NATIONAL ACADEMY OF SCIENCES

ARTHUR JEFFREY DEMPSTER

1886—1950

A Biographical Memoir by

SAMUEL KING ALLISON

Any opinions expressed in this memoir are those of the author(s) and do not necessarily reflect the views of the National Academy of Sciences.

Biographical Memoir

A. J. Dempster.

ARTHUR JEFFREY DEMPSTER*

1886–1950

BY SAMUEL KING ALLISON

Arthur Jeffrey Dempster, one of the outstanding physicists of our time and one of the most eminent of Canadian-born scientists, was born to a prosperous Scotch-Irish family in Toronto on August 14, 1886. His parents were James and Emily (Cheney) Dempster. His scientific career extended from 1911 (the date of his first paper) to almost the day of his death, March 11, 1950. It may be called almost a linear career; for he devoted himself almost exclusively to a single task, which was the discovery of stable isotopes of the chemical elements and the measurement of their relative abundances. He discovered a greater number of stable isotopes than anyone else except the man who opened this field of research, F. W. Aston. This is a distinction which his name is almost certain to retain for all time.

A yellowed page of a Toronto daily newspaper of 1904, preserved by his family, shows that in his teens he won either first or second rank in competitions for scholarships in almost every field of human knowledge. This is the first published evidence of his extraordinary breadth of interest, which was to remain one of his characteristics till the end. He attended the University of Toronto, obtaining the A.B. in 1909 and the M.A. in 1910. His earliest scientific publication seems to be a discussion of Darwin's tidal theory published in the *Journal of the Royal Astronomical Society of Canada* in 1911. This brief venture into geophysics was not repeated, and in his very next paper, "On the Mobility of Ions in Air at High Pressures," in the *Physical Review* for 1912, we find him embarking on the type of problem which broadened into his life work. Dempster used to tell an amusing story about his second paper. He had expressed the independent variable—pressure

*I have drawn very heavily for this biography on a Biographical Memoir prepared by Dr. Karl K. Darrow, sometimes quoting whole passages verbatim. . . SKA of the air—in atmospheres to three or four significant figures, amply accurate for the purpose. His professor told him to convert these values into centimeters of mercury. Being about to leave for Europe, Dempster delegated this task to a fellow-student. The student converted the values and expressed them to *six* significant figures, and in this form they still stand in *Physical Review.*

In 1911 Dempster went to Germany for a sojourn of three years; he was one of the "1851 Exhibition Scholars," so many of whom have imprinted their names on the history of science. He went first to the Universities of Munich and Göttingen for a semester each, then to the University of Würzburg for two years. One would like to know why he chose Würzburg, for this was the decision which determined his whole career. The professor of physics at Würzburg, W. Wien, was engaged in researches which involved the deflection of beams of positive ions by electric and magnetic fields. This was precisely the technique suited to the separation of isotopes, though Wien was using it for the study of electrical discharges in gases, and so did Dempster in the work which was to have been his doctor's thesis. It was not to be his thesis, for Dempster's stay in Germany was suddenly terminated by the tragic first of August of 1914. A British subject, he was in imminent danger of arrest and internment; prudently he fled from Würzburg by the last train which carried civilians before the general mobilization. Another Canadian student made the opposite choice, and spent more than four years in the internment camp at Ruhleben.

Dempster thus found himself forced to recommence his progress toward the doctorate; and for this purpose he chose the University of Chicago. Here he arrived at the opening of the autumn quarter of 1914. It was immediately obvious that here was an outstanding man; and nobody was surprised when in 1916 the University conferred on him the doctorate with the grade *summa cum laude,* which was granted to only one other student of physics throughout the thirty years before the University abandoned the practice of giving gradations with the doctorate. After a period of service in the United

States Army during World War I, which involved his naturalization as a citizen of the United States, he returned to the University of Chicago in 1919 as Assistant Professor of Physics. He was happy at the University of Chicago, and the University was happy in having him; and from 1919 onward he never left it, except for vacations, one summer quarter in which he taught at Stanford University, and once in 1941, when he was briefly engaged in "classified" work at Washington.

In his new appointment at Chicago, Dempster immediately began a series of researches in physics which demonstrated his mastery of experimental technique and his acumen in selecting important problems for study. One may summarize his entire field by saying that practically every experiment performed by him involved a study of the properties of positive rays, or canal rays as they were known at the time he began his work. These are positively charged atoms or molecules set into motion at high speed through the application of electric fields, causing them to appear as a pencil or ray, often faintly luminous, moving through the residual gas in a vacuum. These beams, which normally move in straight lines, can be deviated or deflected by electrical or magnetic methods. The constituents of the beam having heavy mass are in general less easy to deflect than the lighter mass constituents, and thus the deviated beam will separate out into many smaller beams, each representing one of the masses in the original. The analysis of the constituents of a positive ray beam is known as mass spectroscopy, and this particular application of positive rays constituted Dr. Dempster's major effort.

The immediate precursor of the modern mass-spectrograph was the production of the so-called positive ray parabolas by J. J. Thomson in 1913. In this technique, positive rays from a partially evacuated vessel in which an electric glow discharge is taking place leave through a small cylindrical canal in the anode. After leaving the anode, they enter a second vessel at somewhat lower pressure, and pass through an electric field on which a magnetic field is superimposed, the lines of force of the two fields being parallel. The electric and magnetic deflections, thus produced, are at right angles, and inversely proportional to, the energy and to the momentum of a single particle in the canal ray beam. On a photographic plate placed in a plane perpendicular to the axis of the canal, the ions of equal mass are spread into a parabola, and the Cartesian coordinates of any point in the curve give the energy and momentum of the particles which produced the developable image there. Thomson easily observed parabolas due to hydrogen, both atomic and molecular, to carbon monoxide and dioxide, and to mercury. In his classical experiment with natural neon, of atomic weight 20.183, he observed two closely spaced parabolas corresponding to masses 20 and 22, and drew the correct conclusion that natural neon is a mixture of isotopes each having very closely integral atomic weights.

This capital discovery must have stimulated Dempster's mind as it did all those who heard of it and who could appreciate its importance. It is small wonder that Dempster, beginning his career at this time, was attracted to this field. Dempster brought with him a formidable array of talents, some of which may be analyzed as follows:

(1) He had a scholarly interest in physics which led him to read widely and become well oriented in the subject, thus being able to bring various fields of physics to bear upon any problem at hand.
(2) He had an unusual technical ability in the laboratory. He delighted in devising mechanisms and instruments and showed considerable skill in what may be termed scientific invention. In too many cases, this type of ability is not associated with profound scholarship and it is in the combination of these that Dempster excelled.
(3) His intelligence and foresight directed him toward the really important problems and thus he did not dissipate his time and energy on scientific trivia.

The impact of these qualities on the problems of mass spectroscopy was apparent as soon as he entered the field. He saw that J. J. Thomson's original device could be specialized into a true mass-spectrograph, having as its purpose the analysis of an ion beam into the various masses of which it was composed. The parabolas gave more information than was called for; they gave both mass and energy distribution. Furthermore, they did this at the expense of intensity. If one wished merely to establish what masses were present, why distribute the particles of that mass out along a parabola; why not bring all particles of the same mass to a single position?

Actually, the improvement was carried out in two different ways, independently, by F. W. Aston, and by Dempster. Aston crossed the lines of force of the electric and magnetic fields at right angles, and applied them at successive positions in the path of the beam, rather than coincidentally. In this way he attained the result that all particles of the same mass and charge are brought to the same position on the photographic plate irrespective (within limits) of the velocity with which they emerge from the source. However, care must be taken that a beam of ions parallel in direction must be chosen for the analysis. The obvious description of this is velocity-focusing.

Dempster's scheme could properly be described as direction focusing. Here the long canal necessary to select for transmission and analysis only those positive rays traveling in an approximately parallel bundle can be dispensed with, and a divergent bundle of rays accepted, provided they are approximately mono-energetic. Dempster achieved the direction focusing by use of a homogeneous magnetic field which was constant over the region in which the ions were deflected, and by placing the defining entrance aperture and the detector 180° apart on the circular ion path. Instead of the conventional gas discharge as a source of ions, Dempster evaporated a solid deposit of the material to be analyzed from a platinum filament, producing ions by a concomitant electron bombardment. The production of the ions, and their acceleration, was carried out in relatively high vacuum, so that the desired homogeneity in energy was attained.

In this work, the innovation in the type of ion source was fully as important as the introduction of direction focusing to positive ray analysis. The gas discharge type of ion source was necessarily limited to those materials which could be prepared in gaseous form. Dempster was able to extend his researches to solid sources, and it was due to his use of such solids that he was able, seventeen years later, to make his most important single isotopic discovery, that of U 235. He at once applied his new method of analysis to the study of lithium and magnesium, both difficult to prepare in gaseous compounds. He later made the first isotopic analyses of platinum, palladium, iridium and gold.

Many modern mass spectrographs contain both direction and velocity focusing, and Dempster was in the forefront of those constructing such instruments. Actually, in the period 1933-35 three double focusing spectrographs were in independent construction in three different laboratories. In 1935 Dempster was the first to publish the description of such a completed instrument. The double focusing was attained by the use of a cylindrical electrostatic field, for direction, and a subsequent magnetic field, which, if properly adjusted, gives velocity focusing. The mass lines were very sharp and developable images could be made with brief exposures. It was characteristic of Dempster that with this instrument, completed in 1935, he explored exhaustively the remainder of the periodic system, and was working with it at the time of his death. Others took up the new principles which he had helped to introduce, and constructed larger and more elaborate instruments, but he kept to his 1935 machine and extracted from it every bit of information which time allowed him.

Improvements in the source of the ions, however, were always underway. In the early 1920's, Professor R. A. Millikan, who was then on the faculty at Chicago, developed a "hot spark" light source for the enhancement of spectrum lines in the far ultraviolet. These lines arise from highly ionized, or "stripped" atoms, and Dempster was interested in the deflection of such multiply charged ions. His source development paralleled that of Millikan's, and the two stimulated each other. Dempster made exceptionally skillful use of the multiply charged ions of the heavier elements in his work on packing fractions from which the energy content of nuclei can be deduced.

In 1938 Dempster published probably his most important single paper, in which he summarized his results and those of others into a discussion of "The Energy Content of the Heavy Nuclei." He showed clearly that the energy content per nucleon rose in the heavier elements, after passing through a minimum in the region near iron. This was made clear by the use of the multiply charged ions previously mentioned. For instance, if the masses of tin 119 and uranium 238 were exactly integral, the line for doubly charged U 238 should, in a mass spectrograph, coincide exactly with singly charged Sn 119. The fact that the lines do not, in fact, coincide enabled Dempster to supply the data which predicts the energy released when a heavy nucleus, like uranium, divides into two lighter nuclei of approximately half its weight. This is the process we call fission. Although he did not go so far as to predict the phenomenon of fission (and neither did any other physicist at that time), it was Dempster's result which showed that 196 million electron volts of energy per uranium nucleus would be given off in such a dissociation. This of course greatly enhanced the interest in the discovery.

When the so-called "Metallurgical Project" for the development of the military applications of atomic energy came to the University of Chicago, Professor Dempster's laboratory was immediately incorporated in the effort. The importance of the work was such that he was given financial assistance and experimental equipment such as had not been previously available. His joy at the new opportunities, which were continued in the postwar Argonne National Laboratory, was obvious. He remained on leave of absence from the department of physics until the time of his death, and worked every day in his laboratory. One of the many experiments he performed in later years was the detection of the isotope of cadmium which is responsible for the huge neutron absorbing power of the natural material. Cadmium which had been exposed to enormous neutron concentrations in the chain-reacting piles was furnished him, and his mass spectrograph showed at once which of the many isotopes had been transformed by the absorption of neutrons. Similar experiments were performed to detect the neutron-absorbing isotopes of samarium and gadolinium. These beautiful results have already appeared as illustrative material in textbooks on nuclear physics and will be so used for many years.

Although Dempster will be remembered chiefly as an expert in the field of mass-spectroscopy, his researches and his scholarly interests in physics had broader horizons. In an estimate of his own work, which he prepared in 1945 in connection with the honorary degree of D.Sc. which the University of Toronto awarded him shortly thereafter, he lists six other fields of investigation to which he made contributions. These were:

(1) The mobility of ions in air at high pressure
(2) The broadening of spectrum lines by pressure of helium gas
(3) The ionization products formed in gases by pure electron impact
(4) The light excited and emitted by positive ions of various energies
(5) Radiation processes and interference of single light quanta
(6) The passage of protons and other ions through helium gas.

Looked at in retrospect, however, we see that these researches were either digressions from the main path, or preliminary researches before he became engrossed in mass-spectroscopy. None of them was ever pushed far enough to result in a major contribution. In 1929 he spent considerable time investigating the reflection of a proton beam by calcite and other crystals when the beam fell on a cleaved face at a very small glancing angle. In some of his early experiments, a pattern appeared in the beam leaving the crystal face, and he cautiously advanced the suggestion that it might be a diffraction pattern, and might be direct evidence that the motion of protons is governed by quantum, rather than classical, mechanics. The experiments of Davisson and Germer, showing a similar effect for electrons, had been published two years previously. Further experiments, however, showed that the patterns were complex and varied from crystal to crystal. He finally abandoned this work, after convincing himself that no simple explanation, based on diffraction, was possible.

Professor Dempster's contributions to physics were recognized by many honorary awards. He was elected to the National Academy of Sciences in 1937. In 1932 he was made a member of the American Philosophical Society, which conferred on him its Lewis Award and its Glasham Gold Medal, to his great pleasure. In 1944, be became President of the American Physical Society. His own university, Toronto, conferred on him the honorary degree of D.Sc. in 1947, an occasion which was attended and enjoyed by his many relatives in that city. At the time of his death he was Professor of Physics in the Division of the Physical Sciences of the University of Chicago, and Director of the Argonne National Laboratory's Division of Mass Spectroscopy and Crystallography.

Although until his participation in the national effort on atomic energy he regularly taught classes in the standard subjects of physics, he never became at ease in the classroom or on the lecture platform. He did not have the gift of smoothness and lucidity in verbal presentation, and he was himself well aware of this lack. He set very high standards of scholarship for himself, and respected and admired high scholarship and intellectual activity in others. He had a keen interest in University affairs and strong opinions concerning them, especially the role of the faculty in University administration. He was sure that the faculty, and only the faculty, was the competent judge of fitness for University appointments. These opinions were fearlessly maintained and vigorously advocated. Experience at Chicago and in other universities has shown that continuous presentation of this point of view is beneficial in maintaining the principle involved.

In his private life, outside his laboratory and his classroom, he was a man with a very small circle of intimate friends. During his visit to Stanford University, in 1923, he met Germaine Collette, a Belgian scholar from the University of Liege, who was studying medieval literature at Stanford. Their friendship resulted in marriage in 1926. His wife, the holder of Ph.D. degrees from Liege and Stanford, continued her career beside him and has become an outstanding contributor to Chaucerian criticism. Her researches never failed to arouse the sympathetic interest of her husband, who greatly admired and appreciated her work.

Dempster was widely read in the fields of economics and philosophy and had a lively interest in the history of science. He and his wife enjoyed travelling and spent many of his free periods on trips which most often included the countries of continental Europe, but were also extended to Mexico, Egypt, and Guatemala. His comments on the political economy and customs of the countries visited in his travels were eagerly awaited by his friends. In between his longer trips he was fond of shorter excursions from Chicago, always into places where he could walk in the open country. Some of his haunts were Saugatuck, Michigan and the Great Smoky Mountains National Park.

In politics he was staunchly conservative. He was never dismayed to find himself holding opinions widely at variance with those of most of his professional colleagues. Surprisingly enough, he took no objection to, and even approved of, the rigid secrecy imposed by the Government on certain wartime and postwar researches, at a time when many scientists were outraged at what seemed to them the excesses to which the security program was being pushed. When on leave from the University and conducting his researches under the auspices of the Argonne National Laboratory of the Atomic Energy Commission, he was asked whether he would be willing to continue research, granted the very favorable conditions which the Argonne Laboratory was able to offer, but contingent on the stipulation that none of his work would ever be published to the world at large, he answered vigorously in the affirmative.

Physically, Dempster was of medium stature, slender, black-haired, and of finely chiseled features which an artist would have been glad to adopt as the embodiment of the intellectual man. His hands were large, and well and sensitively formed. His appearance and alert demeanor changed little with the years, and he died essentially a young man. His first attack of coronary thrombosis, occurring in June 1948, compelled him to a careful and restricted mode of life; and surely there was never a patient who so meticulously followed the advice of his physicians. The second and final attack was fortunately brief in duration. It occurred on a vacation in Florida and his friends have all seen photographs taken the day before the end, showing him at ease in his informal clothes, enjoying the warm sun and balmy air at a modest outing-place there.

His marriage did not result in children. His wife, surviving him, continues her scholarly career. The National Academy lost in him one of its ablest and most respected members.

KEY TO ABBREVIATIONS

Amer. Jour. Phys. = American Journal of Physics.
Astrophys. Jour. = Astrophysical Journal.
Bull. Amer. Phys. Soc. = Bulletin, American Physical Society.
Jour. Roy. Astron. Soc. Can. = Journal, Royal Astronomical Society of Canada.
Philos. Mag. = Philosophical Magazine.
Phys. Rev. = Physical Review.
Phys. Zeit. = Physikalische Zeitschrift.
Proc. Amer. Philos. Soc. = Proceedings, American Philosophical Society
Proc. Nat. Acad. Sci. = Proceedings, National Academy of Sciences.
Rev. Mod. Phys. = Review of Modern Physics.
R. S. I. = Review of Scientific Instruments.
Sci. Mo. = Scientific Monthly.

BIBLIOGRAPHY

1911

Darwin's Tidal Theory. Jour. Roy. Astron. Soc. Can., May-June.

1912

On the Mobility of Ions in Air at High Pressures. Phys. Rev., XXIV, *1*.

1914

Über Die Theorie Der Schwarzen Strahlung. (Sonderdruck aus der Physikalischen Zeitschrift, Verlag von S. Hirzel in Leipzig). Phys. Zeit., *15*, 694-659. Überreicht vom Verfasser.

1915

Über die Breite von Spektrallinien. Überreicht vom Verfasser. Leipzig. Separat-Abdruck aus den Annalen der Physik, Vierte Folge, *47*, 791.

1916

The Ionization and Dissociation of Hydrogen Molecules and the Formation of H_3. Philos. Mag., *31*, 438-443.
The Light Excitation by Slow Positive and Neutral Particles. Proc. Nat. Acad. Sci., *2*, 374.
The Properties of Slow Canal Rays. Phys. Rev., N. S., *8*, No. 6.

1918

A New Method of Positive Ray Analysis. Phys. Rev., N. S., *11*, 316.

1920

Duration of Light Emission from a Radiating Hydrogen Atom. Phys. Rev., *15*, 138-139.

1921

Positive Ray Analysis of Magnesium. Proc. Nat. Acad. Sci., *7,* 45.
Positive Ray Analysis of Lithium and Magnesium. Phys. Rev., N. S., *18,* 415-422.

1922

Positive Ray Analysis of Potassium, Calcium and Zinc. Phys. Rev., N. S., *20,* 631-638.

1923

Duration of the Process of Light Emission in Hydrogen. Astrophys. Jour., *57,* 193.

1924

Determining Factors in the Life of Metastable Helium. Astrophys. Jour., *59,* 142.

1925

The Passage of Slow Canal Rays Through Hydrogen. Proc. Nat. Acad. Sci., *11,* 552.

1926

The Free Path of Protons in Helium. Proc. Nat. Acad. Sci., *12,* 96.

1927

The Passage of Positively-charged Particles through Helium. Philos. Mag., *3,* 115.
(With H. Batho.) Light Quanta and Interference. Phys. Rev., *30,* 644.

1929

Reflection of Protons from Crystals. Phys. Rev., *34,* 1493.
Paths of Charged Particles in Electric and Magnetic Fields. Phys. Rev., *33,* 1019-1022.

1930

Reflection of Positive Ions by Crystals. Phys. Rev., *35,* 1405.

1932

(With H. Batho.) Doppler Effects in Hydrogen Canal Rays of Uniform Energies. Astrophys. Jour., *75,* No. 1.

1933

(With R. Holzer.) Light Excitation in Neon by Lithium Ions. Phys. Rev., *43,* No. 5.

1934

An Automatic Wilson Cloud Chamber of Simple Design. R. S. I., *5,* 159.
The Emission of Ions and Electrons from Heated Sources. Phys. Rev., *46,* 165.
Sparking Potentials at Low Pressures. Phys. Rev., *46,* 728.

1935

A Table of Nuclear Transformations. R. S. I., *6,* 62.

New Methods in Mass Spectroscopy. (Read in part Apr. 20, 1935.) Investigation supported by grant from Penrose Fund of the American Philosophical Society.

New Ion Sources for Mass Spectroscopy. Nature, *542,* 135.

Isotopic Constitution of Platinum and Rhodium. Nature, *993,* 135.

Isotopic Constitution of Palladium and Gold. Nature, *65.*

Isotopic Constitution of Uranium. Nature, *180.*

Isotopic Structure of Iridium. Nature, *909.*

1936

Atomic Masses of U and Th. Nature, *138,* 120.

Mass Equivalent of the Energy in Radioactive Transformations. Nature, *138,* 201.

Further Experiments on Mass Analysis. Proc. Amer. Philos. Soc., *76,* 491-497.

New Methods in Mass Spectroscopy. Phys. Rev., *75,* 755.

Ion Sources for Mass Spectroscopy. R. S. I., *7,* 47.

The Isotopic Constitution of Barium and Cerium. Phys. Rev., *49,* 947.

The Isotopic Constitution of Iron and Nickel. Phys. Rev., *50,* 98.

The Isotopic Constitution of Strontium and Tellurium. Phys. Rev., *50,* 186.

1937

Isotopic Constitution of Neodymium. Phys. Rev., *51,* 289.

The Isotopic Constitution of Tungsten. Phys. Rev. *52,* 1074.

1938

Atomic Masses of the Heavy Elements. Phys. Rev. *53,* 64.

The Isotopic Constitution of Gd, Dy, Er, and Yb. Phys. Rev., *53,* *727.*

The Energy Content of the Heavy Nuclei. Phys. Rev. *53,* 869.

1939

The Doppler Effect and Field Distribution in the Hailer Canal-Ray Tube. Phys. Rev., *55,* 582.

Isotopic Constitution of Hafnium, Yttrium, Lutetium and Tantalum. Phys. Rev., *55,* 794.

1940

A Thermodynamic Paradox. Amer. Jour. Phys., *8,* 396.

1946

The Mass Spectrograph in Chemical Analysis. Government Publication MDDC-370.

1947

Abnormal Isotope Abundances Produced by Neutron Absorption in Cadmium. (Abstract) Phys. Rev., *71*, 144.

Packing Fraction Measurements of the Heavy Elements. Bull. Amer. Phys. Soc., *4*, 30-48.

(With Lapp and VanHorn.) The Neutron Absorbing Isotopes in Gd and Sm. Phys. Rev., *71*, 745.

Isotopic Changes in Cadmium by Neutron Absorption. Phys. Rev., *71*, 829.

The Yield of Nuclei Formed by Fission. Phys. Rev., *72*, 431.

1948

Neutron Absorption in Samarium. Phys. Rev., *74*, 505.

(With W. Bartky.) The Approach to Equilibrium in Fractionation. Rev. Mod. Phys., *20*, 123.

Mass Spectrographic Identification of Radioactive Isötopes. Bull. Amer. Phys. Soc., *12*, 30-47.

The Alpha-Ray Emitting Isotope in Samarium. Phys. Rev., *73*, 1125.

Thirty Years of Mass Spectroscopy. Sci. Mo., *68*, 203. Centennial Issue.

(With M. G. Inghram and D. C. Hess, Jr.) The Mass Spectrometer Analysis of Volatile Products of Metabolism. AECD-2027.

1949

(With Shaw.) Retardation of High Velocity Ions in Gases. Bull. Amer. Phys. Soc., *24*, 13.