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About the Cover

The cover depicts an important episode in aerosol history—the Pasadena experiment and ACHEX. It includes a photograph of three of the key organizers and an illustration of a major concept of atmospheric aerosol particle size distribution. The photograph is from Chapter 8, Figure 1. The front row shows Kenneth Whitby, George Hidy, Sheldon Friedlander, and Peter Mueller; the back row shows Dale Lundgren and Josef Pich. The background figure is from Chapter 9, Figure 13, illustrating the trimodal atmospheric aerosol volume size distribution. This concept has been the basis of atmospheric aerosol research and regulation since the late 1970s.

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John A. McClelland

The Scientific Work and Legacy of a Physics Pioneer (1870–1920)

Thomas C. O'Connor

Introduction

John Alexander McClelland, FRS[1] (1870–1920) is remembered principally in the history of aerosol science for his pioneering work on the measurement of the mobility of ions in gases. As the professor of physics at University College Dublin from 1900 to 1920, McClelland also was an important figure in the development of science in Ireland, especially in experimental physics. Through the research school he established, he left a fruitful legacy of research on aerosols in Ireland that continues to the present day.

In 2005, the manuscript of an address entitled "The Scientific Work of the Late Professor M'Clelland" by John J. Nolan—who succeeded McClelland as the professor of physics in 1920—came to light and is of special interest to historians of science. (The address is reproduced in full, as a transcript, in Appendix A.) Nolan delivered this address as his inaugural lecture as president of the student Scientific Society at University College Dublin in 1920.

Although it includes a brief biography of McClelland, the address focuses primarily on McClelland's sterling, but tragically brief, academic career. The document is historically valuable as a nontechnical summary of McClelland's research achievements as seen through the eyes of an accomplished physicist who collaborated in much of McClelland's work and viewed it in light of

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1 Founded in 1660, the Royal Society is the national academy of sciences of the United Kingdom. Fellows of the Royal Society (FRS) are elected to the Royal Society by their peers who consider them to have made "a substantial contribution to the improvement of natural knowledge including mathematics, engineering science and medical science." The main criterion for election as a Fellow is scientific excellence.

the physics of the time. It also conveys Nolan's enthusiasm for his subject, his efforts to inspire students to appreciate the craft of research, and the excitement generated by the "new" physics emerging from the Cavendish Laboratory at Cambridge and elsewhere in the early 20th century. The address also provides a valuable assessment of McClelland as a teacher, as an administrator, as a leader in research, as a public servant on governmental committees and academic bodies, and as a person.

The influence of McClelland's work on the subsequent development of physics in Ireland, and on the physics of atmospheric aerosols in particular, was profound and long lasting. His scientific descendants continue to enhance the legacy of his life and work into the 21st century.

A Brief History of University Education in Ireland

Established in 1592, Trinity College of the University of Dublin continues as an independent university to the present day. In 1845, Sir Robert Peel's government in London set up the Queen's University of Ireland, with constituent colleges at Belfast, Cork, and Galway. In 1880, Queen's University of Ireland was replaced by the Royal University of Ireland, which was only an examining and degree-awarding body. It had substantial premises in Dublin at Earlsfort Terrace, with extensive laboratories that were used only for practical examinations a few times a year. The Royal University of Ireland also had Senior and Junior Fellows, selected from the academic staff of existing colleges, who could use the laboratory facilities to conduct their personal research at other times.

The three Queen's colleges and other denominational educational institutions around the country could prepare students to take the Royal University of Ireland examinations. Among the latter was University College Dublin, which had evolved from the Catholic University of Ireland established by John Henry Newman in 1854. The Irish Universities Act, 1908, abolished the Royal University of Ireland, transformed the Queen's College Belfast into the Queen's University Belfast, and established the National University of Ireland as a federal university, with constituent university colleges at Dublin, Cork, and Galway, as well as a recognized college at St. Patrick's College, Maynooth. McClelland, who studied as an undergraduate at Queen's College Galway, was closely associated with the Royal University of Ireland and taught at University College Dublin.

The Life of John A. McClelland

Born at Macosquin, near Coleraine in the north of Ireland on November 18, 1870, John Alexander McClelland was baptized on December 1. The youngest of 11 children, he was educated locally at the Coleraine Academical Institute. He entered Queen's College Galway in 1889 and had a distinguished academic career. In 1893, he was awarded a Master of Arts degree by the Royal University of Ireland, with first-class honors in mathematical physics and experimental physics, a gold medal, and a special prize of £60.

McClelland's first taste of research came in Galway with A. Anderson (1858–1936), the professor of natural philosophy there. He was awarded an 1851 Exhibition scholarship and spent time with Professor A. Schuster in Owens College Manchester before joining Professor J. J. Thomson at the Cavendish Laboratory at the end of 1895. He was able to follow E. Rutherford and J. S. Townsend in availing of the new scheme by which Cambridge University allowed graduates of other universities to pursue research within Cambridge. Among McClelland's fellow researchers at the Cavendish Laboratory were C. T. R. Wilson, who received a Nobel prize for his cloud chamber work; O. W. Richarson, who received a Nobel prize for his work on the thermionic effect; and P. Langevin and J. Zeleny, who were subsequently associated with mobility measurements in France and the United States, respectively.

In 1894, the Royal University of Ireland instituted Junior Fellowships, worth £200 per year for 4 years; and in 1895, McClelland won the award in natural philosophy in open competition. Consequently, he was able to extend his time at Cambridge, where he had more than 4 exciting and fruitful years of research before moving back to Ireland in 1900 to fill the Chair of Experimental Physics at University College Dublin.

In 1901, McClelland was appointed a Senior Fellow of the Royal University of Ireland and resumed his research on the ionization of gases and later on the properties of β-rays, making use of the university's laboratory facilities at Earlsfort Terrace. Beyond his laboratory work, he was deeply involved in debates on the dissolution of the Royal University of Ireland and the establishment of the independent federal National University of Ireland with constituent colleges at Dublin, Cork, and Galway in 1909. He also was active from 1912 onward, in the design and construction of the new University College Dublin building at Earlsfort Terrace, which included an extensive physics department with a lecture theater, laboratories, workshops, and research rooms. Despite his large teaching load and participation on many committees, McClelland succeeded, along with his graduate students, in establishing a flourishing school of research before his premature death on April 13, 1920.[2]

McClelland's considerable contributions to science did not pass unnoticed, especially his pioneering work on the conduction of electricity through gases and the atmosphere as well as the scattering of β rays. In 1901, he was elected as a Senior Fellow of the Royal University of Ireland, and in 1906 the University conferred on him a DSc *honoris causa* for distinguished original research. He became a member of the Royal Irish Academy in 1905 and served as its secretary from 1906 until his death in 1920. He was elected as a Fellow of the Royal Society (FRS) in 1909. Additionally, he received an honorary Doctorate of Science from the University of Dublin in 1917; and in 1918, the Royal Dublin Society awarded him the Boyle medal, its highest honor for scientific achievement. Moreover, McClelland was a member of the Council and Science Committee of the Royal Dublin Society beginning in 1907 and he published much of his early research in Dublin in the scientific transactions and proceedings of this society. He was a member of the Senate of the old Royal University of Ireland and that of the new National University of Ireland from its inception in 1909 until his death.

In July 1915, McClelland was appointed as the representative from Ireland on the first Advisory Council of the Committee of the UK Privy Council for Scientific and Industrial Research. This was a belated response from the UK government to the need to foster scientific research, especially by industry, to make up for the many technological deficiencies exposed during World War I. The Advisory Council set up standing committees for various industries, encouraged the formation of trade associations with their own research institutes, and initiated schemes for research fellowships and the support of individual research projects. This work involved multiple journeys by McClelland to London under uncomfortable and hazardous wartime conditions, which may have taken a toll on his health. An assessment of McClelland's contribution to scientific and technical education and applied research in Ireland, and the consequences of his untimely death on its development, must be left to another study.

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[2] A short biography of McClelland appears in *Physicists of Ireland, Passion and Precision* (O'Connor, 2003) and in *Its Part of What We Are* (Mollan, 2007).

McClelland's Scientific Work

In his address, Nolan summarized the main results of McClelland's investigations (see Appendix A). Additional details regarding McClelland's research can be garnered from the original papers referenced in Appendix B. As described in Nolan's address, McClelland's scientific work can be divided into three periods: the Cavendish Laboratory at Cambridge, the laboratories of the old Royal University of Ireland, and subsequently the laboratories at the new University College Dublin

The Cavendish Laboratory at Cambridge (1895–1900)

It is not surprising that McClelland's main field of research was the conduction of electricity through gases in general and the lower atmosphere in particular. His December 1895 arrival at the Cavendish Laboratory coincided with the discovery of X-rays. His first research assignment was to assist Professor J. J. Thomson in investigating the effect of X-rays on gases. In March 1896, the two scientists published a joint paper entitled "Leakage through Dielectrics Traversed by Roentgen Rays" (Thomson & McClelland, 1896) establishing most of the well-known features of X-ray activity in gases, such as a conductivity that did not obey Ohm's law but reached a saturation current. McClelland also used the conductivity of gases as a method for measuring X-rays and testing the absorbing power of different materials, and he demonstrated that X-rays were not homogeneous.

McClelland also began his well-known work on the ionization produced by flames, arcs, and incandescent bodies. This research is contained in three papers published between 1898 and 1902; however, the research was completed before he left Cambridge in 1900 to take up his position in Dublin. McClelland showed that the conductivity of flame gases was due to the presence of large numbers of positive and negative ions, and that the decrease in conductivity with time was due to the recombination of these ions. He devised a method for measuring the mobility of ions that became a standard for investigating ionization of any kind in gases. This is essentially an early description of what has since been called a large ion.

The Royal University of Ireland, Dublin (1901–1908)

McClelland found that the professorship of physics at University College Dublin, which was then a private institution, provided meager facilities for research. However, in 1901 he was appointed a Senior Fellow of the Royal

University of Ireland and was able to use its laboratories by working on his own. The ensuing years comprised great scientific activity for McClelland. He devoted all of his time outside of his lecturing duties to his experimental work. His first publication from Dublin on “Ionisation in Atmospheric Air” (McClelland, 1903) was significant, marking the beginning of the “Dublin School” of research on atmospheric electricity and aerosols.

He also persuaded the Royal Dublin Society to purchase some of the newly discovered radium, which he borrowed to conduct investigations of the emanation and penetrating radiation from it. His experiments succeeded in demonstrating that the emanation from radium had no electric charge. Then, examining the penetrating radiation from radium—now called γ-rays—he showed that they are akin to X-rays. He published six papers on his extensive investigations on the properties of β-rays and on secondary radiation from substances exposed to the radiation from radium. The citation for his election as a Fellow of the Royal Society in 1909 pointed out that “the line of work opened up in these papers has been taken up by many investigators” (Royal Society London, n.d.).

National University of Ireland, Dublin (1909–1920)

In December 1908, the National University of Ireland was established and the University College Dublin took over the premises and laboratories of the former Royal University of Ireland. This afforded McClelland the opportunity to take on postgraduate research students and to pursue his interest in atmospheric electricity and related topics. One of his first students was John J. Nolan. Together, they studied the electric charge on rain, which also was the topic of the last paper McClelland presented in January 1920.

With H. Kennedy, he investigated the large ions in the atmosphere. This work led to a series of investigations, in collaboration with Patrick J. Nolan (younger brother of J. J. Nolan) and other postgraduate students, into various sources of ions and whether these ions had characteristic mobilities or preferred sizes. A paper with J. J. McHenry on “Uncharged Nuclei Produced in Moist Air by Ultraviolet Light and Other Sources” was published after McClelland’s death (McClelland & McHenry, 1921). An investigation, with Rev. H. V. Gill, SJ, into “The Causes of Self-Ignition of Ether-Air Mixtures” also was published posthumously (McClelland & Gill, 1920). This latter research was undertaken with sponsorship from the Nobel Explosive

Company and may have been due to McClelland's work for the Board of Scientific and Industrial Research in London.

McClelland the Educator

Nolan's address provides some interesting insights into other aspects of McClelland's life and his views on education, which seem to have been strongly influenced by his experience at Cambridge. An important aspect of McClelland's legacy to university education in Ireland was his administrative work and contributions as a professor, serving as a member of the governing authority and of the senate of first the Royal University of Ireland and later the National University of Ireland.

In evidence to the Royal Commission on University Education in Ireland in 1901, McClelland expressed strong views about technical and scientific education in Ireland (McClelland, 1902), arguing that students should receive a general education in secondary schools and specialize earlier in their university education. He posited that 2 or at most 3 years of lectures and textbooks should qualify the honors student to begin 2 years of research for a Master's degree. For this to occur, he argued, the equipment must be amply sufficient and the staff sufficiently large. He compared Cambridge, where staff members might give three lectures per week, to colleges in Ireland, where staff often gave three lectures per day. McClelland was fortunate to have A. W. Conway, FRS, as a colleague and professor of mathematical physics to share the lecturing load.

Additionally, Nolan's address offers a unique, firsthand account of McClelland's excellence as a teacher of elementary and advanced classes. McClelland's interest in secondary education was demonstrated by his work as a governor of St. Andrew's College for boys in Dublin and his service from 1910 on the Board of Commissioners of National Education in Ireland. His interest in technical education and the use of science in support of industry led to his appointment in 1909 to the Board of Technical Instruction in the Department of Agriculture and Technical Instruction in Ireland. In 1915, he was appointed the representative from Ireland to the first Advisory Council of the Committee of the Privy Council for Scientific and Industrial Research in London, which was tasked with devising mechanisms to support industrial research.

McClelland the Man

McClelland also was a devoted family man. In 1901, he married Ina Esdale, and she and their five children survived him. He also was very popular with the students in the College and presided over many of their athletic clubs. He was always an elegant, tall, dark, and handsome figure, with a dark moustache and brown eyes. His friends, like C. T. R. Wilson in an obituary, remembered him as a quiet, strong, kindly, broad-minded man (Wilson, 1924). According to Nolan, all will remember him as "a great leader and a true and kind friend."

On April 7, 1920, in a letter to his eldest daughter Dorothy from his sick bed at home, McClelland wrote, "I had a very nasty heart attack nearly a week ago" and "I have finally promised to take a holiday until October and try to get really well. So there is a lazy time before me." Sadly, this was not to be, as he died 6 days later.

McClelland's Scientific Legacy

By the time of his death, McClelland had discovered a great deal about the mobility of large and small ions in air, some of the sources of such ions, and the mechanisms influencing the charge on the earth's surface. This line of research profoundly influenced physics research in Ireland in the 20th century. It was ably carried on by J. J. Nolan, his successor as professor of physics at University College Dublin until his death in 1952, and by his younger brother P. J. Nolan, who was an assistant in the Department of Physics in University College Dublin from 1920 and a lecturer in Physics there from 1929 until he became Professor of Geophysics in 1954. P. J. Nolan remained active for a considerable time after his official retirement from teaching in 1964. Combined, their work became known internationally as the Dublin School forAtmospheric Electricity and Aerosol Studies.

The main thrust of the work of the Nolan brothers and their students in University College Dublin in the 1920s and 1930s was on ionization equilibrium and the relationships of small and large ions in the lower atmosphere. They used an Aitken pocket nucleus counter to measure particle number concentrations. Their results were summarized by J. J. Nolan (Nolan, 1950).

An important development from this time was the diffusion box or battery method of measuring the size of aerosol particles (Nolan, J. J., & Guerrini, 1935; Nolan, J. J., et al., 1938). During World War II, the collaboration between P. J. Nolan and L. W. Pollak at University College Dublin led to the development and calibration of the photoelectric condensation nucleus counter (Nolan, P. J., & Pollak, 1946). This was a versatile and convenient aerosol particle counter that P. J. Nolan and his research students used for a variety of studies on aerosols. Pollak's interest in the application of the counters to meteorological studies led him to devote considerable time to refining the counter and its absolute calibration. P. J. Nolan's laboratory studies of ionization equilibrium in stored aerosols showed that the fraction of particles remaining uncharged depended on their mean size (Nolan, P. J., & Kennan, 1949). This led him to apply the Boltzmann energy distribution formula to this problem (Nolan, P. J., 1955).

P. J. Nolan introduced two interesting variations on McClelland's method of measuring the mobility of ions. The usual practice involved drawing the gas with the ions at a fixed rate through a concentric cylindrical condenser of fixed dimensions and measuring how the current to the central electrode varied with the potential difference between the electrodes. The mobility of the ions can be deduced from the resultant current/voltage curve. P. J. Nolan and P. J. Kenny (1952) modified McClelland's method by keeping the potential difference constant and varying the airflow, which yielded a current/airflow curve.

Another modification of the method—which was introduced by P. J. Nolan and J. P Deignan (1948)—when dealing with stored air and an approximately constant aerosol particle concentration was to measure with the photoelectric counter the concentration of particles emerging from the condenser or ion tube when various differences of potential were applied across the electrodes. Subtracting these concentrations from that when the potential difference was zero yields the number of particles or large ions captured by each potential difference. This is a measure of the current collected and enables what was called a nucleus/field curve to be plotted. This is more convenient to measure at low concentrations than the usual current/voltage curve.

McClelland's Academic Descendants

A part of McClelland's legacy is a tradition of aerosol research that grew into what might be termed an Irish School of Atmospheric Aerosol Science. From 1934 to 1973, the chairs of experimental physics at the National University of Ireland constituent colleges at Cork, Dublin, and Galway as well as the recognized college at Maynooth, were held by individuals who had done their initial postgraduate research in this branch of physics.

At University College Dublin, Professor J. J. Nolan was succeeded as professor of physics in 1953 by T. E. Nevin, whose M.Sc. thesis under Nolan was on "The Effect of Water Vapour on the Diffusion Coefficients and Mobilities of Ions in the Air," although his subsequent research was on molecular spectroscopy and cosmic rays until his retirement in 1979 (Nolan, J. J., & Nevin, 1930). Other members of the physics department staff who carried on this traditional line of research from the Nolans into the 21st century were Rev. T. P. Burke, J. A. Scott, and J. P. McLaughlin.

At St Patrick's College, Maynooth, Rev. P. J. McLaughlin from 1928 to 1957 and Rev. T. G. McGreevy from 1957 to 1982, both professors of physics, were involved in the area of atmospheric research.

At University College Cork, J. J. McHenry, who did his postgraduate work under McClelland and was for a time a lecturer at University College Galway, became professor of physics in 1934 and president of University College Cork in 1964. His successor, E. F. Fahy, professor of physics from 1964 to 1987, had done his MSc at University College Dublin with P. J. Nolan. Sean Twomey, who did his MSc under McHenry by conducting research on condensation nuclei produced by ultraviolet light (McHenry & Twomey, 1952), went on to a distinguished career in aerosol physics in Australia and the United States.

At University College Galway, C. O'Brolchain, who had done research for a MSc under P. J. Nolan at University College Dublin and a PhD under V. H. Hess in Graz, became professor of experimental physics in 1934. In 1956, he was joined by T. C. O'Connor who had done research for a MSc under P. J. Nolan in University College Dublin and subsequently worked under Professor L. W. Pollak in the Dublin Institute for Advanced Studies. With the material assistance of these two mentors, O'Connor expanded atmospheric aerosol research at University College Galway.

In 1958, taking advantage of Galway's location on the western coast of Europe, O'Connor established a small coastal research station at Mace Head, near Carna, County Galway, for the study of aerosols and trace gases in the marine atmosphere away from sources of man-made air pollution. With the help of graduate students A. F. Roddy, S. G. Jennings, M. A. Byrne, and C. D. O'Dowd, who all subsequently joined the staff of the department of physics, the Atmospheric Research Group in Galway grew and is now recognized internationally.

The research station at Mace Head expanded to become a global baseline site for the World Meteorological Organization's Global Atmosphere Watch (GAW) program and a "super site" of the European Monitoring and Evaluation Program (EMEP). It has hosted numerous international workshops, monitoring projects, and field campaigns on ocean-atmosphere exchange processes involving trace gases and aerosol particles. June 2008 marked 50 years of research at Mace Head (O'Connor et al., 2008). In recent years, these researches have made valuable contributions to international studies of the composition of the atmosphere and global climate change.

It is gratifying to know that John A. McClelland's scientific work, which began during his undergraduate days in Queen's College Galway more than a hundred years ago, is being carried on there by his scientific descendants into the 21st century. The continued growth of University College Dublin led to the department of physics moving in the 1960s from McClelland's building in the city center to new premises in the suburbs. Fortuitously, the manuscript of Nolan's address surfaced in 2005 during the clearance of an office and a laboratory, which marked a change of emphasis in research topics there after just over a hundred years.

Acknowledgments

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Appendix A

Transcript of J. J. Nolan's Address on "The Scientific Work of the Late Professor M'Clelland"

Notes

Biographical Note on the Author J. J. Nolan

John James Nolan was born near Omagh in the north of Ireland in 1888. He received his early education locally and was awarded a scholarship to University College Dublin. He graduated in 1909 and joined the teaching staff of the physics department a year later. He began his research career under McClelland by investigating the electric charge on rain. He continued with independent research on the electrification of splashing water and was awarded a D.Sc. by the National University of Ireland in 1917. After the unexpected death of McClelland in 1920, Nolan succeeded him as the professor of physics in University College Dublin and continued to lead research there on aerosols and atmospheric electricity.

Nolan was elected a member of the Royal Irish Academy in 1920 and served as its Secretary from 1923 to 1949, when he became its President for 3 years. He served as Registrar of University College Dublin from 1940 until his death. He collapsed and died while lecturing in April 1952.

Note on the Scientific Society in University College Dublin

The Scientific Society in the University College Dublin was founded by Professor McClelland in 1907. He was the president of the Society from its foundation and always took a keen interest in its activities. It was a student society aimed at the undergraduate and graduate students of the science faculty in the college and sought to promote an awareness of developments in science in general. The presidential address was usually a highlight of the year's program and was attended by members of the university staff, graduates, students, and the public. It was traditionally held in the large lecture theatre of the physics department that McClelland had planned and provided as part of his legacy to the college.

Editorial Note

The original version of this address is handwritten in blue-black ink on lined foolscap paper. There are 21 pages in total, but pages 1 and 2 appear twice, in draft and in a fair copy in black ink. This transcription is of the fair copy of pages 1 and 2. The rest of the manuscript is a first draft, with some corrections and additions in the margins. The corrections have been silently incorporated in this transcription, and the marginal additions appear in {curly brackets}.

In transcribing this address, the original punctuation and spelling have been retained as much as possible, such as the use of "M'Clelland" by Nolan rather than the more usual "McClelland," which is found in most official documents referring to him. Also the spelling "kathode" is preserved rather than the more common "cathode." Some obvious abbreviations and slips in grammar have also been retained.

Editorial interpolations appear in [square brackets], and are used mostly to clarify references that would be familiar to the original audience but not to modern readers. References to McClelland's research work are inserted in square brackets with R plus a number (e.g., [R1]), which refers to the list of his publications provided in Appendix B.

For words that were hard to decipher, a question mark (?) is inserted beside the most probable word.

The original address had been preserved, along with some copies of M.Sc. theses and other reports from the McClelland era, in the papers of J. J. Nolan's brother, P. J. Nolan. It then found its way into the papers of J. A. Scott, P. J. Nolan's successor at University College Dublin, and came to light in a clearance on Scott's retirement. It is our intention to preserve this address in an archive on atmospheric aerosols in the James Hardiman Library at the National University of Ireland Galway.

Text of John J. Nolan's Address

The Scientific Work of the Late Professor M'Clelland

It has seemed to me, as his successor in the chair of Experimental Physics in this College [University College Dublin, UCD], that the Presidential Address to the Scientific Society of this year, could not be other than a tribute to the scientific work of the late Professor M'Clelland. From its foundation Prof. M'Clelland was President of this Society. But he was much more than a nominal head—he was a continual support to the Society and a continual influence in its work. He aimed at making this Society a vital and an active expression of the scientific work of the College and he strove to keep it continually in touch with the scientific work of the day. But even that was only a small part of his work on behalf of science in this College. This building in which we meet today, these laboratories and research-rooms which you have seen, are a permanent expression of the devotion which he has given to scientific research. The thousands of students whom he taught and the smaller numbers of these whose footsteps he guided on the paths of scientific investigation will hold his memory in life-long reverence.

As one of his pupils—and very unworthy of his place in this College to which I have succeeded—it is not without great diffidence that I undertake to deal with his scientific work and endeavour to pay some tribute to the additions to knowledge which were the fruit of the all-too-brief twenty-five years which he devoted to Science. I think however, that it is safe to say that appreciation of his scientific work, is perhaps the one tribute that he would have cared for.

Prof. M'Clelland was educated at the Academical Institute, Coleraine and at Queen's College, Galway. In the year 1894 he went as a research student to Owens College Manchester {Schuster?} [i.e., Professor Arthur Schuster] where he remained for a year. In the following year, he went to Cambridge, joining that remarkable group of men whom J. J. Thomson had gathered around him in the Cavendish Laboratory, and who have had so much to do with the making of modern physics.

It is well at this stage that we should try to get an idea of the state of experimental physics in the year 1895 when M'Clelland began his work, for we shall find that a survey of his work is to a large extent a survey of the modern developments of physics.

At that time the idea was held by some, that the great exploring work of physical science was over—that nature had yielded most of her great secrets that were accessible to experiment—that the work of the scientific man henceforth must lie in the accurate quantitative examination of the known phenomena, the accurate surveying of the known ground. Extraordinary short sighted as we would consider this view at the present day—still it was held and expressed by some scientific men. {Stagnation?} Yet—say in the [18]80's—there was much development of great interest and importance. To take only two cases we have the remarkable work of Sir W. Crookes and others on electrical discharges in vacuum tubes and the experimental demonstration of electric waves by Hertz. The Crookes tube was later to be the key to unlock a great many mysteries. But as has been pointed at by Millikan the remarkable discovery of Hertz was to prove a hindrance rather than a help to the experimental physicist. For this reason. This brilliant experimental verification of the math. theory laid down many years before by Clerk Maxwell naturally turned men's minds to the ether rather than to matter. Electricity was something in the ether rather than something flowing along a wire. Now the ether is a singularly barren subject for experimental or indeed any other kind of research. How many years and how much effort did Lord Kelvin, greatest of the British physicists of his day, give in the search for a comprehensive theory of ether and matter in all their relations. Trying to picture matter as a state of the ether, he imagined atoms as vortices in the ether. Then we had elastic solid and all sorts of other ethers. Mendelieff even went so far as to attribute to it an atomic weight. Nowadays I'm afraid, the ether gets less respect from scientific men. I think one could almost tell the age of a scientific man from his attitude towards this once universally respected medium. As Eddington has pointed out recently we have ceased to endeavour to explain matter, by attributing the experimentally observed properties of matter to something which we assume to be non-matter. If (he says) physics evolves a theory of matter which explains some property it stultifies itself when it postulates that the same property exists (?----?) in the primitive basis of matter {see Eddington}

But just about the years 1894-5 a remarkable series of discoveries were made which were to prove the beginning of a grand experimental attack. The attack has not ceased nor even noticeably diminished in vigour even to the present day.

Thus in Aug. 1894 Lord Rayleigh announced the discovery of <u>argon</u>. In 1895 Roentgen discovered the X-rays. In 1896 Bequerel discovered the radioactivity of uranium. In 1896 Zeeman discovered the effect of a magnetic field on the nature [of] light emitted by a radiating body. In 1897-1898 J. J. Thomson discovered the electron or atom of electricity in the discharge tube, measured its velocity, its mass and its charge. Each of these discoveries may be said to have opened up a new world for investigation. Now as I have said M'Clelland went to Cambridge in 1896. He has told how going to Cambridge he read in the train an account of the discovery of X-rays. And in Cambridge he found, working under the direction of Prof. Thomson, a group of men who were to be the pioneers of the new physics. With Rutherford, Townsend,

C. T. R. Wilson, Langevin and others for the next five years he took his part in the great movement. It was an inspiring time when almost every day brought a new discovery—and each discov.[ery]of capital importance.

I will first deal therefore with this Cambridge period.

The first work undertaken by M'Clelland was the investigation of the effect of the newly discovered X-rays on gases. The results of this work were published in March 1896 [R1] and the paper is a remarkable one for in it we find practically all of the well known features of X-ray activity in gases dealt with. It was found of course that under the action of the X-rays the gas became electrically conducting. This conductivity was experimentally examined in an exhaustive way. The relative conductivity of diff.[erent] gases was tested, and of the same gas at diff.[erent] pressures, and at different temperatures. The important result was established that for this new kind of conductivity Ohm's law was not obeyed. Then again, using the conductivity of the gas as a method of measuring the X-rays experiments were carried out to locate the exact source of the radiation. In the same way the absorbing powers of different materials for X-rays was tested. The very important result was established that X-rays are not homogeneous i.e. a given thickness of material did not always absorb the same fraction of X-rays that fell on it [R2]. Now at the time, the method by which the conduction of electricity is carried on in a gas was not known. Shortly after it was shown that the current in a gas is conveyed by means of carriers or ions. These are minute bodies, of molecular size or thereabouts, carrying each a positive or negative charge of electricity. These are produced in the gas by the action of the X-rays and as was shown later by the radiation from radioactive bodies. The current is conveyed by the movement of these in the gas—the positively charged ones moving with the current and the negatively charged ones moving against it.

We see then that in his very first experiments M'Clelland was dealing with this question of gaseous ionisation to the knowledge of which he was later destined to contribute so much. And we see that, although at the time of his work the mechanism of the process was not known, still he elicited some of the cardinal features of the behaviour of ionised gases.

Now as so much of M'Clelland's work deals with ionisation I think it would be well at this stage to indicate the interest and the importance of the study of gaseous ions.

An ion is a very small particle of matter—a molecule or a small cluster of molecules, carrying an electric charge. Generally speaking each ion carries an atomic charge of electricity. By the aid of its charge we can experiment on it, set it in motion: because of its charge, we can recognise and follow and examine its motion. We can thus investigate the behaviour of matter in the minutest state of division under the simplest conditions. We are at the same time investigating the behaviour of the ultimate particles of electricity. We are not dealing with long-range phenomena; electricity or matter in the bulk, but with very intimate processes.

In the next year (1897) M'Clelland published two papers dealing with the character of the X-rays [R2] and with the Lenard and kathode rays [R3]. He extended his previous observations as to the absorption of X-rays by different substances and emphasises the non-homogeneous character of the X-rays. He showed that the non-homogeneity of the rays depended a good deal on the hardness of the tube. {Harder tubes give more non homogeneous rad.[iation]} {Lenard Rays. Explain.} In connection with the Lenard rays he showed experimentally that they were of the same nature as the kathode stream and he also investigated the fraction of the current in a discharge tube carried by the kathode rays.

In the following year he published an interesting paper dealing with the effect of electric discharges on photographic plates [R4]. And then began his well-known researches on the ionization produced by flames, arcs and incandescent metals. This work is contained in three papers published between 1898 and 1902, but was completed before he left Cambridge in 1900 [R5, R6, R7].

From a very early time it was known that flames and flame gases had conducting properties for electricity. Gilbert, Volta and Faraday all knew and made use of these properties. But while the phenomenon was well known and had been investigated by a multitude of experimenters during the nineteenth century, the nature of the action was not understood. M'Clelland's investigations cleared up the matter and gave a complete theory to account for the mechanism of this conductivity.

M'Clelland showed that the conductivity of flame gases was due to the fact that they contained large numbers of ions, that is carriers of electricity, positively and negatively charged. He investigated the way in which the ionisation decayed by the combining together of positives and negatives to form neutral groups. {conductivity decreased}. He devised a method to measure the mobility of these ions that is to say the velocity with which they move under a unit electric field. This method is now one of the standard methods for investigating ionisation of any kind. He showed from the results of his measurements that the ions in the flame gases are larger than those produced in air or other gases by X-rays or radium, and he found that they increased in size with the lapse of time. This increase with time he suggested was due to the water vapour condensing around the ion. This is really the first discovery of what has since been called the large ion. We distinguish between the small ion, which appears to be either a single molecule or a small cluster of molecules and which is apparently a stable entity and the large ion, which is a much larger group or cluster and which comes to a condition of stability or semi-stability under the operation of some different laws, not yet clearly understood. M'Clelland examined the ionisation produced by electric arcs and found that it was of the same character as that due to flames [R6]. He then made a very detailed examination of the ionisation produced by incandescent metals {thermions} and by working at low pressures was able to demonstrate the production of fresh ions by impact of ions already formed against neutral gas molecules [R7]. The whole question of the ionisation due to hot wires is now of the greatest practical importance. The modern use of thermionic valves in wireless work and in kindred technical processes which has led to such rapid and far reaching developments; owes much to M'Clelland's pioneer investigations.

In the year 1900 M'Clelland was appointed to the Professorship of Physics in University College [Dublin]. The years that followed were for M'Clelland years of great scientific activity. All the time that was free from his lecturing duties was devoted to his experimental work which was carried on in the laboratory of the Royal University. He began by an investigation into the ionisation of atmospheric, that is the natural, ionisation always found in the atmosphere [R8]. He devised a method of measuring this ionisation and examined its variation under different conditions. He found that it tended to reach a maximum after rain fall and suggested that some part of it at least was due to radioactive matter brought down by the rain. Then he undertook an investigation into the emanation and the penetrating radiation from radium. He succeeded in showing experimentally that the emanation of radium had no electric charge [R9]. {A result of great importance from the point of view of the theory of radioactive transformation.} Then examining the penetrating radiation from radium, called the γ rays, he showed that unlike the α and the β rays they carried no electric charge. He examined the law of their absorption by matter and suggested, what has since come to be held as the true view, that the γ radiations are akin to X-rays, that is to say that they are a wave motion like light, not a stream of charged particles like α and β- rays [R11].

The principal feature of M'Clelland's work during this period was the great investigation which he carried out on the secondary radiation from substances exposed to the radiations from radium [R12]. When the rays from radium are allowed to fall on any substance the substance itself begins to emit a radiation, of pretty much the same character, but of course less intense than that which has fallen on it [R13]. M'Clelland examined this secondary radiation from different substances and found the remarkable result that the intensity of the secondary rays was closely connected with the atomic weight of the substance and further that the manner in which the secondary radiation varied with the atomic weight depended upon the position of the substances in the periodic classification of the elements [R14]. It appeared therefore that the secondary radiation was an intimate atomic effect. This was in fact further shown by a series of experiments on compounds in which M'Clelland demonstrated that the secondary effect for a compound was the sum of the effects due to its atoms [R15]. It is usual nowadays to give the term "scattered radiation" to what M'Clelland termed "secondary radiation"; but as M'Clelland points out in one of his papers "whether the expelled particles (that is the high velocity electron stream of which the radiation consists) are original constituents of the atom, or incident particles absorbed by the atom and subsequently expelled does not really amount to any essential difference". Much work has been done on this subject by subsequent experimenters, but it cannot be said that they have added much to the results obtained by M'Clelland. In connection with this work investigations were also carried out on the mechanism of absorption of β rays by matter. A theory of this process was put forward by M'Clelland which has been the basis of further research into this difficult subject [R16, R17].

Meanwhile M'Clelland's work was winning for him wide spread recognition. In the year 1906 he became Secretary of the Royal Irish Academy and in 1909 he was elected to the Fellowship of the Royal Society. In 1908 he was nominated as member of the first Senate of the National University [of Ireland]. To the work of organising the newly established University and its Colleges he devoted much time and energy during these years. He was especially anxious as to facilities for research schools in science generally but especially in physics. In the old buildings of the Royal University he soon had several of his students at work, and those who were with him in these days will remember the keenness of his spirit and the enthusiasm with which he infected all who were associated with him. Meanwhile the plans for the new buildings were being thought about and here again he was urgent and anxious as to provision for research. This building with its laboratories and research rooms which grew up under his hands are a record of the devotion which he gave to his work.

We come now to deal with his scientific work of this—the third period—the period since the establishment of the National University. This work as we have said, was in part carried out in the old Royal University buildings—and later in the present new building. While of a very varied character, for the most part it has some connection with ionisation and atmospheric electricity. This was partly due to the fact that in recent years the possibility of work on the radioactive substances did not exist. M'Clelland's researches on radioactivity were carried out with some 50 mg of radium bromide which the Royal Dublin Society had purchased at his suggestion in the early days when radium was cheap. This radium he had on loan for a number of years but when the R.D. Society decided to establish a radium institute, for supplying radioactive preparations to medical practitioners the Society naturally called in the radium which it had lent to M'Clelland. One is tempted to enquire whether it is likely that these 50 mg of radium have done as much for medical science in the last few years as they did for physics in the hand of M'Clelland.

A cardinal problem in atmospheric electricity is the origin and maintenance of the electric charge on the earth's surface and in this connection it is of importance to know whether rain or snow have any electric charge and if so how much and of what sign. In the year 1911 satisfactory experimental data existed only for one region and that in the tropics. For Europe the results were contradictory and confusing. The question also had a wider bearing in connection with the mechanism of condensation and the ionisation of the atmosphere. M'Clelland set out to work on this point and the results obtained here in Dublin have had considerable part in clearing up the question [R18, R19]. M'Clelland's interest in this, as in other problems of atmospheric electricity was sustained for we find that in his last paper, he deals again with the electricity of rainfall [R27]. About the same time as the research on rain, he initiated an enquiry into the nature of the larger ions and other nuclei in the atmosphere. This work had a close bearing on his earlier work in Cambridge on flame gases. Perhaps I may be permitted to state here broadly the results of this work. It had been known for a considerable time that when condensation takes place in the atmosphere—that is when a cloud forms—the water condenses into tiny globules each forming round a nucleus. If there is no nucleus, there is no condensation. As to [the] nature of this nucleus, it was generally called "dust." Now what Prof. M'Clelland and Dr Kennedy showed was practically this: that these nuclei are not what we ordinarily call dust [R20]. They are particles of some sort most of them electrically charged, and all uniformly of the same size. They are produced by flames and fires principally and exist in many thousands per cubic inch of the air of cities. They are much less numerous in the pure air of the country. They must not be thought of as "dust." They are too small and too regular—they are the large ions. They play a very important part in many natural phenomena and the whole question of their origin and behaviour is of the greatest interest.

Many other kinds of ions were investigated by M'Clelland and his pupils, ions produced by the spraying and bubbling of liquids [R23, R25] and ions produced by the combustion of phosphorus [R26]. In all these processes it would seem that tiny fragments of matter are detached and acquire an electric charge in some way. The electric charge, as I pointed out already, enables us to manipulate them and to study their behaviour. Much knowledge has been gained in recent years by M'Clelland and his pupils of the behaviour of matter in these highly divided forms.

Other researches in this period deal with the photo-electric effect in leaves [R22], the conductivity of substances in thin layers [R21], the conductivity of liquid dielectrics and the ignition of ether-air mixtures [R28]. But I would like to mention especially a research carried out on frictional electricity. This the oldest in a sense the fundamental and certainly the least understood, effect in electricity had always presented enormous difficulties to the experimenter. It was difficult to obtain any experimental result which could be repeated with certainty. There was no firm ground anywhere, everything was baffling and disconcerting. To this difficult subject M'Clelland was able to make some valuable contributions [R24]. By a series of well planned experiments he succeeded in establishing certain relations between the electric charge produced by friction and the temperature, humidity and gaseous pressure of the medium. We cannot say that much is yet known about the nature of this phenomenon, but at least as the result of M'Clelland's work certain paths have been opened up which are bound to yield greater knowledge to future explorers.

We have now passed in review the contributions to scientific knowledge made by Prof. M'Clelland. We have dealt briefly with the fruitful work which naturally divided itself into three periods—the Cambridge period, the Royal University period and the last period which ended prematurely almost before his real work of building up a research school was properly begun. But in a review of his scientific work we should not consider him altogether as a research worker and as a leader in research; we should consider him also as a teacher. And as a teacher his gifts were very great; perhaps it was the same gift that made him great in both departments—a remarkable clarity of mind, a power of cutting away the unessential and the accidental and getting at the realities of phenomena. He was equally great as a lecturer to elementary and advanced classes. The many students who attended his elementary lectures will remember the clearness and simplicity of his exposition. It was characteristic of him that he preferred that in his elementary classes their should be no taking of notes; the understanding by the student of the thing itself was what he aimed at—not the imparting of formulae.

As a lecturer to advanced classes he was unequalled. Here his great powers of clear thinking, accurate reasoning and plain exposition were fully revealed. In the hands of some men nature is obscured by a mist of mathematical analysis: M'Clelland was always insistent on the physical realities. I do not mean that he rejected the fullest applications of mathematical reasoning—quite the contrary—but he was insistent throughout in the recognition of the physical meaning behind the mathematical symbol. He did not perplex his students by unexplained assumptions, sudden jumps of thought or a too facile treatment of real difficulties—everything was reasoned out fully, everything treated from the point of view of the explorer. He aimed at giving his students the research point of view and he liked to set them at an early stage at some original or quasi-original investigation. His point of view was that of the student, who has acquired the necessary fundamental knowledge and the necessary initiation into experimental methods, his own gain will be as great and the gain of knowledge in general will be greater if he works out something which is new rather than something merely routine.

From the consideration of M'Clelland as a teacher we are thus led back again to his aspect as a leader in research. And naturally so for the idea of research dominated all his teaching. M'Clelland was too great a teacher and devoted too much care and energy to the teaching side of his work for there to be any risk of misunderstanding if I say that he always held teaching to be secondary to research. Indeed I think it would be still more correct to say that he made research the first interest of his life.

It is interesting to note certain points about his direction of the research work of students. He much preferred to set a student making observations and measurements at once rather than let him spend much time in conning the results of previous workers. The time for that would come later—but he wished the experimental attack and the ideas that developed in connection with it to be fresh and uninfluenced by what had gone before. Then again he strenuously steered away students from wandering off on any of the inviting side issues that invariably present themselves in any piece of work. He expected from a student hard work and patience—just as he himself would give both to the solution of any problem and while never in any way damping the enthusiasm of youthful workers—his dominant note with them as throughout his own work was caution.

At the beginning I said that the review of M'Clelland's work is in a large degree a review of the newer physics of the last 25 years. We have dealt with his work on Kathode Rays, Lenard Rays and X-rays and then with his original studies in ionisation; later his researches into the radiations of radium. In recent years he had we may say founded a school of his own for the study of ionisation. But though in addition to that main interest many other enquiries were as I have shown, carried out with great success, still in practice, many lines of experiment were inaccessible. I have already shown how the loss of the radium closed one path: in the absence of a liquid air plant and of highly trained mechanical aid other lines of investigation are practically barred. But how many men with the most elaborate equipment have done as much for science as M'Clelland did with resources in some degree circumscribed? Indeed it was not altogether a disadvantage to him to have to contrive his experiments in a simple form. He had the same fondness for simplicity as say Stokes or Lord Rayleigh and something of the same powers of wresting from some simply contrived experiment important natural truths. If therefore he was precluded from any of the more "fashionable"—if I may use the word—types of research, perhaps the gain is all the greater. On the other hand good scientific work can not be done without reasonable facilities and the best work of any worker however able would be better done and done with far less toil if suitable resources were available. If the modern world is in any degree grateful for what science has given it or has any interest even the most utilitarian in the gaining of knowledge it should give its scientific men and indeed scholars of any sort a fairly free hand. All this is very close to the subject of my paper for M'Clelland's zeal for the encouragement of research was well known and much of the time and energy of his later years was given to work in connection with the Committee for Scientific and Industrial Research.

It is given to few men to leave so permanent a record of themselves as M'Clelland has left—not merely in the science of his day but in the scholarship of his country. To the great Irish theoretical physicists of the last century MacCullagh and Fitzgerald we may add his name as the first great experimental physicist. In the school which he created, as in the material fabric of laboratories which grew up under his inspiration he has made his place a permanency in this College and University. And in the minds of all associated with him as colleagues or as pupils he [his?] memory remains as that of a great leader and a true and kind friend.

Appendix B

Published Scientific Papers of John A. McClelland

R1 McClelland, J. A., & Thomson, J. J. (1896). On the leakage through dielectrics traversed by Roentgen rays. *Proceedings of the Cambridge Philosophical Society, 9,* 126–140.

R2 McClelland, J. A. (1897). Selective absorption of Roentgen rays. *Proceedings of the Royal Society of London, 60,* 146–148.

R3 McClelland, J. A. (1897). Cathode and Lenard rays. *Proceedings of the Royal Society, 61,* 522–525.

R4 McClelland, J. A. (1898). On the figures produced on photographic plates by electric discharges. *Proceedings of the Cambridge Philosophical Society, 9,* 522–525.

R5 McClelland, J. A. (1898). On the conductivity of hot gases from flames. *Philosophical Magazine, 46,* 29–42.

R6 McClelland, J. A. (1900). On the conductivity of gases from an arc and from incandescent metals. *Proceedings of the Cambridge Philosophical Society, 10,* 241–257.

R7 McClelland, J. A. (1902). On the action of incandescent metals in producing electric conductivity in gases. *Proceedings of the Cambridge Philosophical Society, 11,* 296–305.

R8 McClelland, J. A. (1903). Ionization in atmospheric air. *Scientific Transactions of the Royal Dublin Society, 8,* 57–64.

R9 McClelland, J. A. (1904). On the emanation given off by radium. *Transactions of the Royal Dublin Society, 8,* 89–94; also (1904). Philosophical Magazine, 7, 355–362.

R10 McClelland, J. A. (1904). The comparison of capacities: An application of radio-active substances. *Proceedings of the Royal Dublin Society, 10,* 167–177; also (1904). Philosophical Magazine, 7, 362–371.

R11 McClelland, J. A. (1904). The penetrating radium rays. *Transactions of the Royal Dublin Society, 8,* 99–108; also (1904). *Philosophical Magazine, 8,* 67–77.

R12 McClelland, J. A. (1905). On secondary radiation. *Transactions of the Royal Dublin Society, 8,* 169–182; also (1905). *Philosophical Magazine, 9,* 230–243; also (1905, February 23), *Note in Nature, 71,* 390.

R13 McClelland, J. A. (1905). On secondary radiation (Part II) and atomic structure. *Transactions of the Royal Dublin Society, 9,* 1–8.

R14 McClelland, J. A. (1906). The energy of secondary radiation. *Transactions of the Royal Dublin Society, 9,* 9–26.

R15 McClelland, J. A., & Hackett, F. E. (1906). Secondary radiation from compounds. *Transactions of the Royal Dublin Society, 9,* 27–36.

R16 McClelland, J. A., & Hackett, F. E. (1907). The absorption of β-radium rays by matter. *Transactions of the Royal Dublin Society, 9,* 37–50.

R17 McClelland, J. A. (1908). Secondary β-Rays. *Proceedings of the Royal Society, 80,* 501–515.

R18 McClelland, J. A., & Nolan, J. J. (1912). The electric charge on rain; Part I. *Proceedings of the Royal Irish Academy, 29 A,* 81–91; also (1912). La Radium, 9, 277–282.

R19 McClelland, J. A., & Nolan, J. J. (1912). The electric charge on rain. Part II. *Proceedings of the Royal Irish Academy, 30,* 61–71; also(1912). La Radium, 9, 421–426.

R20 McClelland, J. A., & Kennedy, H. (1912). The large ions in the atmosphere. *Proceedings of the Royal Irish Academy, 30,* 72–91; also (1913). La Radium, 10, 392-400.

R21 McClelland, J. A., & Dowling, J. J. (1915). The electrical conductivity of powders in thin layers. *Proceedings of the Royal Irish Academy, 32,* 51–58.

R22 McClelland, J. A., & Fitzgerald, R. (1916). Photo-electric discharge from leaves. *Proceedings of the Royal Irish Academy, 33,* 1–8.

R23 McClelland, J. A., & Nolan, P. J. (1916). The nature of the ions produced by bubbling air through mercury. *Proceedings of the Royal Irish Academy, 33,* 24–34.

R24 McClelland, J. A., & Power, C. J. (1918). Electrification by friction. *Proceedings of the Royal Irish Academy, 34,* 40–50.

R25 McClelland, J. A., & Nolan, P. J. (1918). The ions produced by bubbling air through alcohol. *Proceedings of the Royal Irish Academy, 34,* 51–61.

R26 McClelland, J. A., & Nolan, P. J. (1919). The nature of the ions produced by phosphorus. *Proceedings of the Royal Irish Academy, 35,* 1–12.

R27 McClelland, J. A., & Gilmore, A. (1920). Further observations of the electric charge on rain. P*roceedings of the Royal Dublin Society, 35,* 13–29.

R28 McClelland, J. A., & Gill, H. V. (1920). An investigation into the causes of the self-ignition of ether-air mixtures. *Proceedings of the Royal Dublin Society, 16,* 109–119.

R29 McClelland, J. A., & McHenry, J. J. (1921). Uncharged nuclei produced in moist air by ultra-violet light and other sources. *Proceedings of the Royal Dublin Society, 16,* 282–303.