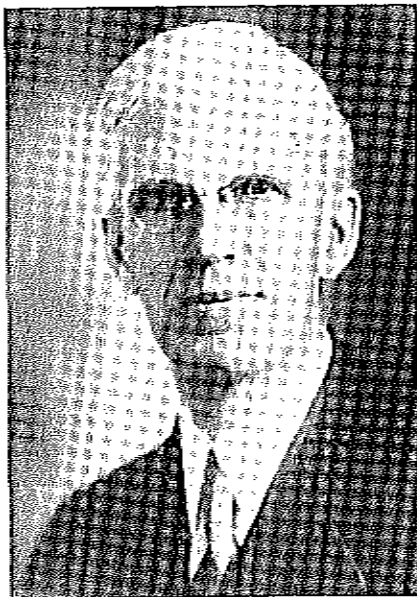
First Physics Building



L. Gilchrist



J. Satterly



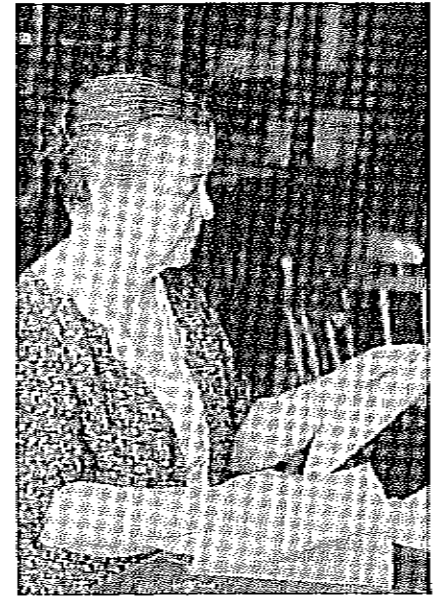
H.A. McTaggart



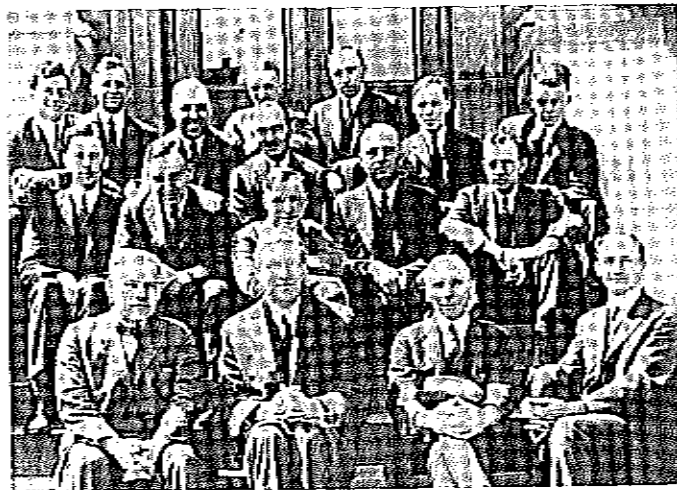
D.S. Ainslie



H.J.C. Iretton
Acting Head, 1947-49



A.T. Reed
Department Secretary, 1910-1946



Professors and Graduate Students, 1922

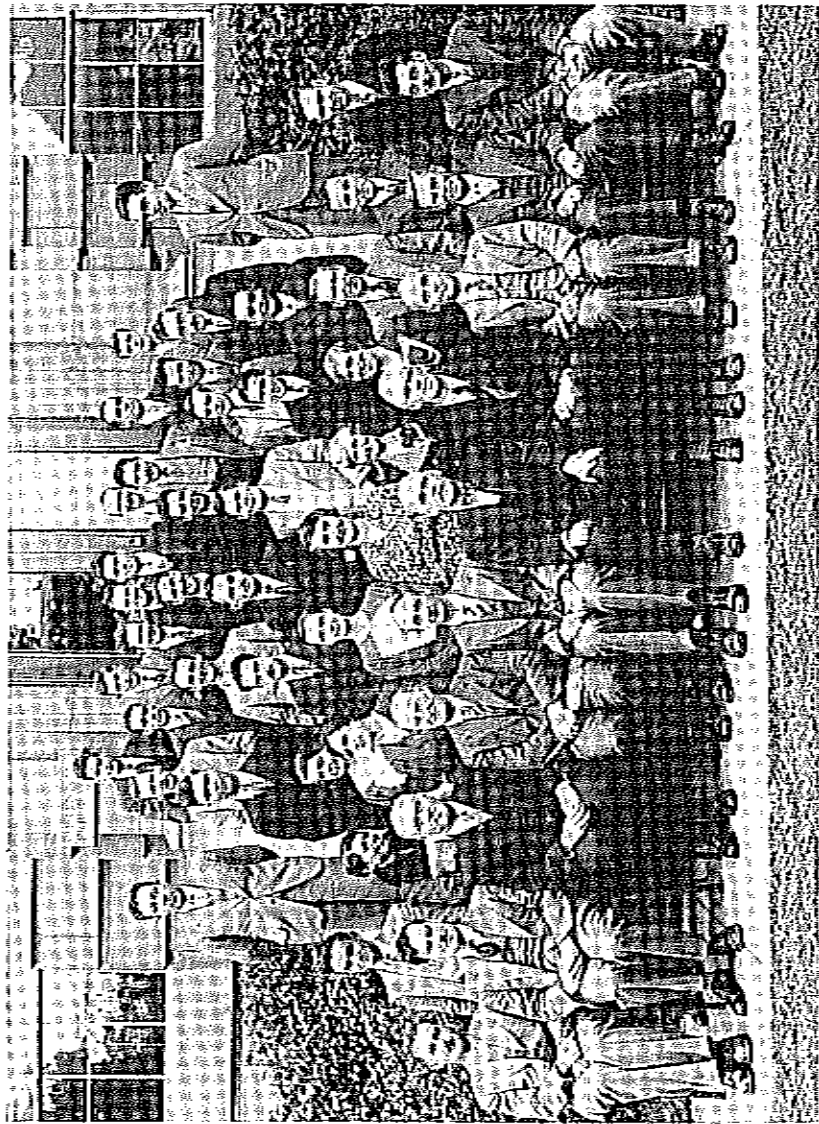
Front row: E.F. Burton, H.A. McTaggart, C.A. Chant, J. Satterly. Second row: W.W. Skene, D.W. Bates, J.E. Currie, H.J.C. Iretton, R.J. Laug. Third row: H.G. Smith, D.S. Ainslie, J.F.I. Young, A.G. Shenstone, W.C.H. McQuarrie, C.S. Beals. Back row: A.B. McLay, G.M. Skene.



E.J. Allin



M.F. Crawford



Staff and Graduate Students, 1935

Front row: W. Kazanles Middleton, C. Barnes, H.J.C. Irton, J. Patterson, J. Sutterly, E.F. Burton,
 H.A. McTaggart, D.S. Ansley, F. H. Grayson Smith, Second row: R. Haurwitz, E. Haurwitz, A.T. Reed, E. Cohen,
 E.J. Allen, F.M. Quinlan, B.M. Swager, K.M. Crossley, A. Pitt, J.O. Wilhelm, J.D. Leitch, Third row: A.G. Clark,
 W.F. Ottimer, L.C. Pennington, J.E. MacDonnell, A.D. Munnery, S.A. Dworkin, G.P. Clark, Pennington



J.M. Anderson

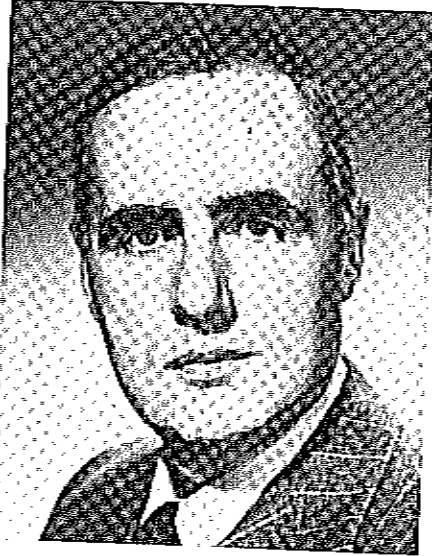


R.W. McKay



D.G. Ivey

J.N.P. Hume



*E.C. Bullard
Head, 1949-50*

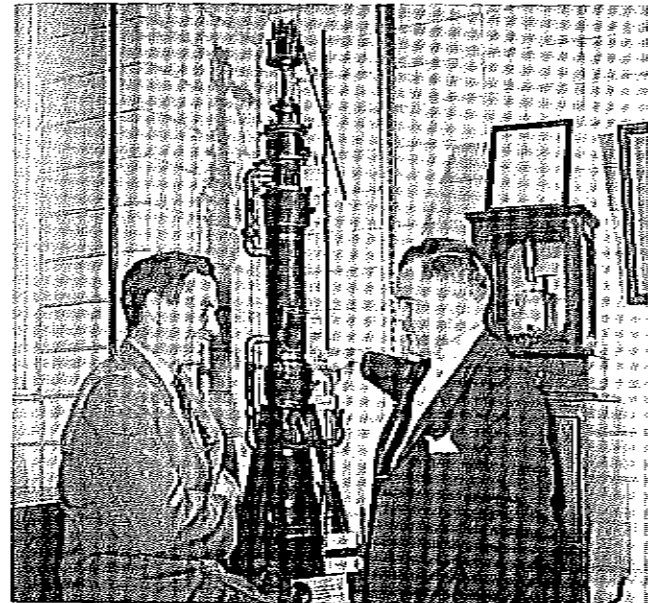


*W.H. Watson
Head, 1950-62*



Workshop staff and Laboratory Assistants, May 1959

*Front row: F. Edwards, B. Clark, W.H. Watson, G. Woodward, A. Owen, H. Hellenkamp,
F. Vossge. Middle row: D. Brown, ? , ? , S. Pugh, L. Doyle. Back row: B. Reid,
H. Christie, P. Dayrell, D. Beuk.*



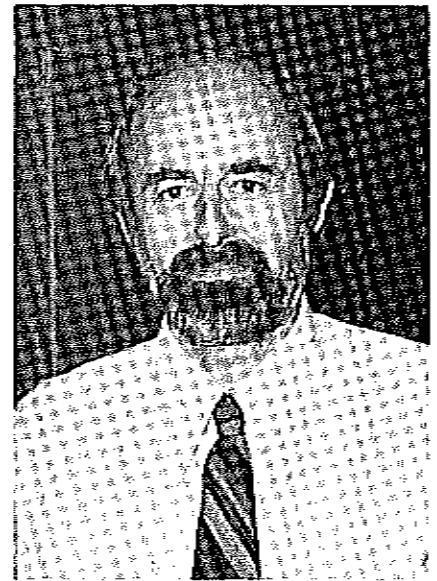
*First Toronto Electron Microscope
with G.D. Scott and James Hillier*



*H.L. Welsh
Chairman, 1962-1968*



J. Van Kranendonk



R.M. Farquhar



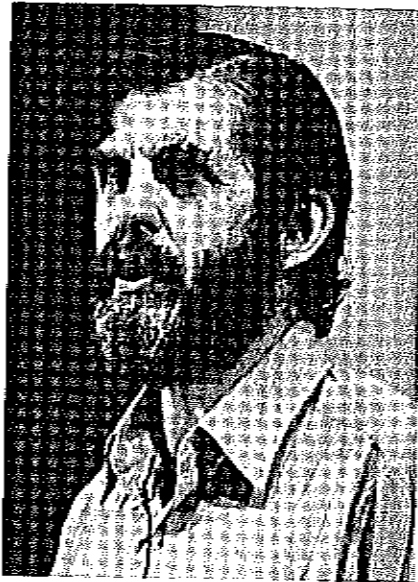
*D.G. Scott
Acting Head, 1961-62*



K.G. McNeill



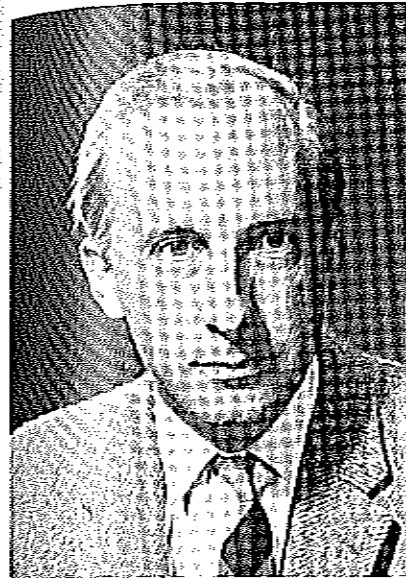
J.C. Stryland



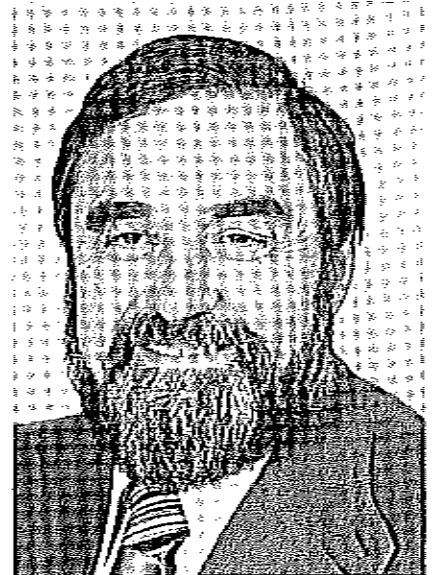
J.D. Prentice



R.E. Azuma



F.D. Manchester



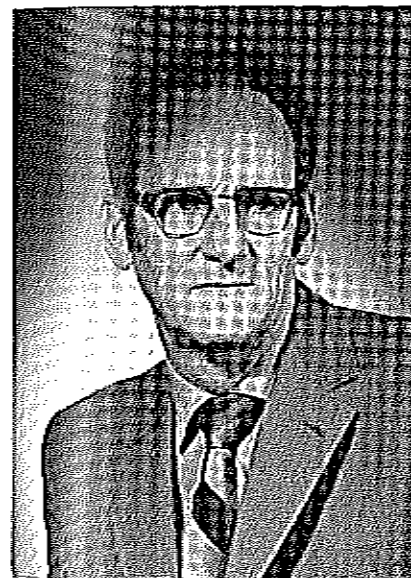
R. List



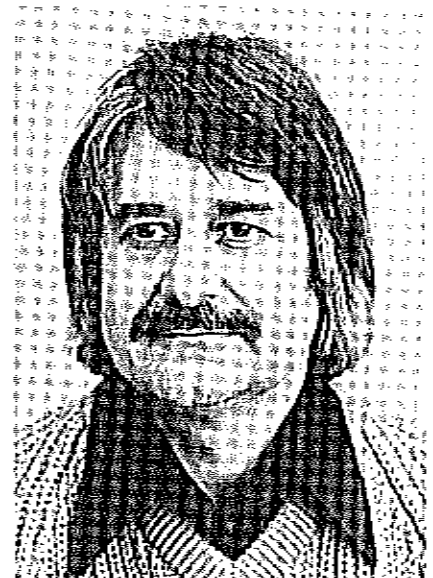
G.F. West



A.D. May



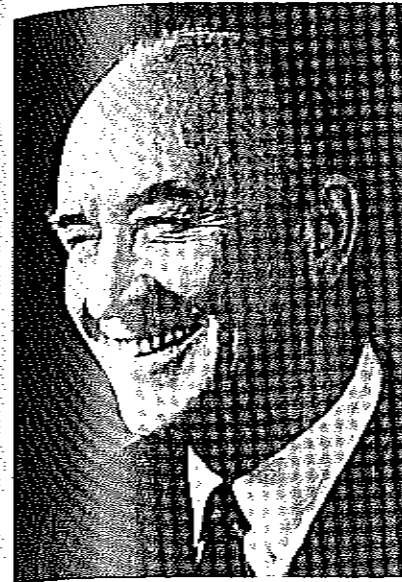
L.E.H. Trainor



J.W. Moffat



J.M. Daniels
Chairman, 1969-74



J.T. Wilson



H.E. Johns

R.L. Armstrong
1974



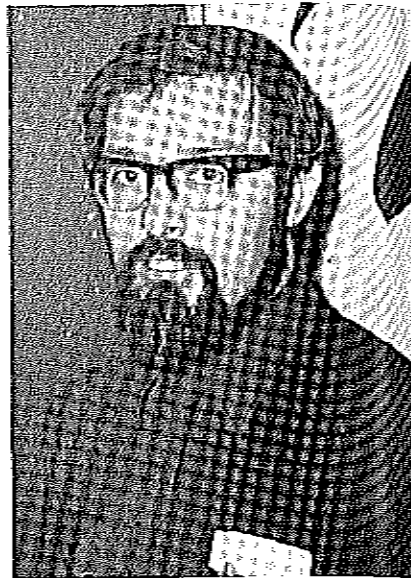
A.E. Litherland



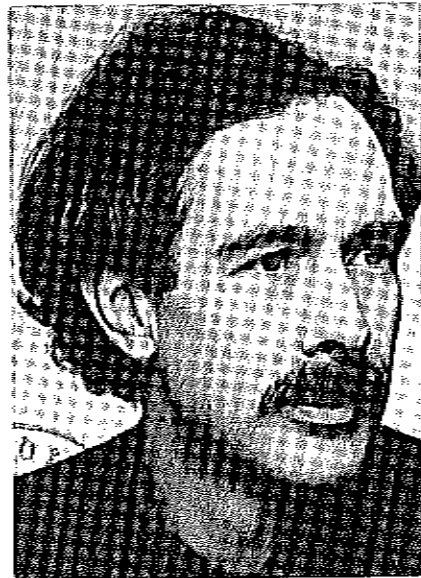
B.P. Stoicheff



G.D. Garland



D. York



D.A.L. Paul

seismic surveys of various regions of the earth's crust and the interpretation of the observations made in such surveys.

With increased numbers of both undergraduate and graduate students and the growth of new fields of research, a lack of laboratory space was felt soon after the war and it became necessary to move some research projects from the McLennan Laboratory to nearby buildings. It proved possible to convince the University administration that additional space was urgently required and agreement was reached to extend the south wing of the building to the west to match the existing north wing. The official opening of the new wing took place in 1949. It provided much needed space for staff offices, an additional lecture room, an expanded laboratory for physical electronics and a large laboratory on the third floor for the pre-professional classes. Unlike the old north wing this new wing had an attic which was finished and provided a floor given over completely to research. Further space to be occupied by the cryogenic laboratory was found in the basement. To commemorate Burton's long service to the Department the new structure was officially named the "Burton Wing".

In 1947 the Computer Centre was established as a separate division in the University. The motivation did not come from members of the Department of Physics but from V.G. Smith of the Faculty of Applied Science and Engineering, and A.F.C. Stevenson and B.A. Griffith of the Department of Applied Mathematics. The first person employed was C.C. Gotlieb who had just completed his Ph.D. in physics and was a member of the staff in physics. Because of this and because some of the problems basic to the design of computer components were problems in physics, the Department became closely associated with the early development of the Centre. This involvement will be treated in the next chapter since it belongs to the period after 1948 and to Burton's successors.

IV / THE YEARS OF AFFLUENCE, 1948-1969

The period between 1948 and 1950 was one of frequent changes. Burton was succeeded as Head by Edward Crisp Bullard (afterwards Sir Edward) who at the time of his appointment was Reader in Experimental Geophysics at the University of Cambridge where he had gone when he retired as Assistant Director of Naval Operational Research in 1945. Appointed in 1948, he remained in Toronto less than two years, returning to England to become Head of the National Physical Laboratory in 1950.

In 1949 Grayson Smith went to Edmonton as Head of the Department of Physics in the University of Alberta and Misener to London, Ontario, as Head of the Department of Physics in the University of Western Ontario. There were also several new appointments. Those of G.D. Scott in 1948 and of C.C. Gottlieb in 1949 have been referred to in the preceding section. Others in 1949 were those of M.A. Preston and D.G. Ivey. Preston, a theoretical nuclear physicist, was a Torontonian who had graduated in M and P in 1942 and had obtained his Ph.D. at the University of Birmingham in 1949. Ivey was a graduate of the University of British Columbia who had recently completed his Ph.D. in polymer physics at the University of Notre Dame.

In 1950 J.N.P. Hume, who had completed his Ph.D. in atomic spectroscopy under Crawford's supervision in 1949 and had since been at Rutgers University, returned to Toronto. McTaggart had died in 1941, and the retirement of Satterly in 1950 marked the departure of the last of the five men who had made up the professorial staff during the nineteen-twenties. Both he and Gilchrist continued to visit the laboratory frequently.

William Heriot Watson assumed the position of Professor of Physics and Head of the Department of Physics in 1950. A native of Edinburgh, Scotland, he had come to Canada first in 1931 to join the faculty of McGill University. From 1944 to 1946 he had been Professor of

Mathematics and Head of the Department of Mathematics at the University of Saskatchewan, and at the time he came to Toronto he was Head of the Theoretical Physics Branch of the Division of Atomic Energy of the National Research Council.

Physics and the Computer Centre

Bullard and Watson both had an interest in computing. As a geophysicist Bullard's interest when he came to Toronto was in the theory of the earth's magnetism, and he had obtained a complicated set of differential equations, representing flows in the interior of the earth, which he was anxious to have solved. N.R.C. was a supporter of the Computer Centre and the scientists at Chalk River had been users of its computing facilities as they became available and were eager to see them improved. Coming to Toronto from Chalk River, Watson was familiar with what had been done and strongly supported the development of the Centre.

Almost from the beginning the work of the Centre followed two different paths. Money for the project came from N.R.C. and D.R.B. and both needed computation facilities. In his wartime research Gottlieb had had considerable experience with computing as well as with electronics. As Acting Head of the project he soon became involved in the provision of computing facilities, while the design of an electronic computer was undertaken by a group under the leadership of J. Kates, then a graduate student. A computing system based on IBM punched card equipment was set up in the Physics Building. A proposal for a pilot model of an electronic machine which came to be known as the UTEC (University of Toronto electronic computer) pilot machine was produced and space to set it up and demonstrate its possibilities was also found in the Physics Building. In 1950 a grant was obtained to build a full-scale version of this machine but it was in fact never built. Bullard's support was undoubtedly important if such grants were to be obtained and it was equally important that Watson, when he replaced him, continued this support.

The 1950 grant had been to build a full-size UTEC, but in 1951 an electronic machine, built by Ferranti in England, unexpectedly came on the market. The donors of the grant requested that the money be directed to the purchase of this machine as they felt that this would result in the earlier provision of improved computation facilities. Reluctantly the group agreed and a smaller grant was provided to enable progress to be made towards the full-size UTEC. The Ferranti machine arrived in September, 1952, and was set up in the new

Burton Wing. Named FERUT by the members of the Centre it was in service from 1952 to 1958. It was the first electronic machine in Canada and in 1954 - 1955 was still the only large computer operating in Canada. According to Gottlieb, it was an unreliable machine but by exercising great patience they did an enormous amount of good calculation with it. No one at the time had better machines.

Watson became Chairman and later Director of the Computer Centre. When in 1961 he resigned that position he was succeeded by Gottlieb and at this time the name of the Centre was changed to "Institute of Computer Science". Meantime other members of the staff in Physics, in particular Hume and McKay, had become involved and two persons whose first interest was computation had been added to it. Boris Davison, a graduate of Leningrad University and a Ph.D. from Birmingham, was appointed in 1959 and Beatrix Worsley, a graduate of Toronto and Ph.D. from Cambridge, in 1960. Courses in computing were at first given by Gottlieb in the Department of Extension but in a short time such courses were listed as courses in physics for which credit was given towards a degree.

On July 1, 1964, a Department of Computer Science was established in the School of Graduate Studies. The Institute of Computer Science continued to be responsible for the provision of a computing facility. The Graduate Department assumed responsibility for teaching formal graduate courses and for research. Undergraduate courses as in the past were given by special arrangement with an established undergraduate department, usually Physics, in which case they were listed in the calendar with the courses in physics.

When the new McLennan Physical Laboratories were opened, the Department of Computer Science moved to quarters in the Burton Tower but the Institute of Computer Science remained in the old building which, when vacated by the Department of Physics, had been re-named the Sandford Fleming Building. The undergraduate department in the Faculty of Arts and Science was formed in 1970 and like the graduate department was accommodated in the McLennan Laboratories. Its first Chairman, T.E. Hull, was not a member of the Physics staff but its second, J.N.P. Hume, was.

When in February, 1977, the Sandford Fleming Building was partially destroyed by fire, the Institute of Computer Science was moved to the north wing of the McLennan Laboratories and will probably remain there. Once the reconstruction of the Sandford Fleming Building is completed the Department of Computer Science may, however, be transferred there. From the time the Computer Centre was first set up in 1947 it was closely associated with the Department of Physics and that department made important contributions to its success.

PHYSICS IN THE FIFTIES

The forties had been a period when the immediate needs of the present had taken precedence over all else. However, in the early fifties it became possible to pause to re-evaluate the existing courses and to plan for the long-term future. By 1952 the number of undergraduates in physics was only a little greater than, and the number of Ph.D. registrations about twice, the pre-war number. The opening of the Burton wing in 1949 had greatly alleviated the over-crowding. There was a need to consider the effects of the technological advances due to the war and changed social attitudes.

There was at this time in the population a much larger-than-normal proportion of persons of pre-university age. Hence the over-riding theme of university policy became the need to prepare for large numbers of students who would be seeking admission in the future. This was true in all universities and some projections of the numbers to be expected showed graphs having an almost exponential rise with no levelling off foreseeable. The application in peace-time industry of scientific and technological advances made during the war was creating opportunities for scientists and engineers. Hence it was anticipated that the need to expand the Physics Department would be urgent.

In Toronto it seemed that the first priority for expansion should be given to theoretical physics and nuclear physics. Both McLennan and Burton had been primarily experimental physicists and under their direction experimental rather than theoretical research had been emphasized. Early in their careers both had been interested in radio-activity and both remained interested in the medical applications of gamma rays. At no time, however, had a research programme in basic nuclear physics been set up. With the advent of the atomic bomb and nuclear reactors public interest dictated that facilities for nuclear research should be established. Watson appeared to be well-qualified to direct expansion in both theoretical physics and nuclear physics.

Although there had been frequent changes in staff personnel in the post-war years, there had been no overall increase in number to match the increase in student population, and in the early fifties new staff members were urgently required. This provided an opportunity to appoint persons who had as their special field of interest either theoretical physics or nuclear physics.

It has been mentioned in an earlier section that a theoretical physicist, M.A. Preston, was appointed in 1949. He was the first non-experimentalist to be appointed in physics but in 1953, before any additions were made, Preston resigned to join the faculty of McMaster University. The vacancy left by his resignation was filled

in 1954 by the appointment of N.F. Steenberg, a graduate of Queen's University, Kingston, who had completed the D.Phil. at Oxford and whose interest was in theoretical nuclear physics.

A most important appointment in theoretical physics was that of Jan Van Kranendonk in 1958. Born in Delft, Holland, he had attended the University of Amsterdam and completed his doctorate there in 1952. In his thesis he had developed the quantum mechanical theory of infrared absorption induced by intermolecular interactions, a phenomenon which, as noted previously, had been first observed in 1949 by the experimental spectroscopists in Toronto. The latter were eager to have him come to the Department and in 1958 he accepted the position offered him.

The first step towards the establishment of an experimental nuclear group was taken in 1956 with the appointment of Harold E. Johns. Johns was not unknown in the Department since he had received his Ph.D. there in 1939 for work in low temperature physics. Since that time he had become well-known as a radiation physicist, particularly in the field of the medical applications of radiation. He returned to Toronto in 1956 from Saskatoon where he had designed and supervised the building of the first cobalt-60 unit for the treatment of cancer. He provided a link with the Faculty of Medicine and more importantly with the Princess Margaret Hospital. He was made Professor of Physics and Medical Biophysics in 1958 and Head of the Department of Medical Biophysics in 1962.

The second step in the building a nuclear physics group was the appointment of Kenneth McNeill in 1957. The following is a quotation from a memorandum furnished by him: "In 1956 I spent the summer at the University of Saskatchewan. During the summer I talked with Dr. Watson about physics in Canada; there was some further correspondence and subsequently (1957) I was offered a post as Associate Professor at Toronto, with the intent that I would build up a viable experimental nuclear physics group there. To aid in doing this he cited the plans for a betatron and a van de Graaff at the Princess Margaret Hospital and the desire of a joint physics/medical group for a facility for measuring fall-out in Canada."

McNeill, who had obtained his D.Phil. at Oxford, was at the University of Glasgow before coming to Toronto. A Canadian, James Prentice, who had been a graduate student working on nuclear projects under his supervision, accompanied McNeill when he returned from a holiday in Glasgow in the summer of 1958. Prentice stayed in Toronto and was appointed Assistant Professor in 1959. He later was primarily responsible for the establishment of a high energy physics group in the Department.

The following account of the early growth of the research in nuclear physics is based on information provided by McNeill who, as noted previously, was entrusted on his arrival in August 1957 with its organization. During the first year there were two graduate students working with him. They built the first whole-body counter in Canada and devised methods for identifying protons ejected from nuclei by betatron x-rays. In the summer of 1958 Robert Storey and James Prentice, both of whom had been graduate students at the University of Glasgow when McNeill was there, came to Toronto with him when he returned from a visit to Glasgow. The three worked in cooperation with the hospital group on the installation of the van de Graaff and by October 1959 two graduate students were able to present M.A. theses based on experimental nuclear research accomplished with the van de Graaff. At the same time work was started on photoneutron problems with the betatron.

Support for these projects came in the case of the pure physics programmes on the betatron and the van de Graaff from N.R.C. and for the whole-body counter from the Department of Health and Welfare. The support of the Faculty of Medicine, either through the Princess Margaret Hospital or the joint committee overseeing the fall-out project, played an essential role in the build-up of nuclear research and very strong connections with medicine still exist. Cooperation between Steenberg and the more recently arrived experimentalists was important to both.

The low temperature group had been slow to recover from the effects of wartime inactivity. During the war, operation of the helium liquefier had been discontinued and since then experiments had been in progress to test alterations in design. A Simon type liquefier had been constructed and made a small amount of liquid helium limited to use at the liquefier. A hydrogen liquefier was in operation and made liquid hydrogen for the above and other experiments. Only liquid air was available in quantity. The operation of the plant was in the hands of Albert Owen, a most efficient technician who continued to supervise it for many years. The departure of Wilhelm in 1948 and of Grayson Smith and Misener in 1949 had left the low temperature group without senior staff. Soon after becoming Head of the Department Watson took steps to rectify this situation. In 1951 K.R. Atkins, then at the Mond Laboratory in Cambridge, accepted an appointment as Assistant Professor and in the same year A.C. Hollis Hallett, a graduate of Toronto who had recently completed his Ph.D. work in Cambridge, was brought back to Toronto with an appointment as Lecturer.

A new helium liquefier was required. In 1923 it had been necessary

to construct the liquefier in the laboratory but in 1951 a commercial enterprise, the Arthur D. Little Company, had designed and already built one Collins-type liquefier for M.I.T. and was prepared to accept orders for others. The decision was taken to buy one of these and it was installed and operating in 1952. Then other apparatus such as a demagnetisation system and a booster pumping station was built. Studies of the properties of liquid helium involving particularly measurements of viscosity and density were begun.

Atkins resigned from the staff in 1954 but Hallett had been given professorial rank in 1952 and Watson maintained his interest in the low temperature group. By 1956 there were about ten graduate students working on the properties of liquid helium and in metal physics. When in 1956 G.M. Graham, a graduate of Dalhousie University who had recently completed his Ph.D. studies in Cambridge, joined the group, work was begun on the thermal expansion of metals at low temperatures. In 1960 the members of the group were hosts to the seventh International Conference on Low Temperature Physics.

The research projects which the spectroscopy group had initiated in the post-war period were continued and expanded in the fifties. Crawford continued his studies of atomic spectral lines and Welsh his studies of the spectroscopy of gases at high pressures; joint projects involved the newly-discovered phenomenon of collision-induced infrared absorption, many aspects of which waited to be investigated.

Stryland, after he joined the group in 1954, was of great assistance in all studies involving substances at high pressures. He, himself, had as a first interest transport phenomena in gases and problems involving change of state.

Experiments on the Raman effect of gases at higher pressures and of liquids led to attempts to record Raman spectra of low density gases and at higher dispersion. Success in this was achieved through the use of a high intensity mercury arc which came to be known as the Toronto lamp, multiple reflection Raman tubes and high speed, high dispersion spectrographs. High resolution Raman spectroscopy became an important field of research and continues so.

It was noted earlier that Van Kranendonk developed the theory of collision-induced absorption soon after its discovery. He did not join the staff in Toronto until 1958 but in the interval the experimentalists had kept in touch with him. To facilitate the interpretation of the observations in terms of the theory, the substance used in a large proportion of the experiments came to be an hydrogen isotope or a mixture of hydrogen with another simple gas.

In the mid-fifties the low temperature group was able to supply

the spectroscopists with liquid helium and low temperature experimental know-how, and a long, fruitful investigation of the spectra of solid hydrogen was initiated. The possibilities of new discoveries inherent in this work evoked the interest of Elizabeth Allin, a long-time member of the staff who was an atomic spectroscopist whose most recent work had been studies in x-ray scattering. She joined the group working with hydrogen in 1954. One of the earliest achievements of the studies of solid hydrogen was the observation in 1956 for the first time of the Raman spectrum of the solid. More than a quarter of a century had elapsed since the Raman spectrum of the liquid had been first observed by McLennan and McLeod in 1928, soon after the discovery of the Raman effect. Not only the Raman spectrum but also the infrared absorption spectrum of solid hydrogen, deuterium and hydrogen deuteride were intensively studied. All proved of great interest and the observations extended well beyond the fifties.

A different but closely related experiment was carried out by Crawford at this time. He observed absorption in solid hydrogen induced, not by the interaction of one molecule with the field of a colliding molecule, but by the interaction of the molecule with a static electric field.

J. Tuzo Wilson's espousal of controversial theories of continental drift and of mountain building brought him acclaim and the Department increasing notice during this period. In 1977 he received the prestigious Veplesen award, generally regarded as the equivalent in Earth Sciences of the Nobel Prize in other sciences. Another prominent member of the geophysics staff in the mid-fifties was J.A. Jacobs. He had come to Toronto in 1951 as Associate Professor of Applied Mathematics but in 1954 had transferred to geophysics. In 1957 he went to the University of British Columbia as Professor of Geophysics and Director of the Institute of Earth Sciences.

Both laboratory and field studies of various methods — magnetic, electromagnetic, gravitational and seismic — to be used for the determination of the geologic nature of areas of the earth's crust were being made. Two Toronto graduates who had also obtained their Ph.D. degrees in Toronto joined the staff, R.D. Russell in 1956 and R.N. Farquhar in 1957. As graduate students they had worked on the determination of the relative abundances of various isotopes in rocks and estimates of the age of the earth based on the values of these abundances. This work was continued under their leadership using both methods based on the radioactivity of rock samples, and methods utilizing mass spectrographic analysis. F.S. Grant, another Toronto Ph.D., joined the staff in 1958.

Research groups other than those specifically mentioned above were also active. For example, under the supervision of G.D. Scott the electron microscope was being used as a transmission instrument in the study of thin films and also for the study of small crystals by electron diffraction. The electronics group led by Anderson and McKay was studying various aspects of electrical gas discharges, in particular the persistence of excited states. It was a time in which all members of the department were able to obtain support for their individual research interests.

In the later fifties and early sixties a different type of educational activity was engaged in by two members of the staff. Donald Ivey was Master of Ceremonies in the early shows of the series "The Nature of Things" broadcast by the C.B.C. — live since these were early days in television. Those programmes entitled "Two for Physics" showed experiments demonstrating physical principles. J.N.P. Hume cooperated with Ivey in setting these up and carrying them through. These programmes were very successful. In 1963 at the National Mass Media Awards Dinner of the Edison Foundation Hume and Ivey received a special citation for one of their films "Frames of Reference" as the "Best Science Education Film".

The increases in staff detailed in the above paragraphs were more than justified by the increase in undergraduate student numbers which occurred during the same period. In 1955 the decision was made that all instruction in physics given to engineering students should be the responsibility of the Department of Physics. About five hundred students were added to the number to be provided with lecture and laboratory facilities. There was a second sharp increase when, in the academic year 1958 - 59, an entirely new course, General Science, was introduced by the Faculty of Arts and Science. The number of students from that faculty rose from three hundred and seventy-nine in 1956 - 57 to eight hundred and ninety-eight in 1959 - 60.

The completion of the Burton Wing had provided much needed space in 1948, but even then this space was insufficient to accommodate the sub-department of Geophysics which, until much later, continued to occupy an old dwelling house at 49 St George Street. The expansion of the fifties with its increased number of undergraduate lectures and laboratory classes, and additional staff requiring offices and research space, made it necessary to occupy rooms outside the McLennan Laboratory. The situation of the mid-forties was repeating itself and once again the Department sought larger quarters. This time its request was in accord with general University planning. Land for new buildings, among them one for physics, had been obtained

on the west side of St George Street. Construction of the new building for physics did not begin until 1963 but in the meantime a new building for engineering, now known as the Galbraith Building, was built to the west of the existing physics building and connected to it. Some space in it was made available to Physics on a temporary basis.

Planning for a new building was well under way by the late fifties, the Department had broadened its interests with the addition of nuclear and theoretical physicists, and the undergraduate classes had been re-structured in an attempt to make better provision for a student body which had approximately doubled in the decade. Nevertheless there were complaints that Physics was lagging behind in its planning for the influx of students anticipated in the sixties.

It may have been Watson's natural Scottish reticence which gave the administration the impression that he was not whole-heartedly involved in expanding the Department. In any case it was suggested to him that he resign as Head but continue as Professor. In 1961 he went to California on leave of absence and decided to remain there.

It was important that a new Head of the Department should have the confidence of the administration. It was also important that he should be able to use the opportunity provided by expansion to build a department respected for its scientific excellence by all physicists and by other departments within the University. The Dean of the Faculty of Arts at this time, V.W. Bladen, states in his memoirs that the first choice of the selection committee was Gerhart Herzberg, Director of the Physics Division of the National Research Council. He was a molecular spectroscopist who, a few years later in 1971, was the recipient of the Nobel Prize in chemistry. Since Herzberg could not be persuaded to come to Toronto, H.L. Welsh, also a molecular spectroscopist and already a member of the staff, was chosen. He had graduated from Toronto in honours physics in 1930 and had spent the following year as a research student of McLennan and obtained his M.A. He then had gone to the University of Göttingen to work with the Nobel Laureate, James Franck. When the rise of Hitler led Franck to emigrate to America, Welsh returned to Toronto where he completed the requirements for the Ph.D. in 1936. First appointed to the professorial staff in 1942, he shared with Crawford the responsibility for the rapid expansion of spectroscopic research during the immediate post-war years. On Crawford's sudden death in 1960 he became leader of the spectroscopic research group. The excellence of his research was recognized world-wide and he was well known to Canadian physicists, many of whom had carried out their graduate programmes under his direction.

Planning for the new building was well advanced in 1962 but final decisions had yet to be made. Also, as a result of the addition of several nuclear physicists to the staff, the need for a nuclear facility was being pressed. The two projects could not be dissociated from each other, since the laboratory to house the new machine must form a part of the new building. When in 1962 the nuclear group decided upon an electron linear accelerator or Linac, the matter was discussed with President Bissell and approval was given to go ahead with plans for the accelerator and for an underground laboratory to house it in part of the site for the new physics building.

When Welsh became Chairman in 1962, the plans for the new building were not yet complete and those for the proposed Linac laboratory were scarcely on the drawing board. The space in the old building was becoming more and more inadequate to the needs of the Department. The sub-department of geophysics was still in 49 St George Street and some research projects were being carried on in the basement of the old chemistry building from which some chemists had moved to the newer Wallberg building. The number of staff offices was less than the number of professorial staff and shared accommodation was not unusual. When to the problems of inadequate space, others associated with a rapid growth of both graduate and undergraduate student numbers were added, the task facing the new Chairman appeared very great indeed. Since he was anxious that administrative duties should not make it impossible for him to continue teaching and research, Welsh requested that an associate chairman be appointed to share these duties. An obvious choice for the new position of Associate Chairman was G.D. Scott. He had been appointed Acting Chairman when Watson had left and was familiar with the requirements of the office and the organization of the University. He was offered and accepted the appointment.

The period of the later fifties and of much of the sixties was unique in the history of higher education in Ontario. The economy was buoyant and university degrees were highly regarded. As a result of this favorable climate the provincial government was willing to provide money for expansion of both staff and facilities in the already existing universities and to establish new ones.

One of the most urgent problems in Toronto was still an inadequate number of staff. Florence Quinlan, who had been responsible for lectures and laboratory classes offered students from the Faculty of Music, from the School of Physical and Health Education, and from the Faculty of Food Sciences as well as those in the honours course of Household Economics in the Faculty of Arts, died in 1958 after a

comparatively brief illness. Ireton, who in addition to his teaching duties, had carried a heavy administrative load retired in 1959. This left only Kathleen Crossley of those who had been members of the staff continuously since the end of the first world war.

Crawford died very suddenly in 1960. His death was a severe loss to the Department not only because of his pre-eminence as an atomic spectroscopist but also because of his interest and success in undergraduate teaching and his knowledge of departmental and university administration.

When the above losses are taken into account the net increase in staff over 1943 was in 1962 only eight persons although in the same interval the total registration in physics courses had more than doubled. Another consideration which intensified the need for a larger number of staff was the planning for the suburban colleges of Scarborough and Erindale. Fortunately circumstances were favorable and it was possible to make an average of four additional appointments each year from 1962 to 1969 inclusive.

The increase in staff implied a need for more staff offices and more research space if the best persons were to be obtained in a competitive market. Until the new building was completed these needs created difficulties only partially alleviated by the temporary use of space in the Galbraith building. Construction of the new building and of the nuclear facility began in 1963. The Linac laboratory was pushed ahead to have it ready to receive the machine which was delivered early in 1966. The official opening of this laboratory took place in September 1966 but that of the main building not until about a year later.

The opening of the new physics building took place on September 14, 1967. The building possesses a fourteen-storey tower, a south wing containing four large lecture theatres, and a second three-storey wing to the north which was initially assigned to undergraduate laboratories only, but since has been given over partially to other uses. It also contains several small lecture rooms and a number of staff offices. An important feature is a basement which is considerably larger in area than the complete ground floor of the tower and wings. Designed as research space and equipped accordingly, it accommodates much of the spectroscopy, low temperature and nuclear research as well as the mechanical workshop, glassblowing shop and helium liquefaction plant. The Linac laboratory is situated underground just east of the main basement, and access to it is provided through a sub-basement. The building was officially designated as the "McLennan Physical Laboratories" and the tower as the "Burton Tower". Space is assigned not only to Physics but also to Astronomy and Computer Science.

As noted above the opening of the new McLennan Laboratories took place on September 14, 1967; it was made the occasion for scientific as well as social activities. Six lectures were arranged, to be given by pre-eminent physicists on the forenoon of the day of the official opening ceremonies and on the succeeding day. Notices with invitations were sent to other universities and individually to former staff members and graduate students of the Department. Many came to revisit old haunts and to renew old associations; others to wish the Department well and to inspect its new facilities. Undoubtedly the decision to come or not to come was influenced by the opportunity to hear the distinguished lecturers. A large group assembled in the area east of the building for the opening ceremonies. The climax came when Dr. Herzberg unlocked the door with a golden key. Afterwards, at a reception held in the building, the visitors were shown about or could wander at will through the laboratories. The lectures were well-attended and for those who heard them made the occasion a memorable one. On the evening of the day of the opening ceremonies a party was given by the three departments who would occupy the building. All their members with their families and all visitors were invited. It was a happy event, a sense of achievement and of optimism for the future pervading the whole gathering. A list of the lecturers with the subjects of their addresses is given below:

Dr. G. Herzberg, Director, Division of Pure Physics, National Research Council, Ottawa.

The problem of diffuse interstellar lines

Professor C.H. Townes, Professor at Large, University of California, Berkeley.

What an intense laser beam does to matter and vice versa

Professor S. Chandrasekhar, Distinguished Service Professor of Theoretical Astrophysics, Enrico Fermi Institute of Nuclear Physics, University of Chicago.

Gravitational Collapse

Professor A. Kastler, Professor, École Normale Supérieure, University of Paris.

Interactions between atoms and electromagnetic fields studied by optical pumping techniques

Professor M. Kac, Professor of Mathematics, The Rockefeller University, New York.

High speed computing as a new experimental technique in mathematics and physics

Professor R.H. Dicke, Cyrus Fogg Brackett Professor of Physics, Princeton University.

Gravitation and the sun's rotation

There were those who had argued against abandonment of the old building and may even have caused some delay in the decision to build the new one. They preferred to see an extension for physics in the area now occupied by the Galbraith building. This, however, did not conform to the overall planning of the University. The argument used against it had been the interruption which the move would cause in the work of the Department, but affection for the old building was probably involved. Some interruption in research projects certainly did result but it was more than compensated by the improved facilities in the new laboratories. There was little disruption in the undergraduate teaching. For the first time in almost thirty years there was space for all sections of the Department within a single building. Any thought that McLennan would have regretted the departure from the old building, of which he was indeed very proud, can be discounted. He would undoubtedly have been even more proud of the new McLennan Laboratories and happy that, once again, as when the first building was completed, the Department was provided within a single building with the facilities which it required.

When the first Professor of Physics had become certain that a building for physics was assured, he had resigned, no doubt considering that he had achieved the task he had set himself. His action was paralleled by that of Welsh who resigned as Chairman in December 1968 when the move to the new building was completed.

RESEARCH IN THE SIXTIES

The expansion of the teaching staff to provide in the best possible way for a greatly increased undergraduate population had as its concomitant the growth and broadening of research activities. The total number of professorial staff members rose to more than sixty by 1970. It becomes increasingly difficult to summarize the scientific activities of the Department and extensive use will be made of pamphlets issued by the Department in 1967 - 68 and succeeding years; the purpose of these was to inform new graduates, particularly those graduating from other universities, of the opportunities for graduate study and research available in Toronto. In the pamphlet published in 1967, research in the Department is listed under five main headings: (1) Atomic and Molecular Physics; (2) Low Temperature and Solid State Physics; (3) Nuclear and High Energy Physics; (4) Theoretical Physics; (5) Geophysics and Meteorology. Each will be considered in turn.

(1) The atomic and molecular physics section is that previously designated as the spectroscopic group and spectroscopic methods are

still widely used by its members, but the range of phenomena studied has been extended. This has been due largely to changes in personnel.

H.P. Gush, who came to Toronto from Saskatchewan as a graduate student and completed his Ph.D. in 1956 working on induced infrared absorption, returned as a staff member in 1959 after two years in Paris at C.N.R.S. He had a particular interest in the study of induced absorption in hydrogen in the far infrared and at very low temperatures. In 1967 he decided to leave Toronto for the University of British Columbia.

The death of Crawford in 1960 resulted in the phasing out of the work on the hyperfine structure of atomic spectral lines. A.D. May, who joined the staff in 1961, had a special interest in atomic spectroscopy but not in that aspect of it. May, a graduate in M and P, had completed his Ph.D. in 1959 working on the Raman effect of gases at high pressures and then had spent two years in France on a post-doctoral fellowship. He had become familiar with the phenomenon of optical pumping and set up experiments for the study of excited atomic states.

Boris Stoicheff, after completing his Ph.D. working with Welsh on the Raman effect in gases at high pressures, joined the staff of the National Research Council where he became known for his work on high resolution Raman effect and the precise determination of molecular constants from measurements of the Raman spectrum. Rejoining the Toronto group in 1964, he continued this work and began to use the laser, a then newly-developed source of monochromatic radiation, to excite the scattering in place of the formerly-used mercury arc lamp. He also began observations of Brillouin scattering which are still yielding information of great interest.

In summary, it can be said that earlier work in induced infrared absorption, in high resolution Raman effect, in the spectra of compressed gases and solid hydrogen, and in the studies of transport phenomena had been continued, and new projects involving optical pumping and Brillouin scattering had been initiated. Further details of these studies may be found in "Spectroscopy Research at the McLennan Physical Laboratories" appearing in *Applied Optics*, volume 6, 1967.

In 1962 two new staff members introduced two new fields of research into the Department. R.L. Armstrong, a graduate of Toronto who had obtained his doctorate working with Welsh on the infrared spectroscopy of compressed gases, returned from a post-doctoral year in Oxford during which he had studied the techniques of nuclear magnetic resonance spectroscopy. He at once set about establishing a

magnetic resonance laboratory, in which in succeeding years he and his students developed a program of molecular dynamics in gases and molecular motions in insulating crystals, by means of nuclear magnetic resonance and nuclear quadrupole resonance. At about the same time J.M. Harvey, also a Toronto graduate, who had obtained his D. Phil. in Oxford in 1962 was appointed to the staff. His field of electron spin resonance was also a new interest in the Department. Armstrong remained a staff member and has been Chairman of the Department since 1974 but Harvey resigned in 1969.

In 1967 one of the first appointments to the physics teaching staff of Scarborough College was Vello Soots, who had completed the requirements for the Ph.D. in 1963 studying the Raman spectrum of solid hydrogen with E.J. Allin. On joining the staff he entered upon a study of the Raman effect in ionic crystals. This work was discontinued when Soots left the Department in 1973.

(2) By 1967 the former low temperature research group had also broadened its field of study. In 1964 F.D. Manchester and R.J. Balcombe came and began projects on the hydrogen in palladium problem and the de Haas-van Alphen effect, respectively. In 1966 J.M. Perz joined the staff and attacked the latter problem using his expertise in ultrasonics. In 1967 when the move to the new building was completed the first large superconducting magnet was acquired. When in 1968 Balcombe resigned, his place was taken by P.P.M. Meincke in 1969. His interests were mainly in superconductivity and quantum liquids. In 1970 E. Fawcett joined the group and Fermi surface studies were intensified, especially those to do with strain dependence.

A few words about each of the new staff members mentioned in the above paragraph are given below. F.D. Manchester is a New Zealander who obtained his Ph.D. from the University of British Columbia. R.J. Balcombe came to Toronto from Britain, having obtained his Ph.D. in Cambridge; after several years he decided to return to the United Kingdom. J.M. Perz is a graduate of Toronto in Engineering Physics with a Ph.D. from Cambridge. P.P.M. Meincke graduated from Queen's University, and obtained his Ph.D. in 1963 for work in low temperature physics at Toronto. He spent several years in the Bell Telephone Research Laboratories before returning to Toronto as a staff member in 1969; in 1979 he left to become President of the University of Prince Edward Island. Eric Fawcett is a native of England who obtained the Ph.D. at Cambridge in 1954. At the time he decided to come to Toronto he was at the Bell Telephone Research Laboratories.

J.M. Daniels, who came to Toronto in 1961, had attended Oxford

as both undergraduate and graduate student and had obtained the D.Phil. degree in 1952. After a post-doctoral year in low temperature physics there, he had come to Canada in 1953 as a member of the faculty of the University of British Columbia where he was Professor of Physics at the time he moved to Toronto. He had spent some time in the Argentine as Unesco expert in experimental physics at the University of Buenos Aires and Visiting Professor at the Balseiro Institute of Physics. Well-known for work in solid state physics and magnetism, his interest at this time was in the spatial orientation of nuclei. He set up experiments in Mossbauer spectroscopy and in methods to polarise helium-3 nuclei and construct a dense target of such nuclei. In 1969 he succeeded Welsh as Chairman of the Department.

P.J. Kirkby, a Ph.D. from McGill who joined the staff in 1969, was interested in studying high energy scattering from a dense target of polarised helium-3, then under construction. He stayed only until 1973.

(3) Experimental nuclear and high energy research was greatly expanded in the sixties. The decision to construct the Linac laboratory emphasized the importance nuclear research was assuming in departmental plans and additional nuclear physicists were attracted to the staff. Some looked forward to working with the Linac and others to working with the other facilities such as the van de Graaff and the betatron.

R.E. Azuma, a graduate of the University of British Columbia and a Ph.D. from Glasgow, joined the staff in 1961. His principal interest is the structure of nuclei. H.S. Caplan who also came from the University of Glasgow made his contribution in the design of the Linac laboratory and the instrumentation for the Linac. He remained in Toronto from 1963 to 1966 when he moved on to the University of Saskatchewan. D.A.L. Paul, a graduate of the University of Cambridge, obtained his Ph.D. at Queen's and came to Toronto in 1964. Initially he sought to use the Linac for the production of beams of positrons in the eV to keV energy range but later this effort was separated from the Linac.

When he came to Toronto in 1965, J.D. King was the first physicist acquired for the teaching staff of Scarborough College. He had graduated from Toronto in 1956 and obtained the Ph.D. from the University of Saskatchewan in 1960. Likewise when H.W. Taylor came from the University of Alberta in 1965 he was the first physicist appointed to the staff of Erindale College. Since Erindale had not yet opened he joined King at Scarborough for a year. Taylor was a graduate and Ph.D. from the University of Manitoba. A nuclear spectro-

scopy project to study the decay schemes of various isotopes produced by the linac was set up at Scarborough in 1966 and relocated in Erindale in 1967.

In 1966 A.E. Litherland was persuaded to come to Toronto from Atomic Energy of Canada. Born in England, he had graduated from the University of Liverpool in 1949 and obtained his Ph.D. from that university in 1955; he had come to Canada as a research fellow at the National Research Council in 1953. His particular interest was the structure of the atomic nucleus. He and Azuma used the van de Graaff accelerators at McMaster University and Chalk River as well as the 3 Mev van de Graaff at Toronto.

D.B. McConnell, M.Sc. (Western), Ph.D. (M.I.T.), another nuclear physicist, also joined the staff in 1966 but in 1970 he resigned to take a position in the research laboratories of Ontario Hydro.

During the past several decades the field of high energy physics has made outstanding contributions to our understanding of the basic laws of the universe. That the Department at Toronto became active in this field in the sixties was largely due to the urging of Prentice and Steenberg, whose interest in sub-nuclear elementary particles had led them to appreciate the future importance of research at high energies. It was not planned to build a high energy facility at Toronto but scanning tables, measuring machines and computers for the study of observations taken elsewhere were provided. The University of Toronto became a charter member of the University Research Association which has the management responsibility for the Fermi National Laboratory at Batavia, Illinois. The work at Toronto is described in the pamphlet on research and graduate studies issued in 1972 as follows: "The experimental high energy physics group is involved in the study of elementary particles. These studies involve scattering experiments using bubble chamber and counter detector techniques. The data are obtained at one of the major U.S. accelerator laboratories, often in collaboration with other university groups, and are then processed and analysed at the University of Toronto. The aim of these experiments is to make experimental observations about the nature of elementary particle interactions."

Prentice was joined in this work by A.W. Key in 1968 and by T.S. Yoon in 1969. Born in Edinburgh, Key graduated from the University of Aberdeen where he received an M.A. in 1960 and then went to Oxford where he was awarded the D.Phil. in 1964. From then until 1966 he was Lecturer in Physics at the University of Natal. Yoon obtained his M.Sc. at the University of Seoul and his Ph.D. at the University of Illinois. E.C. West, a graduate of Stanford in 1958, who

had received the Ph.D. at Wisconsin in 1966, came to Toronto as a lecturer and research assistant in 1966. He was promoted to Assistant Professor in 1967 but in 1972 resigned that position and is now on the staff of the Institute of Computer Science.

(4) The Department now has among its staff a number of distinguished theoretical physicists. Below are the names of those in the staff list for 1970 - 71, grouped according to their fields of work. Working in theoretical solid state, molecular and statistical physics were: J. Van Kranendonk, Ph.D. (Amsterdam), R.C. Desai, Ph.D. (Cornell), P.A. Griffin, Ph.D. (Cornell), J.D. Poll, Ph.D. (Toronto), A.E. Jacobs, Ph.D. (Illinois), L.E.H. Trainor, Ph.D. (Minnesota), S.H. Vosko, Ph.D. (Carnegie Institute), M.B. Walker, D.Phil. (Oxford). Working in nuclear physics were: L.E.H. Trainor, D.J. Rowe, D.Phil. (Oxford), S.S.M. Wong, Ph.D. (Rochester), N.F. Steenberg, D.Phil. (Oxford). Working in elementary particle physics and relativity were: J.W. Moffat, Ph.D. (Cambridge), R.E. Kreps Ph.D. (Princeton), R.E. Pugh, Ph.D. (Iowa), P.J. O'Donnell, Ph.D. (Glasgow), R.K. Logan, Ph.D. (M.I.T.).

All of these with the exception of Van Kranendonk and Steenberg had come since 1960. Almost all are still here in 1980. Poll resigned in 1970 to join the faculty of the University of Guelph. Kreps gave up physics and Steenberg was forced by ill-health to retire in 1974. Of those who have stayed, six were born in Canada and obtained their first degree in a Canadian university; Pugh and Griffin at British Columbia, Walker and Vosko at McGill, Trainor at Saskatchewan and Jacobs at Toronto. Of the non-Canadian-born Desai obtained his first degree at the University of Bombay, Wong at the International Christian University in Tokyo, Logan at M.I.T., O'Donnell at Glasgow, and Moffat and Rowe at Cambridge. The rapid growth of the group and the variety of experience and interest among its members is evident.

(5) Wilson remained as active as ever and the theories of continental drift which he expounded were gaining a wider acceptance. He became Principal of Erindale College in 1967 and some geophysical projects were established there. Derek York who joined the staff in 1960 became associated with Farquhar in mass spectrographic determinations of isotope abundances in rocks. York was born in England and attended Oxford University where he obtained the degree of D.Phil. in 1960. His interest in isotopic geophysics stemmed from an interest in the evolution of continents and in the timing of reversals in the earth's magnetic field.

The history of the earth's magnetic field and of ancient reversals in that field also was a major interest of D.W. Strangway who was appointed Associate Professor of Physics in 1968. Having graduated

from the University of Toronto in 1956, he remained as a graduate student and gained the Ph.D. in 1960. He then served as geophysicist with several large corporations and as Assistant Professor of Geology at the University of Colorado. In 1968 before returning to Toronto he was Assistant Professor of Geophysics at M.I.T. He had important connections with NASA and as a result Toronto was one of the institutions which received for magnetic study a portion of the first lunar rock samples brought back to earth. He later became Chairman of the Department of Geology.

G.F. West, a graduate of U of T who received his Ph.D. there in 1960, became a staff member in 1962 and joined F.S. Grant (whose appointment has already been noted) in experimental and theoretical research directed toward improving the interpretation of data obtained from gravimetric, magnetic, electrical and electromagnetic measurements of the earth's crust.

G.D. Garland who came as Professor of Physics in 1963 was a graduate of U of T who obtained his Ph.D. from St Louis University in 1951. Before returning to Toronto he was Professor of Geophysics at the University of Alberta. His interest in the electromagnetic study of geothermal areas led to what was probably the first observational project outside of Canada by the geophysics group: a study of crustal conditions in Iceland, carried out between 1964 and 1966. Equipment was also available in the laboratory for investigations of seismic phenomena and in these West played a leading role. J.C. Savage, a member of the staff from 1967 - 69, took part in this work as did R.A. Wiggins who joined the staff in 1970 and remained for about four years.

An important action taken during the sixties was the appointment of meteorologists to the staff of the Department, resulting in the teaching of meteorology as a regular curriculum subject. The establishment in 1933 of the course leading to the M.A. degree did not carry with it an undergraduate programme in the subject, but in 1947 a Ph.D. was granted to W.L. Godson for research in meteorology. The meteorological subjects were taught by scientists of the Meteorological Service of the Department of Transport, several of whom held appointments as honorary staff members. This arrangement was completely satisfactory to neither the University nor the Meteorological Service. In 1962 A.W. Brewer, a meteorologist from Oxford University known for his studies of the structure of the atmosphere, was appointed Professor of Physics. This recognized meteorological teaching and research as a responsibility of the Department. Brewer was interested in making ozone measurements using ultraviolet spectroscopy and in the study of stratospheric transport problems.

Other specialists in fields related to meteorology were appointed,

namely R. List in 1963, J.V. Iribarne in 1966 and C.O. Hines in 1967. Roland List was born in Switzerland and studied at the Swiss Federal Institute of Technology where he obtained the Diploma in Physics in 1952 and the degree Dr. Sc. Nat. (atmospheric physics) in 1960. Before coming to Toronto he was head of the section for atmospheric ice formation of the Swiss Federal Institute for Snow and Avalanche Research. J.V. Iribarne was born in Buenos Aires and educated at the University of Buenos Aires where he received the degree of D.Chem. in 1942. Before coming to Toronto he was Head of the Institute of Atmospheric Physics and Professor of Meteorology. His interests are cloud physics, atmospheric electricity and aerosol physics. C.O. Hines was born in Toronto and obtained his M.A. from U. of T. in 1950. He then went to Cambridge where he gained the Ph.D. in mathematics in 1953. Before returning to Toronto he was Professor of Aeronomy at the University of Chicago. His interest lies in the phenomena occurring in the earth's upper atmosphere.

Cooperation with the Department of Transport continues but meteorological studies are now on the same footing in the Department as other branches of physics.

A TIME OF CHANGE *Undergraduate Courses*

Honour courses had become a distinctive feature of the undergraduate programme at Toronto before the end of the nineteenth century. Both they and the pass or general courses had entrance requirements and prescriptions which were set down in detail. The pass and general courses covered a wider spectrum of subject matter than the honour courses which were designed to provide a greater depth of knowledge within a narrower field. One of the first honour departments to be recognized was Mathematics and Physics. As knowledge in these and related fields increased, diversification was facilitated by sub-division of the M and P course and the introduction of new honour departments. Physics and Chemistry was so designated in 1906, discontinued as such in 1916 and re-introduced in 1926. Physics and Geology was added in 1928. There were eight divisions in M and P in the sixties but the first year prescription was common to all and to P and C and to P and G. In spite of the number of options available the honour courses were criticized as too specialized and too research oriented.

During the sixties the undergraduate programme was under study throughout the University. The "new programme" which resulted from these discussions was first implemented in 1969. It did away

with the former pass, general and honour courses and replaced them by combinations of lecture and laboratory courses chosen by the individual student in consultation with one or more members of the staff. Based on its previous experience each department set up a spectrum of courses which it felt would provide for the needs of all students including those who planned to enter later one of the professional faculties. The traditional pass and honour courses in the Faculty of Arts and Science died with the sixties.

Administration

Changes in the administration of the Department had taken place gradually through the years and had been accelerated by the war, the rapid growth after the war and the still more rapid expansion of the sixties. Students were now demanding a say in decisions taken in academic matters.

Even in less democratic days members of the Mathematics and Physics Society had taken from time to time a critical look at the undergraduate courses. In general the resulting recommendations had been for an up-grading of the material covered. On the other hand persons outside this group had become increasingly critical of the honour courses in the physical sciences for their high failure rate and research orientation. In the sixties when the structure of the undergraduate programme was under study throughout the University, Welsh formalized the involvement of the undergraduate students by setting up a departmental curriculum committee, made up of members from both the staff and student body, which met frequently to discuss course content and methods of student evaluation.

From the early days graduates, and sometimes senior undergraduates as well, had assisted in laboratory instruction. The position of assistant demonstrator was well-defined in the twenties and thirties and provided an important means of support for graduate students who were without scholarships. In the pre-war years only a lucky few could obtain such positions. After the war for some years the Department requested all graduate students to accept some teaching responsibilities and the available positions were diversified. In the sixties the graduate students asked to have a greater say in the conditions of their employment and the remuneration offered them. There was a need to provide for a discussion of these matters as well as of the research requirements for the Ph.D. and M.A. degrees and the role of their supervisors in this work. A committee to implement such discussion was required.

One of the consequences of inadequate space in the early and mid-sixties was the impossibility of arranging time-tables so that there was a time when all members of the staff were free to meet together when a suitable room was available. This was particularly unfortunate because of the number of new staff members who, in organizing their teaching and research, felt the need to be familiar with the activities of the Department as a whole, and who also needed to feel involved in setting the policy of the Department. After much discussion it was decided to elect from the academic staff an executive committee which would meet weekly. Its members were to be chosen to represent the research interest groups and were expected to keep in close communication with the members of these groups. The first election for the executive committee took place in December 1966. The Chairman and Associate Chairman were ex-officio members. This committee was the forerunner of the present Departmental Council and predated the formation of such Councils throughout the University.

V / MODERN TIMES, 1969-1980

Welsh's resignation as Chairman became effective not at the end of the academic year but at the end of the calendar year. He was succeeded by J.M. Daniels on January the first, nineteen hundred and sixty-nine. The high regard in which Daniels was held as a scientist was probably of less importance at this time than his sympathetic treatment of student demands. The period of greatest student militancy was yet to come but the work of the Department suffered comparatively little from it. Student evaluations of lecture courses were accepted and given serious consideration by staff members. Students were admitted to staff meetings although many staff members felt they should be allowed to discuss departmental matters in private if they so desired. The Executive Committee instituted by Welsh evolved into the Departmental Council which has members representing students and non-academic staff. Two Associate Chairmen — Roland List with special responsibility for the concerns of the graduate students and Robin Armstrong with special responsibility for undergraduate affairs were named to assist Daniels.

None of the above changes produced serious repercussions on the teaching or research activities of the Department. Much more exasperating were the periodic "bomb scares". The university police would be informed that a bomb had been placed in the building and it would be evacuated and searched, sometimes in severe weather. In every case the warnings proved unjustified with the result that they came to be ignored by many persons working in the building. It remained necessary to dismiss all classes but staff members could remain at their own risk. Fortunately these occurrences were confined to a fairly short period.

Changes which had taken place in University policy affected the departments directly. For several years administrative officers had been appointed for an initial period of five years only. This applied

to Departmental Chairmen and was implemented in the case of Physics at this time.

By 1970 the Department had a professorial staff numbering between sixty and seventy, the members of which were specialists in many different branches of physical knowledge, but in spite of its diversity, size was not a problem since members with related interests formed smaller groups. Several were members of the teaching staff of Scarborough or Erindale College but the graduate staff was an entity. Facilities were available to all in the McLennan Laboratories but some preferred to set up their research projects in the College in which their undergraduate teaching was carried on. The future appeared very bright and the Department had ambitious plans for research projects some of which would be carried on jointly with other Departments. Not all of these plans have been realized since circumstances over which the universities had little if any control brought the period of expansion to an end.

Certain sections of the public had come to regard the universities as training schools which prepared their graduates for definite employment opportunities and had come to look upon a university degree as a passport to success. On the other hand some employers had demanded a university degree as a qualification for jobs for which it had little relevance and were critical when further specialised training was required. When university graduates did not meet their expectations, members of the public became dissatisfied with the universities because of their lack of involvement in technical education. Public disillusionment was also a result of the realization that new knowledge could be used for undesirable as well as desirable ends. Physicists in particular were out of favour since they were held responsible for the scientific discoveries which had made the atomic bomb possible. Government support of the universities became less generous and their expansion was halted.

However the seventies have shown that the future still holds promise. In spite of reduced support and little growth potential the Department has been able to maintain both research and teaching at a high level of excellence. Careful planning has kept and can continue to keep in balance the groups specializing in different fields of physical knowledge even though the effects of attrition due to retirements and resignations are not felt equally by all groups in any given period.

The group designated "Atomic and Molecular Physics" in 1970 has been replaced in 1980 by one designated "Lasers and Spectroscopy" or alternatively "Laser Physics and Quantum Optics". Elizabeth Allin retired in 1972, Welsh in 1978 and Stryland in 1980. The two remaining

senior members of the group, May and Stoicheff, and three new appointees, Stegeman in 1970, Code in 1972 and van Driel in 1978, have a special interest in the use of lasers in Raman and Brillouin scattering, atomic spectroscopy, and the study of non-linear optical effects.

All three, Stegeman, Code and van Driel are graduates of the University of Toronto and Stegeman and van Driel also obtained the Ph.D. there. Stegeman worked with Stoicheff on Brillouin scattering and van Driel with Armstrong using nuclear quadrupole resonance to study phase transitions. Code went to Harvard to obtain the Ph.D. As a result of his appointment to the teaching staff at Erindale College, Stegeman felt it would be to his advantage to set up his research projects at the College and did so. Code when he joined him on the teaching staff two years later also set up research experiments at Erindale as did Van Driel in 1978. A well-equipped modern optics laboratory was built up. It forms one section of the J.T. Wilson Research Laboratories, in which research in geomagnetism and nuclear physics is also in progress.

Stegeman's first interest was in non-linear optics and in 1979 A.T. Georges, a Ph.D. from Southern California, and a theoretical physicist interested in non-linear optical phenomena was appointed to the staff. When in 1980 Stegeman resigned to go to the Optical Science Centre in Tucson, Arizona, Georges also left.

Those who in 1970 were members of either the "Low Temperature and Solid State Physics" or the "Theoretical Molecular and Solid State Physics" group are in 1980 listed as a single group designated "Condensed Matter Physics". Armstrong's research interests now place him in this group and a new member is M.J.G. Lee, a Ph.D. from Cambridge who was appointed in 1975. He is a specialist in surface physics and the physics of metals.

The group in "Nuclear Physics" in 1980 contains only persons who were members in 1970 and in "High Energy Physics" only N. Isgur, appointed in 1979, is new. He obtained his Ph.D. in Toronto in 1974 in the field of high energy particle physics.

The group in "Geophysics" has in 1980 four members, Farquhar, Garland, West and York, who were already members in 1970 and four who have joined since. C.H. Chapman, Ph.D. (Cambridge) is a theoretical physicist who works on seismic wave propagation. D.J. Dunlop, Ph.D. (Toronto) directs the rock magnetic research in the special laboratory on the Erindale campus, and R.N. Edwards, Ph.D. (Cambridge) is particularly interested in the interpretation of electromagnetic observations made at the earth's surface, in terms of crustal structure. Chapman was appointed in 1975, Dunlop and Edwards in 1970.

R.C. Bailey, Ph.D. (Cambridge) was appointed jointly by the Departments of Physics and Geology in 1973. He is a theoretical physicist with an interest in exploration geophysics.

The "Atmospheric Physics" group had as its first member A.W. Brewer who was appointed in 1962. He retired in 1977 but List, appointed in 1963, and Iribarne, appointed in 1966, are still active members in 1980. Hines who came in 1967 is on leave in 1980. W.R. Peltier who obtained his Ph.D. in Toronto has been a charter member in the University Corporation for Atmospheric Research which administers the National Center for Atmospheric Research at Boulder, Colorado. His interests are geophysical fluid dynamics and he has gained recognition for his work on thermal convection models of continental drift. H.R. Cho who joined the Toronto group in 1975, is a Ph.D. from Illinois with atmospheric dynamics as his special field of interest. T. Gal-Chen, M.Sc. (Tel-Aviv), Ph.D. (Columbia) was a member of the group from 1975 to 1979. A theorist and a specialist in atmospheric dynamics he was active in computer modelling of atmospheric phenomena. C.A. Lin, who graduated in 1974 from the University of British Columbia, completed his Ph.D. at M.I.T. in 1979 and came to Toronto after spending a short time with the Atmospheric Environment Service of Canada. He studies the large-scale circulation of the earth's atmosphere. The compositions of the stratosphere and mesosphere are being investigated by J.R. Drummond, D.Phil. (Oxford) who also joined the Toronto group in 1979.

Daniels remained as Chairman of the Department for only one term and was succeeded at the beginning of 1974 by Armstrong. By this time Armstrong had earned recognition for his studies of the physical properties of transition metal antiferromagnetic crystals, especially those associated with the structural phase transition. In addition to magnetic resonance experiments at Toronto he also carried out neutron scattering studies in collaboration with the staff physicists at the Chalk River Nuclear Laboratories. As Associate Chairman with responsibility for undergraduate affairs during the previous five years he had become familiar with the administration of the Department. He is still Chairman at the end of 1980 since at the end of his first term he was offered and accepted a second. During his first term Azuma was Associate Chairman for graduate affairs, Farquhar for undergraduate affairs. At the beginning of Armstrong's second term, Rowe and Ivey, respectively, assumed the two positions but in 1980 Ivey resigned to become a Vice-President of the University. At this time Armstrong restructured the Departmental administration returning to a single Associate Chairman — D.J. Rowe.

No effort will be made to describe the individual research projects of the seventies, but some events such as the dismantling of the Linac in 1978 must be noted. Installed in 1966, the Linac had played an important role in making nuclear physics an active field of research in the Department. Since then it had proved a valuable facility not only for the staff and graduate students in Physics but also for personnel from other departments in the University, and from the University of Waterloo. The demise of the Linac did not mean that nuclear physics was being phased out but only that the nature of the investigations was changing.

The Linac Laboratory is now the Trace Laboratory. Instruments for The Rare Atom Counting Equipment project, including particle accelerators and mass spectrometers, when assembled will occupy a large part of the former Linac Laboratory. As a young man the nuclear physicist, Litherland, had had a serious interest in archeology. He had retained this and, when in 1974 he taught a joint physics-archeology course, became interested in the possible use of particle accelerators in radio-carbon dating. The advantage anticipated for such a method is that samples at least a thousand times smaller can be dated with approximately the same accuracy as the larger sample using earlier methods. Although initially the intention was to create an ultra-sensitive device for carbon dating, it should count other than carbon atoms. Consequently it has the potential to be useful in many investigations in which the detection and measurement of trace elements is required. A joint proposal was submitted by the three departments of physics, geology and archeology and support has been obtained from NSERC and the federal Department of Supplies and Services.

Involvement of the physicist in other branches of science arises from the nature of physics. The goal of the physicist is the understanding of the basic laws of the universe, and he therefore strives to extend his knowledge of them. He also feels a responsibility to interpret these basic laws to non-physicists so that the latter can apply them to develop useful procedures and devices in other fields of science and for daily life.

The staff of the Department of Physics has maintained close relations with other departments through the years, that cited above in TRACE being one of the most recent examples. The growth of the sub-department of geophysics resulted from Gilchrist's desire to show that physical principles could be applied advantageously in mineral exploration. The present close relationship with Geology followed. Cooperation with the Faculty of Medicine was strengthened when nuclear physicists were added to the staff of the Department and when

the Department of Medical Biophysics was created. Not only have staff and graduate students in Physics made extensive use of the facilities at the Princess Margaret Hospital, but staff members have been cross-appointed. McNeill is a Professor in the Faculty of Medicine and Dr. Silverman in the Department of Physics. Recently Trainor has extended his research interests to include theoretical biophysics.

Although physics and chemistry are recognized as separate fields of scientific endeavour, there is a somewhat ill-defined field known as chemical physics, and physical chemistry is an important branch of chemistry. Some members of the staff of the Department of Chemistry who use lasers in their research have interests close to those of members of the physics laser group. Three members of the chemistry staff have been cross-appointed to physics and a joint seminar is held weekly.

Astronomy is another field of science which is traditionally closely associated with physics. In 1975 R.A. McLaren was appointed jointly to Physics and Astronomy. A graduate of M and P who completed his Ph.D. in 1973 in Toronto working with Stoicheff, he investigated the application of infrared techniques to astronomical problems while away on a post-doctoral fellowship.

The inauguration of the H.L. Welsh Lectures in Physics in 1975 has enriched the life of the Department. As Chairman from 1962 to 1968, Welsh had guided the Department during its period of most rapid growth in such a way that its effectiveness in both teaching and research had been enhanced. To mark his sixty-fifth birthday and his attainment of the age of official retirement, his colleagues established a series of public lectures by pre-eminent scientists to be given annually. The lectures take place early in May, and are scheduled over a two or three day period, and during this time additional more specialized lectures are given within the Department. The programmes of the series of the past six years are given in Appendix 5.

When in 1887 Physics became administratively separate from Mathematics, the staff consisted of James Loudon (Professor), W.J. Loudon (Demonstrator), and A.C. McKay (Fellow). A glance at the staff listed in the Calendar of the Faculty of Arts and Science for 1980 - 81 will disclose more than sixty members with professorial status and others of various ranks. In 1887 the space available to Physics was to be found in a small number of rooms in the University College building designed for non-scientific purposes. In 1980 the Department has for its use a large part of a well-equipped modern building which it shares with Astronomy and Computer Science. It also occupies some space in other laboratories at Scarborough and

Erindale Colleges. The expansion of the Department has been due in part to the increase of the population which it serves, but more largely to the growth of the physical sciences and the role they play in modern life. As our society comes to depend more and more on technicians to keep ordinary activities running smoothly, it requires more persons familiar with the basic laws of physics and more research physicists to extend our understanding of these laws.

The role of the physicist will not become less important in the years ahead. Only physicists can develop the fundamental science basic to techniques for the more efficient use not only of atomic, but of all forms of energy, and for safeguards against the misuse of any of them.

 APPENDIX 1

HEADS AND/OR CHAIRMEN OF THE DEPARTMENT

Richard Potter, M.A.	1843 - 44
Rev. Robert Murray, M.A.	1844 - 53
J.B. Cherriman, M.A.	1853 - 76
James Loudon, M.A., LL.D.	1876 - 1906
John Cunningham McLennan, O.B.E., Ph.D., D.Sc., LL.D., F.R.S., F.R.S.C. (Afterwards Sir John McLennan, K.B.E.)	1906 - 32
Eli Franklin Burton, O.B.E., B.A., Ph.D., F.R.S.C.	1932 - 48
Henry John Cunningham Ireton, M.A., Ph.D. (acting)	1947 - 49
Edward Crisp Bullard, M.A., Ph.D., Sc.D., F.R.S. (Afterwards Sir Edward Bullard, Kt.)	1949 - 50
William Heriot Watson, M.A., Ph.D., F.R.S.C.	1950 - 62
George David Scott, M.A., Ph.D. (acting)	1961 - 62
Harry Lambert Welsh, O.C., M.A., Ph.D., D.Sc., F.R.S., F.R.S.C.	1962 - 68
James Maurice Daniels, M.A., D. Phil., F.R.S.C.	1969 - 74
Robin Louis Armstrong, M.A., Ph.D., F.R.S.C.	1974 -

APPENDIX 2

The following list includes the names of those staff members who attained the rank of assistant professor or higher before 1980. The dates given are those of continuous service in the Department and include years spent in lower ranks.

d - died while still a staff member

ret. - retired res. - resigned

D.S. Ainslie, M.A., Ph.D. (Toronto)	1915 - 18; 1931 - 61 ret.
E.J. Allin, M.A., Ph.D. (Toronto)	1930 - 72 ret.
J.M. Anderson, M.A., Ph.D. (Toronto)	1937 - 70 ret.
R.L. Armstrong, M.A., Ph.D. (Toronto), F.R.S.C. Chairman of Department 1974 -	1962 -
K.R. Atkins, M.A., Ph.D. (Cambridge)	1951 - 54 res.
R.E. Azuma, M.A. (B.C.), Ph.D. (Glasgow) Associate Chairman, 1974 - 79	1961 -
R.C. Bailey, B.Sc. (Dalhousie), Ph.D. (Cambridge)	1973 -
R.J. Balcombe, M.A., Ph.D. (Cambridge)	1964 - 69 res.
C. Barnes, M.Sc. (Leeds), Ph.D. (Toronto)	1923 - 68 ret.
A.A. Brant, M.A. (Toronto), Ph.D. (Berlin)	1936 - 49 res.
A.W. Brewer, M.Sc., Ph.D. (London)	1962 - 77 ret.
E.C. Bullard, M.A., Ph.D. (Cambridge), F.R.S. (Afterwards Sir Edward Bullard, Kt.) Head of the Department	1949 - 50 res.
E.F. Burton, O.B.E., B.A., Ph.D. (Toronto), F.R.S.C. Head of the Department, 1932 - 48	1902 - 48 d.
H.S. Caplan, B.Sc., Ph.D. (Glasgow)	1964 - 67 res.
C.A. Chant, M.A. (Toronto), Ph.D. (Harvard) Became first Head of the Department of Astronomy	1891 - 1918
C.H. Chapman, M.A., Ph.D. (Cambridge)	1975 -

Appendix 2

J.B. Cherriman, M.A. (Cambridge)	1853 - 75 ret.
H.R. Cho, B.S. (Taiwan), Ph.D. (Illinois)	1975 -
R.F. Code, B.A. (Toronto), A.M., Ph.D. (Harvard)	1972 -
J. Convey, B.Sc. (Alberta), Ph.D. (Toronto)	1945 - 48 res.
H.C. Corben, M.A., M.Sc., Ph.D. (Cambridge) Chairman, Division of Physical Sciences, Scarborough College	1972 -
M.F. Crawford, M.A., Ph.D. (Toronto), F.R.S.C.	1930 - 60 d.
K.M. Crossley, B.A. (Toronto)	1920 - 61 ret.
J.M. Daniels, M.A., D.Phil. (Oxford), F.R.S.C. Chairman of the Department, 1969 - 74	1961 -
B. Davison, U. of Leningrad, Ph.D. (Birmingham)	1959 - 61 d.
R.C. Desai, B.Sc. (Bombay), Ph.D. (Cornell)	1968 -
T.E. Drake, M.Sc. (Queen's), Ph.D. (Sask.)	1971 -
J.R. Drummond, D. Phil. (Oxford)	1979 -
D.J. Dunlop, M.A., Ph.D. (Toronto)	1970 -
L. Dworin, B.Sc. (City College, N.Y.), Ph.D. (Columbia)	1967 - 68 res.
R.N. Edwards, B.Sc. (London), Ph.D. (Cambridge)	1970 -
R.M. Farquhar, M.A., Ph.D. (Toronto), F.R.S.C. Associate Chairman, 1974 - 79	1955 -
E. Fawcett, M.A., Ph.D. (Cambridge)	1970 -
M.F. Fowler, B.A., Ph.D. (Cambridge)	1965 - 68 res.
G.D. Garland, M.A. (Toronto), Ph.D. (St. Louis), F.R.S.C.	1963 -
A.T. Georges, Ph.D. (Southern California)	1979 - 80 res.
L. Gilchrist, M.A. (Toronto), Ph.D. (Chicago), F.R.S.C.	1906 - 45 ret.
J. Goldemberg, B.S., Ph.D. (Sao Paulo)	1970 - 72 res.
C.C. Gotlieb, M.A., Ph.D. (Toronto), F.R.S.C. Director of the Institute of Computer Science	1949 -
G.M. Graham, M.Sc. (Dalhousie), Ph.D. (Cambridge)	1952 -
R.H. Graham, M.S. (Chicago), Ph.D. (Purdue)	1956 -
F.S. Grant, M.Sc. (Illinois), Ph.D. (Toronto)	1968 - 75 res.
P.A. Griffin, M.Sc. (B.C.), Ph.D. (Cornell)	1956 - 71 res.
H.P. Gush, B.A. (Sask.), Ph.D. (Toronto)	1967 -
A.C.H. Hallett, B.A. (Toronto), Ph.D. (Cambridge) Principal of University College 1972 - 77	1959 - 67 res.
H.C. Halls, M.Sc. (Durham), Ph.D. (Toronto)	1951 - 77 res.
F.K. Hare, B.Sc. (London), Ph.D. (Montreal), D.Sc. (McGill), LL.D. (Queen's, Western Ontario) Also Professor in Department of Geography	1979 -
J.S. Harvey, M.A. (Toronto), D.Phil. (Oxford)	1969 - 76 res.
C.O. Hines, M.A. (Toronto), Ph.D. (Cambridge)	1962 - 69 res.
J.H. Hodgson, M.A., Ph.D. (Toronto)	1967 -
	1946 - 49 res.

J.N.P. Hume, M.A., Ph.D. (Toronto)	1950 -
Chairman of Department of Computer Science	1975 - 80
H.J.C. Ireton, M.A., Ph.D. (Toronto)	1916 - 59 ret.
Acting Head of Department	1947 - 49
J.V. Iribarne, Dr. in Chem. (Buenos Aires)	1966 -
N. Isgur, B.S., Ph.D. (Toronto)	1976 -
D.G. Ivey, M.A. (B.C.), Ph.D. (Notre Dame)	1949 -
Associate Chairman of Department	1979 - 80
Principal of New College	1967 - 73
Vice-President of University	1980 -
K.P. Jackson, M.Sc., Ph.D. (Toronto)	1970 - 75 res.
A.E. Jacobs, M.A. (Waterloo), Ph.D. (Illinois)	1969 -
J.A. Jacobs, M.A., Ph.D., D.Sc. (London)	1954 - 57 res.
Associate Professor of Applied Mathematics	1951 - 54
H.E. Johns, OC, M.A., Ph.D. (Toronto), LL.D. (Sask.), D.Sc. (McMaster), F.R.S.C.	
Chairman of Department of Medical Biophysics	
University Professor	
N.B. Keevil, M.Sc. (Sask.), Ph.D. (Harvard)	1943 - 46 res.
A.W. Key, M.A. (Aberdeen), D.Phil. (Oxford)	1968 -
J.D. King, B.A. (Toronto), Ph.D. (Sask.)	1965 -
Associate Dean, Scarborough College	
P. Kirkby, M.Sc., Ph.D. (McGill)	1969 - 73 res.
R.E. Kreps, B.Sc. (Stanford), Ph.D. (Princeton)	1967 - 75 res.
M.J.G. Lee, M.A., Ph.D. (Cambridge)	1974 -
C.A. Lin, B.A. (B.C.), Ph.D. (M.I.T.)	1980 -
R. List, Dipl.phys.E.T.H., Dr.Sc.Nat. (Zurich)	1963 -
Associate Chairman	1974 - 79
A.E. Litherland, B.Sc., Ph.D. (Liverpool), F.R.S., F.R.S.C.	
University Professor	
R.K. Logan, B.Sc., Ph.D. (M.I.T.)	1968 -
J. Loudon, M.A., LL.D. (Toronto)	1864 - 1906 ret.
President of the University	1892 - 1906
W.J. Loudon, B.A. (Toronto)	1881 - 1907
Became Professor of Mechanics	
G.J. Luste, B.A. (Mt. Allison), Ph.D. (Johns Hopkins)	1972 -
D.B. McConnell, M.Sc. (Western Ontario), Ph.D. (M.I.T.)	1966 - 70 res.
R.W. McKay, M.A., Ph.D. (Toronto)	1942 - 73 ret.
R.A. McLaren, M.A., Ph.D. (Toronto)	1975 -
Also on staff of Department of Astronomy	
J.C. McLennan, O.B.E., M.A., Ph.D. (Toronto), D.Sc. (Manchester), LL.D. (Toronto, McGill), F.R.S., F.R.S.C.	1902 - 32

(Afterwards Sir John McLennan, K.B.E.) Head of the Department	
K.G. McNeill, M.A., D.Phil. (Oxford)	1957 -
Also Professor in the Faculty of Medicine	
H.A. McTaggart, M.A., Ph.D. (Toronto), F.R.S.C.	1914 - 41 d.
F.D. Manchester, M.Sc. (New Zealand), Ph.D. (B.C.)	1964 -
A.D. May, M.A., Ph.D. (Toronto)	1960 -
P.P.M. Meincke, M.A., Ph.D. (Toronto)	1967 - 78 res.
Became President of the University of P.E.I.	
A.D. Misener, M.A. (Toronto), Ph.D. (Cambridge)	1934 - 49
Director of Great Lakes Institute, 1966 - 72	
J.W. Moffat, Ph.D. (Cambridge)	1964 -
R.E. Munn, Ph.D. (Michigan)	
On staff of Institute for Environmental Studies	
Rev. R. Murray	1845 - 53
P.J. O'Donnell, B.Sc., Ph.D. (Glasgow)	1967 -
P.E. Pashler, B.A.Sc., Ph.D. (Toronto)	1946 - 50 res.
D.A.L. Paul, B.A. (Cambridge), Ph.D. (Queen's)	1964 -
W.R. Peltier, M.Sc., Ph.D. (Toronto)	1971 -
C.M. Penner, M.A. (Toronto)	1967 - 73
Department of Transport	
J.M. Perz, M.A. (Toronto), Ph.D. (Cambridge)	1965 -
A. Pitt, B.A. (Houghton)	1927 - 45 res.
J.D. Poll, Ph.D. (Toronto)	1960 - 70 res.
R. Potter, M.A. (Cambridge)	1843 - 45 res.
J.D. Prentice, M.Sc. (McGill), Ph.D. (Glasgow)	1959 -
M.A. Preston, C.D., M.A. (Toronto), Ph.D. (Birmingham) F.R.S.C.	1949 - 53 res.
R.E. Pugh, M.A. (B.C.), Ph.D. (Iowa)	1963 -
F.M. Quinlan, M.A., Ph.D. (Toronto)	1917 - 58 d.
R. Richmond, M.A., Ph.D. (Toronto)	1931 - 71 ret.
M.G. Rochester, M.A. (Toronto), Ph.D. (Utah)	1960 - 61 res.
R.C. Roeder, M.Sc. (McMaster), Ph.D. (Illinois)	1975 -
Also on the staff of the Department of Astronomy	
D.J. Rowe, M.A., D.Phil. (Oxford)	1968 -
Associate Chairman	1979 -
R.D. Russell, M.A., Ph.D. (Toronto)	1956 - 63 res.
J. Satterly, M.A., D.Sc. (London), F.R.S.C.	1912 - 49 ret.
J.C. Savage, B.S. (Arizona), Ph.D. (Cal Tech.)	1967 - 69 res.
G.D. Scott, M.A., Ph.D. (Toronto)	1949 -
Acting Chairman	1961 - 62
Associate Chairman	1962 - 68
Associate Dean of Science, Graduate Studies	

M. Silverman, B.Sc., M.D.C.M., (McGill), F.R.C.P. Also on the staff of the Faculty of Medicine	1975 -
H.G. Smith, M.B.E., M.A., Ph.D. (Toronto), F.R.S.C.	1935 - 49 res.
V. Soots, M.S. (Illinois), Ph.D. (Toronto)	1967 - 73 res.
N.R.F. Steenberg, M.Sc. (Queen's), D.Phil. (Oxford)	1954 - 73 ret.
G.I.A. Stegeman, M.Sc., Ph.D. (Toronto)	1970 - 80 res.
B.P. Stoicheff, M.A., Ph.D. (Toronto), F.R.S., F.R.S.C. Chairman of Engineering Science 1973 - 78 University Professor	1964 -
D.W. Strangway, M.A., Ph.D. (Toronto), F.R.S.C. Chairman of the Department of Geology	1968 -
J.C. Stryland, Ph.D. (Amsterdam)	1954 - 80 ret.
H.W. Taylor, B.A., Ph.D. (Manitoba)	1965 -
P.A. Taylor, B.A., Ph.D. (Bristol)	1969 - 70 res.
D.C. Tozer, Ph.D. (Cambridge)	1968 - 70 res.
L.E.H. Trainor, M.A., (Sask.), Ph.D. (Minnesota)	1963 -
M. Trefler, M.A., Ph.D. (Toronto)	1970 - 72 res.
H.M. van Driel, M.A., Ph.D. (Toronto)	1978 -
J. Van Kranendonk, Ph.D. (Amsterdam), F.R.S.C.	1958 -
S.H. Vosko, M.Sc. (McGill), Ph.D. (Carnegie Inst.)	1970 -
D.I. Wardle, B.A., Ph.D. (Cambridge)	1969 - 70 res.
M.B. Walker, B.Eng. (McGill), D.Phil. (Oxford)	1968 -
W.H. Watson, M.A. (Edin.), Ph.D. (Edin., Cambridge) F.R.S.C. Head of the Department	1950 - 62 res.
H.L. Welsh, O.C., M.A., Ph.D. (Toronto), D.Sc. (Windsor, Memorial), F.R.S., F.R.S.C. Chairman of the Department 1962 - 68	1934 - 78 ret.
G.F. West, M.A., Ph.D. (Toronto)	1962 -
E.C. West, M.Sc., Ph.D. (Wisconsin)	1966 - 72 res.
J.O. Wilhelm, O.B.E., B.Sc. (Sask.), M.A. (Toronto)	1932 - 48 res.
J.T. Wilson, C.C., O.B.E., Ph.D. (Princeton), Sc.D. (Cambridge, Franklin and Marshall), LL.D. (Carlton), D.Sc. (Western Ontario, Acadia, Memorial, McGill), D.Univ. (Calgary), F.R.S., F.R.S.C. Director General of the Ontario Science Centre Distinguished Lecturer, Physics and Geology Principal of Erindale College 1967 - 74	
B.H. Worsley, S.M. (M.I.T.), Ph.D. (Cambridge)	1960 - 66 res.
S.S.M. Wong, M.S. (Purdue), Ph.D. (Rochester)	1969 -
T.S. Yoon, M.Sc. (Seoul), Ph.D. (Illinois)	1969 -
D. York, B.A., D.Phil. (Oxford)	1962 -

APPENDIX 3

Ph.D. degrees in physics awarded in the year indicated.

1900 J.C. McLennan
1903 W.R. Carr
1910 E.F. Burton
1913 V.E. Pound
1918 H.F. Dawes
1919 R.C. Dearle
1920 K.H. Kingdon
1922 H.A. McTaggart
1923 R.J. Lang; W.W. Shaver; G.M. Shrum; J.F.T. Young
1925 D.S. Ainslie
1926 M.L. Rotenberg; H.G. Smith
1927 A.B. McLay; W.C.H. McQuarrie
1928 C.D. Niven
1929 E. Cohen; B.M.R. Deacon; J.H. McLeod
1931 E.J. Allin; A.M.I.A.W. Durnford
1932 C. Barnes; A.C. Burton; F.M. Quinlan
1933 J.M. Anderson; M. Annetts; H.D. Smith; R. Turnbull; J.F. Allen
1934 H.J.C. Ireton; R.W. McKay; A.C. Young
1935 A.M. Crooker; G.N. Patterson; F.G.A. Tarr
1936 S. Bateson; G.F. Clark; M.F. Crawford; S.M. Dockerty; L.B. Leppard; S. Levine; R. Richmond; L.G. Turnbull; H.L. Welsh
1937 J.M. Thomson
1938 E.O. Braaten; M.W. Johns; K.G. Mann; D.W.R. McKinley; L.T. Newman
1939 C-K Cheng; H.E. Johns; J.D. Leitch
1940 A.R. Clark; J. Convey; A. Prehus

- 1941 J. Hillier
 1943 L.H. Turl; J.H.L. Watson
 1946 S.G. Ellis; P.E. Pashler; M. Rubinoff; G.D. Scott
 1947 C.C. Gotlieb; W.L. Godson; J. Levinson; G.R. Love
 1948 E.B. MacNaughton; F.E.J. Sentfle; M.A. Thangaraj
 1949 D. Andrychuk; L.D. Armstrong; F.A. Grant; W.M. Gray;
 J.H. Harrold; J.N.P. Hume; A.F. Johnson; J. Kastner;
 F.M. Kelly; J.L. Locke; C.J. Moen; I. Paghis; A.L. Schawlow;
 H.O. Siegel; R.S. Sennett; H.D. Vasileff
 1950 F.W.C. Boswell; B.N. Brockhouse; J.A. Cowan; A.F. Dunn;
 J.K. Hurwitz; A.C. Lauriston; T.A. McLaughlan;
 D.E. McLennan; N. Olson; G.E. Reesor; S.V. Soanes;
 W.J. Staple; R. Thomas; B.P. Stoicheff
 1951 D.V. Anderson; C.B. Collins; D.J. Eckl; F.S. Grant;
 J.H. Hodgson; S.M. Karim; J. Katz; A.W. Love; S.Z. Mack;
 J.C.F. MacDonald; G.E. Noakes; J.E. Noakes; T.D. Northwood;
 P.H. Serson; H.A. Slack; B.H.J. Stallwood; K. Whitham;
 Kuo-Chang Wu
 1952 R.J. Allenby; J.E. Blanchard; D.A. Chisholm; C. Cumming;
 M.F. Duret; M.J.S. Innes; C.M. Mitchell; L.W. Morley;
 A.K. Mousuf; A. Pearson; P.J. Sandiford; G.E. StJohn;
 E.J. Stansbury; S.H. Ward; D.C. West
 1953 J.R. Bird; K. Buckthought; L.R. Dagg; M.H. Edwards;
 K.H. Hart; G. Luchak; C.A. Plint; R.A. Stasior; F.C. Stephenson
 1954 R.M. Farquhar; W.J. Heikkila; D.R. Lovejoy; P.N.S. O'Brien;
 C.H.J. Oldham; J. Romanko; R.D. Russell
 1955 R.A. Aziz; C.B. Benson; G.L. Cumming; J.R. Cunningham;
 T. Feldman; V. Gauzauskas; G.R. Hanes; W.F.J. Hare;
 L. Krause; N.R. Patterson; J. Shapiro; H.A. Shillibeer; A.W. Smith
 1956 D.W. Allan; B.C. Blevis; J.A. Galt; H.P. Gush; J.E. Hogg;
 P.J. Hood; A. Kavadas; P.M. Mathai; J.E. Marcoux; G.G. Shepherd
 1957 R.E. Barrington; G. Duwalo; R.E. MacDonald; T. Obayashi;
 J.R. Stevens; A.D.B. Woods
 1958 Satish Chandra; Chung Won Cho; K.M. Eisele; D.B. Fraser;
 J.A. Mair; M. Ozima; L.J. Vasek
 1959 S.S. Bhatnagar; F.E.J. Cariou; M.W. Dowley; W.E. Gravelle;
 J.L. Hunt; Z.J. Kiss; A.D. May; A.J. Nanassy; E.H. Richardson;
 R.C. Sharma; G.N. Srivastava; M.A. Thomas
 1960 R.G. Baker; J.N. Barry; A.I. Carswell; A. Landau;
 Cheng-Chuan Lim; J.P. Mitchell; R.A. Olafson; J.D. Poll;
 W.B. Reid; L.D. Skarsgard; K.C. Smith; D.W. Strangway; G.F. West

- 1961 R.L. Armstrong; N. Aspin; J.R. Burrows; R.M. Green; N. Madaiah;
 M.A. Mastoor; D.M.C. Sweeney
 1962 M.A. Chinnery; O.M. Mitchell; L.W. Oleksiuk; W.B. Sampson
 1963 A.F. El-Saharty; N.W. Gebbie; R.K. McConnell; P.P.M. Meincke;
 V.F. Sears; D.E. Smylie; V. Soots; W. Van Witzenburg;
 J.H.P. Watson; R.A. Williams
 1964 N. Deveraj; Y.Y. Lee; D.W. Lepard; V.K. Mohindra; N.A. Morgan;
 M.C. Robinson; G.K. Rodgers; A. Watanabe
 1965 A.N.D.H. Amisshah; M.J. Berry; D.R. Bosomworth; A. Crane;
 C.H. Fagerstroem; A.M. Forrest; H.S. Freedhoff; R.N. Gupta;
 A. Hayatsu; Karnail Singh Jammu; K.S. McCormick; A. Sattar;
 M.M. Shapiro; P. Taras
 1966 D.J. Dawson; E. Farrar; S.M. Hussain; R.J. Kriegler;
 R.M. Macintyre; C.P. Martel; O.A.D. Trojan; H.L. Pai;
 E.G. Rawson
 1967 S.M. Blumenfeld; J.C. Burford; L.E. Carlson; G.H.C. Clarke;
 D.W. Cooke; C.K. Eoll; J. Felsteiner; D.J. Goble; C.G. Gray;
 J.F. Hermance; K.P. Jackson; J.W. Purdy; P.H. Schuepp;
 D.E. Shaw; J.I. Strickland; E. Tward; G. Varghese
 1968 M.J. Clouter; L.A. Copley; D.J. Dunlop; T.A. Khan;
 A. Spector; G.C. Tabisz; M. Tresler; W.J. Wiesehahn;
 W.K.M. Wong; J.A. Wright
 1969 V.G. Cooper; V.M. Cowan; H. Ing; K.R. Jeffrey; A. Kudian;
 A. Lin; C.Y. Leung; A.K. McQuillan; G.I. Stegeman
 1970 E.T. Agard; G.L. Baker; A.K. Baksi; R.B. Charlton; H. Fast;
 H.C. Jamieson; T.F. Johnston; L.S. Kunar; E.C. Looi;
 R.G. Macdonald; A.R. McKellar; W.A. Murray; J. Noolandi;
 K.P.B. Thomson; R.S. Timsit; D.M. Whelpdale; Y. Yanase
 1971 P.L. Berenyi; P.M. Bronsfeld; A.M. Charlesworth; T.H. Gheung;
 T.L. Clark; P. Coodin; D.F. Cooke; J.A. Courtney; P.H. Curry;
 J. DeRemigis; V. Elaguppillai; B.K. Gupta; M.A. Goldstein;
 J.F. Harris; L.M. Hastie; R.F. Hernandez; J.P. Hodych;
 N.A. Kellar; J.K. Lewis; L. Mannik; E. Manoukian;
 J.A.J. Mathews; J.W. McTaggart; M.S. Milgram; I.O. Moen;
 M.A.R. Molla; K.G. Neave; R.R. Oyarzun; B.I. Pandit;
 W.R. Peltier; W.R.C. Prior; B. Singh; R.J. Turner
 1972 S.A. Boggs; W.R.L. Clements; J.A. Demers; M.K. Ghosh;
 D.M. Harrison; W.K. McClary; M. Meiners; C. Ngo-Trong;
 V.J. Novotny; G.J. Palacky; F.N.D.D. Pereira; D.W.O. Rogers;
 R.S. Schemenauer; W.F. Schiosser; R.B.G. Selvage;
 S.R. Shewchuk; V.G. Snell; R.D. Watts

- 1973 G.W. Berger; A.G. Brown; A.C. Chao; T.E. Clee; S. Gewurtz;
C.R. Girard; L.G. Haacke; L.C. Ho; J.D. Irish; B. Jaduszliver;
J.B. Kerr; S.I. Kogitz; P.R. Kry; R.D. Kurtz; J.J. Lajoie; P. Lee;
R.A. McLaren; J.D. McTaggart-Cowan; W.Y. Ing; G.W. Pearce;
H.V. Troutvetter; M. Wisniewska; T.P. Wong; S.F. Zeber
- 1974 M.A. Angadi; A.A. Ayad; W.R.J. Bassermann; I. Berka;
S.K. DeySarkar; W.T. Diamond; P. Dworkin-Charlesworth;
N. Gauthier; M.H. Hubert; N. Isgur; K. Kisman; D. Landheer;
A. Mao; S.E. Moore; S.K. Panda; R.L. Penner; J. Radzuik;
D.M. Spector; G. Tenti; K.A. Usiu; P. Vella; B. Weisman;
A.C.D. Wright; E. Zaremba
- 1975 R.C. Bennett; D.H. Boal; F. Donati; G.D. Enright; H.B. Geddes;
J-Y. Harnois; C. Martin; M. Miller; T. Ng; G.R. Olhoeft;
J.E. Sipe; R.A. Stuart; H. Van Driel; E.S. Vittoratos;
H.W. Willemsen
- 1976 R.P. Beukens; A. Buchnea; M.G. Donnelly; W. Egnatoff;
K.M. Hong; J.K. Jacobs; A. Koziar; G.D. Loughheed;
J.R. Mehaffey; D.G.C. McKeon; S.B. Nickerson; G. Rosensteel;
Tr. Vo-Van
- 1977 R. Allis; K.L. Buchan; P. Davis; J. Gillespie; M. Goddard;
W. Goruk; A. Hollinger; C. Kennedy; W.E. Kieser; G. Levman;
G.S. Lodha; T. Low; R.G.C. McElroy; J.R. Roositer; A. Sandorfi;
R.E. Stewart; P. Thomas; Th. Vo-Van; J. Wright
- 1978 P.M. Duncan; P. Goulet; P. Guishani; G.A. Gumbs; E.M. Haacke;
J. Higinbotham; W. Kalechstein; G. Kovacs; H. Kranz;
C. Lumsden; S. Luryi; H. Melling; J.R. Mernagh; C.L. Ong;
S.C. Rand; P. Savaria; H. Sharpe; S. Tanaka; B.A. Thomson;
J.Y. Woodworth
- 1979 O. Caporaletti; C.W. Cheng; L. Cheng; R. Egloff; R. Fedosejevs;
I.R. Fletcher; V. Ghaem-Maghani; E. Kostyk; G. Kunstatter;
K. Lamothe; K.L. Liu; D.K. Mak; J.D. Mintz; N. Rowell;
P. Stagg; L. Wilk; J. Wong
- 1980 M.E. Bailey; D.W. Buker; R.A. Cordery; J.A. Dankowych;
B.J. Garcia; R.G. Konuik; S.R. Kreitzman; D.S. Montgomery;
R.J-M. Normandin; D.J. Toms; J-S. Tsai; E. Weinberger;
R.A. Young.

APPENDIX 4

Number of graduate students in Physics and number of Ph.D. degrees awarded in the academic year indicated.

Year ending July 1	Number Graduate Students	Number Ph.D.'s Awarded
1900		1
1901		0
1902		0
1903		1
1904		0
1905		0
1906		0
1907		0
1908		0
1909	8	1
1910	8	0
1911	9	0
1912	7	0
1913	5	0
1914	4	1
1915	9	0
1916	11	0
1917	9	0
1918	9	1
1919	8	1
1920	14	1

Year ending July 1	Number Graduate Students	Number Ph.D.'s Awarded
1921	11	0
1922	17	1
1923	19	4
1924	7	0
1925	16	1
1926	16	2
1927	29	2
1928	18	1
1929		3
1930		0
1931		2
1932	18	3
1933	35	5
1934	35	3
1935	26	3
1936	30	9
1937	23	1
1938	36	6
1939	32	3
1940	35	3
1941	21	1
1942	12	0
1943	20	0
1944	0	0
1945	10	0
1946	26	4
1947	66	3
1948	65	4
1949	90	16
1950	77	14
1951	92	18
1952	44	15
1953	55	9
1954	48	7
1955	40	13
1956	39	10
1957	53	6

Year ending July 1	Number Graduate Students	Number Ph.D.'s Awarded
1958	45	7
1959	74	12
1960	77	13
1961	79	7
1962	72	4
1963	90	10
1964	102	8
1965	117	14
1966	94	9
1967	145	17
1968	175	10
1969	185	6
1970	181	17
1971	157	33
1972	171	18
1973	170	24
1974	158	24
1975	162	15
1976	160	13
1977	160	19
1978	146	20
1979	149	17
1980	151	13

 APPENDIX 5

Appendix 5

Below are listed the names of the speakers and the titles of the *H.L. Welsh Lectures* given in the years 1975 to 1980.

May 22 and 23, 1975

G. HERZBERG

National Research Council, Ottawa, Nobel Prize in Chemistry, 1971

Opening Remarks

A.L. SCHAWLOW

Stanford University

Lasers, Present and Future

M. TINKHAM

Harvard University

Studies in Superconductivity

J.A. JACOBS

University of Cambridge

Problems of the Earth's Deep Interior

J.L. LOCKE

National Research Council, Ottawa

Canada-France-Hawaii Telescope

Sir D. WILKINSON

Oxford University

What is the Nucleus made of

A. SALAM

International Centre for Theoretical Physics, Trieste

Unity of Matter and its Interactions

May 3, 4, and 5, 1976

C.N. YANG

State University of New York, Stony Brook,

Nobel Prize in Physics, 1957

Gauge Fields, Magnetic Monopoles and Fibre Bundles

75 Years of Equilibrium Statistical Mechanics

Speculation and Insight

R. HOFSTADTER

Stanford University, Nobel Prize in Physics, 1961

Laser Induced Fusion

The Validity of Quantum Electrodynamics

May 16, 17 and 18, 1977

C.H. TOWNES

University of California, Berkeley,

Nobel Prize in Physics, 1964

Molecules in Interstellar Clouds

Infrared Astronomical Spectroscopy

**Infrared Heterodyne Spatial Interferometry*

F. BLOCH

Stanford University, Nobel Prize, 1952

Josephson Effect in a Ring

Superfluidity in a Ring

**Density-and-Phase-Variables in Boson Systems*

May 15, 16 and 17, 1978

S.L. GLASHOW

Harvard University, Nobel Prize, 1979

Aesthetics and Elementary Particle Physics

On the Road to a Unified Theory

**Future Developments in Elementary Particle Physics*

W.M. FAIRBANK

Stanford University

Fundamental Physics Experiments

using Low Temperature Techniques

The Search for Fractional Charges

**Experiments on Freely Falling Electrons and*

a New Surface Shielding State in Copper

D.W. SCIAMA

Mount Holyoke College and Oxford University

The Present Status of Black Holes:

I Classical Black Holes; II Quantum Black Holes

**A Fluctuation Dissipation Theorem for Black Holes*

Physics at the University of Toronto, 1843-1980

May 7, 8 and 9, 1979

M.E. FISHER

Cornell University

Critical Points, Their Exponents and Scaling
Renormalization Groups - Concepts and Successes
 **Bicritical and Tricritical Points*

C.H. LLEWELLYN SMITH

Oxford University

Quarks and Leptons: Flavour, Colour and Gauge Symmetries:
I Facts; II Theories and Speculations
 **QCD Perturbation*

N.F. RAMSEY

Harvard University

Electric Dipole Moment of the Neutron
Magnetic Dipole Moment and Spin Rotations of the Neutron
 **Molecular Beam and Stored Atom Experiments*

May 5, 6 and 7, 1980

T. GOLD

Cornell University

Deep Earth Gas: Will it Resolve the Energy Crisis:
Lectures I and II

**Pulsars: The Most Intense Sources of Radiation*

W. KOHN

National Science Foundation Institute of Theoretical Physics
 Santa Barbara, California

Density Functional Theory: An Approach to the Structure of
Condensed Matter: Lectures I and II

**Different Ways of Thinking About Solid Surfaces*

R.R. HAERING

University of British Columbia

Recent Developments in Electrical Energy Storage
A New Canadian Super Battery

**The Physics of Intercalation Batteries*

SAU LAN WU

University of Wisconsin

*Probing the Gluon***Recent Results from Petra*

* Indicates specialized lectures given in the McLennan Laboratories. All others were of a more general nature and were given in the Medical Sciences Auditorium.