Howard T. Barnes

HOWARD TURNER BARNES

1873–1950

HOWARD TURNER BARNES rapidly came to prominence for his part in the high precision basic experiments in classical physics which first set an international standard in the science at McGill University. Most noteworthy are his determinations of the mechanical equivalent of heat and of the specific heat of water over the full range of temperature. Later he studied ice formation and became world famous, not only for his highly original and practical methods for the removal of ice jams, but for the great skill with which he used them.

Born at Woburn, Massachusetts on 21 July 1873, Howard was the son of Reverend William S. Barnes, LL.D., and of Mary Alice (*née* Turner). At the age of six he came to Montreal with his parents. Here his father founded the Unitarian Church and is remembered as a noted clergyman of his time. Howard was tutored by Reverend John Williamson and attended Montreal Academy before entering McGill University. He received the degree of B.A.Sc. in 1893, just as the new Macdonald Physics Building was completed.

Barnes immediately began a series of coordinated and well-sustained fundamental researches while at the same time holding posts in the University of rapidly increasing rank. He was appointed Macdonald Professor of Physics and Director of the Laboratory at the early age of thirty-four.

Professor Barnes selected important research problems and quickly grasped the real practical difficulties of each problem in complete detail. While courage, imagination and resourcefulness were essential, the great amount of work done in a relatively short period demonstrates an intuition that was unfailing throughout his scientific life. The dispatch with which the work proceeded equally well in the laboratory or in the field cannot be dissociated from the nobility of Professor Barnes, and his charming simplicity.

In the first solid demonstration of his exceptional research ability, Barnes made a precision determination of the specific heat of water over the full range of temperature. This work was completed in 1900 by the method of continuous flow calorimetry, but the tributaries dealing with fundamental elements ran back to undergraduate days. The experimental results immediately gave a precise value for the mechanical equivalent of heat in terms of international electrical units. The extent of this work, and its quality, attracted much attention and Barnes was appointed to international bodies dealing with fundamental units. Here it is possible to give only a brief sketch of the main features of the investigation.

Water flowed through a small glass tube and was heated by electrical power

supplied to a central wire. The quantity of water which flowed in an observed time was found by weighing, and the rise in temperature determined by a pair of platinum resistance thermometers.

The calorimeter was supplied with a vacuum jacket to reduce loss through convection currents. A flow of water from a source under thermostatic control kept the outside of this jacket at the temperature of the inflow to the calorimeter. This temperature was obviously changed from time to time and techniques for control were necessarily varied over different regions of temperature. Barnes saw, however, that if the rise in temperature was kept constant, no matter what the flow through the calorimeter, then the loss by radiation should be constant and be determined by observations on two rates of flow. In the experiments it was essential to avoid streamline flow.

Much attention was given to measurements of electrical power which were based on the electromotive force of a Clark cell, and the standard ohm. After years of study, Barnes adopted a modified form of hermetically sealed 'crystal' cell which he made. The two used in the experiments were kept in a bath. The accepted ohm was an average of several standards from different sources.

The proper design and use of platinum thermometers was routine with Barnes; the recording chronometer was carefully checked, and suitable attention paid to water vapour in the collecting flasks.

Representing by $JQ\,d\theta = (4{\cdot}2 + \delta)Q\,d\theta$ the electrical equivalent of the heat absorbed by a mass Q of water raised through $d\theta$ on corrected temperature scale, what Barnes measured was the variation of δ with temperature. Specific heats were calculated by taking as the thermal unit the heat capacity of water at 16° C. This unit he found to be 4·1883 joules in absolute measure.

The increase in specific heat of water as the freezing point is approached had been observed earlier by Rowland, who suggested that the value might go to infinity. Although this seemed most improbable to Barnes, who had worked very close to zero, a later experiment by Barnes and Cooke settled the matter. With pure water free of dust, they found they could supercool the liquid some degrees, once it was brought below zero. The results proved that below the freezing point the specific heat continues to rise with no discontinuity whatever.

Barnes took little part in the studies of radioactivity which for a time ran parallel to his own researches. Rutherford and Barnes examined the heating effect of radium in equilibrium with its products and of the emanation driven from it. The object of the experiments was to check variations in heating effects as predicted by the disintegrations with known periods. These general ideas were confirmed as was the value obtained by P. Currie and Laborde for the heat per hour from one gramme of radium. The method was to use a differential air thermometer consisting of two similar litre flasks connected by a manometer containing xylene. The whole apparatus was placed in constant temperature water bath. The radioactive samples were admitted alternately to one flask and

the other, and shifts in the level of xylene observed with a microscope provided with a micrometer eyepiece. Calibration was obtained by the use of small heating coils. The maximum rate at which heat was developed by the active samples was 6×10^{-4} cal per sec. It was shown that the heating effect from the emanation together with its active products is about 75 per cent of the total heat emission from radium.

With a great river only a mile or so from the laboratory, Professor Barnes began to study it under winter conditions. This prolonged study, which was aided by techniques developed in earlier researches, represents a second major stage in his life. Between not very sharply defined limits, it extended over a period of about thirty years.

The St Lawrence River, backed by the Great Lakes System, has a remarkably steady flow of water under normal conditions. Professor Barnes learned that in winter the temperature of the water is nearly uniform and never departs from the freezing point by more than a few thousandths of a degree. In his opinion, the St Lawrence should be regarded as a river within a river. He thought the main channel should bring the comparatively warm lake water through the colder northern region by a straight path separated as well as possible from the colder water in lakes and bays. In this fashion, one should expect the period of navigation to be appreciably extended. Professor Barnes has indeed expressed the view that navigation may be maintained all winter between Montreal and the open sea by breaking up ice packs as fast as they are formed, so that ice may continue to pass out to sea.

Under present conditions he observed that the formation of surface ice starts on a large scale after ice packs are caught at narrow points in the river. These arise mainly from wind-driven scum, but thereafter build upstream rapidly. The resulting surface ice commonly attains a thickness of two feet or slightly more.

In addition to the surface ice, it is well known that very small ice crystals are formed in cold weather, especially in rapids and swiftly moving open water. They are more numerous on cloudy days with a strong wind blowing upstream. Professor Barnes noted that a quarter of a million such crystals per cubic foot commonly appear in the St Lawrence and that this number rises to several million under exceptional conditions. These crystals, known to the Canadians of French ancestry as *frazil*, are not formed under surface ice or even in the open if the sun is strong. They may drift under the surface ice and even continue downstream for several miles. In cold weather, however, they may stick to the surface ice and build a dam down on either side of the channel. These effects may take place very rapidly, since the ice jam has nothing to do with the formation of ice. Whether the frazil becomes attached to objects or continues in the stream, Barnes found to be dependent upon exceedingly small changes in the temperature of the water. The speed with which the jam developes depends upon the temperature and upon the amount of available frazil. According to Barnes, the greatest concentration of frazil in the St Lawrence occurs at Cornwall, following the forty miles of rough open water below Prescott. He reports that

frazil frequently drifts into bays and builds up ice, found to be eighty feet thick in one locality. In like manner, he observed a complete blocking of a penstock by frazil in a few hours. While a very moderate amount of local heating was found sufficient to prevent this formation, Barnes once told me that he had succeeded with flood lights alone. From the point of view of an ice engineer, Barnes considers frazil as the most troublesome form of ice in the St Lawrence.

In all cold countries, and for more than 150 years, it has been known that ice frequently forms on the bottom of the rivers, being firmly attached to the river bed. Barnes called this anchor ice. He reports that it rarely forms under surface ice; it forms on dark rocks more readily than on light ones; it never forms under a cloudy sky, day or night. It does form very rapidly on a cold night under a clear sky, and is readily released by a bright sun. For these reasons, Barnes concluded that the initial layer of ice on the river bed followed cooling by radiation. Once the layer is formed, it may build up rapidly in cold weather, by catching passing frazil. Blocking of passages in this manner has been observed by Barnes on rare occasions. On the other hand, he notes that the release of tons of anchor ice by the first rays of the sun—following a clear, cold night—is so well known to boatmen on the St Lawrence that they never cross the river under such circumstances for fear of being caught in a pack of released anchor ice and carried down to the rapids.

The above considerations of the delicate balance of nature as affecting the St Lawrence ice, led Barnes to make suggestions for more extensive engineering projects. While the main idea was to get the lake water down a deep straight channel, he considered it very important to use dams to prevent mixing of cold shallow water round the Thousand Islands and the Sorel Islands. The latter also help to form jams which imperil ice breakers.

The method which Barnes eventually used with great success for the removal of ice jams actually came to him through a study of icebergs. With the sinking of the *Titanic*, there arose a great public interest in means to detect and possibly destroy them. It had been demonstrated by many sea captains that the temperature of the water was a thoroughly unreliable indication. With a sensitive, recording micro-thermometer, Barnes was nevertheless able to demonstrate beyond question a characteristic small fluctuation in temperature as the ship approached the berg. The thermometer was kept a few feet below the surface and the temperature recorded in a cabin.

On a later expedition, in 1924, Barnes was accompanied by his son William —by this time a Demonstrator in the Department of Chemistry—and by his brother Wilfred, a professional painter. Under suitable lighting, Professor Barnes always considered icebergs among the most beautiful objects in nature. Since few people commonly have an opportunity to see them, the group of paintings brought back by Mr Wilfred Barnes, R.C.A., were all the more valuable, and were greatly admired.

On the scientific side, an observation was made at this time which proved important for later development. Since the bergs were observed to crack more

at night, and with the first rays of the morning sun, Professor Barnes became convinced that the cracking was due to strains arising from temperature gradients. Many important results followed his deliberate attempt to set up strains in ice.

Indeed, two years later, in 1926, Barnes placed a 100 lb. charge of thermit three feet down from the top of an iceberg having twenty-five million cubic feet of ice above water. He says, 'the effect of the intense heat in direct contact with the hard ice was to send a temperature wave into the mass which produced a great deal of cracking and visible disruption, apart from the explosive shock of the dissociated ice itself. This cracking went on all the evening after we returned to the village and could be distinctly heard out at sea five miles away. Towards early morning, a very loud report woke many of the people of Twillingate, and when we visited the berg the next day we found the great bulk of the interior had come away.' An action so extended in time proved to be characteristic of thermit. Small bergs could be so shattered that they melted and disappeared, but the main value of the experiments arose from the fact that a small quantity of thermit could shatter a great mass of ice. The destruction of icebergs was therefore abandoned and thermit was thereafter used by Barnes to remove ice jams in rivers.

The light, heat and shock released when this material is fired seem singularly suited to the removal of ice jams, as amply demonstrated by the following notable achievements by Barnes. The first ice jam treated by this method was the Waddington jam on the St Lawrence. This was taken out in February 1925, by three 90 lb. thermit units reacting in the ice mass. Two hundred and fifty thousand tons of ice moved out in a few hours after treatment. At the Chimney Island jam in March 1925, about a million tons of ice were removed in nine hours following the use of two similar 90 lb. charges. At Clark Island a block of 8 500 square feet in area and 9 feet thick was lifted off a shoal and broken up by one 90 lb. charge. In February of the following year, the Allegheny ice gorge at Oil City and Franklin, Pa.—consisting of a dry jam twenty-five miles in extent—was removed without damage to property in about ten days. In the same year the Moira River ice jam at Belleville, Ontario, was treated and removed, thus preventing a bad flood in that city. In March 1927, the St Maurice River ice jam at the foot of La Tuque Falls was successfully opened, and a ten-foot flood relieved.

Most famous of the above operations is the one in the Allegheny River. Early in February the surface ice broke and moved down over a distance of some fifty miles above the cities mentioned. The restriction of the river at Brandon, fourteen miles below Franklin, caused the ice to jam so that the gorge was filled back to that city. The ensuing rise in water level caused no apprehension. Towards the end of the month, however, a large quantity of ice came down from Kinzau and jammed into the pack below Franklin without dislodging it. The river rose to a level higher than had ever been experienced by these communities. This second run of ice blocked the river up to Oil City and thus formed a solid ice gorge for twenty miles. This was shortly extended to

twenty-five miles. The entire water works was put out of commission at Oil City and the two cities were in grave danger.

It is clear, of course, that each ice jam presents an individual problem which calls for much intelligence. In this case, the solution was not more difficult than the handling of engineers who compared the heat from any reasonable amount of thermit with the weight of ice in the Allegheny River. Professor Barnes was, nevertheless, supported by the combined Chambers of Commerce in the two cities and the Pennsylvania Railroad ran a special train along the gorge to permit a preliminary inspection of the whole jam.

The entire gorge was divided into two parts. The lower, represented by the older gorge, which was dry and the ice grounded with most of the water forcing its way round through side channels, and the newer gorge, with the ice lifted high on flood waters accumulating above Franklin. The water, when it reached the lower pack, already had lost any appreciable power to melt ice and was flowing in the wrong places.

The object of the first thermit treatment was not to dislodge the great body of ice in the lower pack, but to open channels under the ice. The charges were, therefore, placed as deep as possible in the pack. The liberation of heat when these were fired, together with the accompanying explosions, caused cracks and disruptions which allowed the water to force its way through low-lying passages under a high head, and gradually work its way down the gorge, clearing a channel much larger than was evident to the eye at the time. The idea was to let more water come down from the upper pack to relieve the flood there and to bring it under the old pack which might thereby be lifted out and carried downstream. This process, however, had to be kept under control in order that an excessive flow might not cause further floods downstream. Near the conclusion of this process, however, a warmer spell of weather did produce a large flow which caused a near flood at Reno. Here a traction bridge was lifted eighteen inches above its supporting cement piers by the pack ice. By careful use of thermit, this bridge was brought back on its piers without damage and the entire jam was taken out without further difficulties. It will be easily understood that the day and night operations called for incessant supervision and were more complex than indicated above.

Hard pressed as he was by University duties during the First World War, Barnes nevertheless found time to invent and manufacture a model of a vortex gun intended for use against submarines. His inability to convince authorities of its power was a bitter disappointment to him. Members of the family vividly recall riding at high speed round Lake Memphramagog in a boat propelled by the model.

As a student, Barnes received thorough instruction and much inspiration from Professor Hugh Callendar, F.R.S. In appreciation of this help Barnes dedicated his first book on *Ice formation* to Professor Callendar. His second book on *Ice engineering* is dedicated to John R. Freeman, D.Sc., a consulting engineer and lifelong friend.

Most scientists have experienced some difficulty in persuading the press to

present their views accurately to the public. In this respect Barnes was somewhat gifted and received excellent cooperation from the press, the world over. This was important for his ice engineering.

In 1898 Barnes was awarded the Joule Studentship by the Royal Society of London. Although the award was particularly appropriate, the Studentship had never before gone to a Canadian and it was deeply appreciated. In 1904 he was Secretary of Section A, International Electricity Congress, Saint Louis. Appointed Macdonald Professor of Physics in 1908, he was in the same year elected President of Section III of the Royal Society of Canada; and became Director at McGill in 1909. Elected Fellow of the Royal Society in 1911 he gave the Tyndall Lectures at the Royal Institution in the following year. These dealt with 'Ice formation in Canada, physical and economic aspects'.

In 1925–1926 he was President of the Canadian Committee of the International Electrotechnical Commission. Owing to his wide interests, he was elected to many learned societies.

Professor Barnes was very painstaking in his instruction to all classes. His colleagues and students uniformly comment upon the undivided attention he received from large classes. Although sensitive about his severe lameness, he had a great natural dignity and a deep sympathetic understanding of students and their problems. He was always available to advise young men in his Department. Undergraduate and advanced students alike understood that he was their sincere friend, and he was beloved and respected in marked degree.

In September 1901, just after Barnes was well established as a scientist, he married Miss Anne Kershaw Cunliffe, younger daughter of Thomas Cunliffe of Bolton, Lancashire. For only eleven years he had the support of a charming companion of beautiful character. In 1912 she died quite unexpectedly, leaving her husband and four children, William, Thomas, Anne and Mary (twins). Mary died in June 1920. Barnes was shortly thereafter subjected to an exceptional burden as a good portion of his staff left to engage in the First World War. This burden, combined with his personal loss, proved excessive, and he had a breakdown so serious that medical authorities offered no hope of recovery. Fortunately an able nurse, Mrs C. Gale, failed to agree, and through her well-sustained assistance he returned in a few years to normal research activities as Emeritus Professor. Indeed, it was during this later period that his knowledge and wisdom led to the most clear presentation of problems of great national importance, together with detailed proposals for their solution. It was in this period, too, from 1924 to 1930, that he developed his wonderful method for relieving floods. At the age of fifty-seven he suffered a second breakdown, which prevented further work during the last twenty years of his life. During this period at Queen City Park, Burlington, Vermont, his letters showed the same fine spirit. He passed away on 4 October 1950. With present plans for a St Lawrence Seaway, built under Canadian leadership, one may expect to see some features which will serve as a memorial to this great Canadian scientist.

Friends who mourn his passing are grateful for their contacts with the resolute determination of this noble life so touched with sadness. It may help to sustain members of his family who carry on the tradition in spirit and knowledge. These members are: Dr William H. Barnes, National Research Council, Ottawa; Mrs George Poland (Anne C. Barnes), Chateauguay, Quebec; and Dr Thomas C. Barnes, Hahnemann Medical College, Philadelphia.

J. S. Foster

BIBLIOGRAPHY

1896. On some measurements of the temperature of the river water opposite Montreal. (With a differential platinum thermometer.) *Trans. Roy. Soc. Canad.* (2), **2**, Sec. III, 37.

1897. On some measurements of the temperature of the Lachine Rapids. *Trans. Roy. Soc. Canad.* (2), **3**, Sec. III, 17.

1897. (With H. L. Callendar.) On the variation of the electromotive force of different forms of the Clark standard cell with temperature and with strength of solution. *Proc. Roy. Soc.* **62**, 117.

1898. (With A. P. Scott.) Solution densities. *J. Phys. Chem.* **2**, 536.

1899. Notes on frazil and anchor ice (with consideration as to the freezing point of water). *Trans. Roy. Soc. Canad.* (2), **5**, Sec. III, 17.

1899. On the molecular weight of sulphur in carbon disulphide solutions. *J. Phys. Chem.* **3**, 156.

1900. Note on the relation of the electrical and mechanical units. *Trans. Roy. Soc. Canad.* (2), **6**, 71.

1900. Note on the effect of a change in dissociation on the density curve of a hydrated electrolyte in aqueous solutions of different concentration. *Trans. Roy. Soc. Canad.* (2), **6**, Sec. III, 75.

1900. On the inversion of the hepta and hexahydrates of zinc sulphate in the Clark cell. *J. Phys. Chem.* **4**, 1.

1900. In reply to a statement made by Dr E. Cohen in a paper on the theory of the transition cell of the third kind. *J. Phys. Chem.* **4**, 306.

1900. On the Weston cell as a transition cell and as a standard of electromotive force, with a determination of the ratio to the Clark cell. *J. Phys. Chem.* **4**, 339.

1900. An hermetically sealed type of Clark standard cell. *Phys. Rev.* **10**, 268.

1901. (With E. G. Coker.) On a method for the determination of the critical velocity of fluids. *Phys. Rev.* **12**, 372.

1901. On the density of ice. *Phys. Rev.* **13**, 55.

1902. (With H. L. Cooke.) On the density of ice. *Trans. Roy. Soc. Canad.* **8**, Sec. III, 146.

1902. (With J. G. W. Johnson.) The fall of potential method as applied to the measurement of the resistance of an electrolyte in motion. *Trans. Roy. Soc. Canad.* (2), **8**, Sec. III, 135.

1902. (With H. L. Cooke.) On the specific heat of supercooled water. *Phys. Rev.* **15**, 65.

1902. On the absolute value of the mechanical equivalent of heat. *Trans. Roy. Soc. Canad.* (2), **8**, Sec. III, 141.

1902. Theory and practice of continuous-flow electrical calorimetry. *Trans. Amer. Electrochem. Soc.* **2**, 197.

1902. (With H. L. Cooke.) On the inversion of zinc sulphate. *J. Phys. Chem.* **6**, 172.

1902. On the capacity for heat and water between the freezing and boiling points, together with a determination of the mechanical equivalent of heat in terms of the international electrical units: Experiments by the continuous-flow method of calorimetry performed at McGill University, Montreal. *Phil. Trans.* A, **199**, 149. (Shorter presentation under same title. *Proc. Roy. Soc.* **67**, 238 (1900).)
1902. Further experiments by the thermal method on the variation of the critical velocity of water with temperature. *Rep. Brit. Assoc.* A, Belfast, p. 512.
1903. (With D. McIntosh.) A new form of platinum resistance thermometer, specially adapted for the continuous-flow calorimeter. *Phil. Mag.* (6), **6**, 350.
1903. (With H. L. Cooke.) Notes on the variation of the specific heat of mercury with temperature. Experiments by the continuous-flow method of calorimetry. (Copy of paper as presented to B. A. Mtg. at Belfast (1902).) *Phys. Rev.* **16**, 65.
1903. (With J. G. W. Johnson.) On the resistance of a hydrated electrolyte and the relation to the density-concentration curve. *Trans. Roy. Soc. Canad.* (2), **9**, Sec. III, 31.
1903. (With H. M. Tory.) An experimental study of some electrode effects. *Trans. Amer. Electrochem. Soc.* **3**, 95.
1904. (With S. B. Lucas.) On the Weston cell. *J. Phys. Chem.* **8**, 196.
1904. The mechanical equivalent of heat measured by electrical means. *Report of International Electrical Congress at St Louis.*
1904. (With E. G. Coker.) The flow of water through pipes. Experiments on stream-line motion and the measurement of critical velocity. *Proc. Roy. Soc.* **74**, 341.
1904. (With C. H. McLeod.) Notes on the difference of temperature McGill College grounds and Mount Royal, Montreal, Canada. *Trans. Roy. Soc. Canad.* (2), **10**, Sec. III, 71.
1904. (With E. Rutherford.) Heating effect of the radium emanation. *Phil. Mag.* (6), **7**, 202.
1904. On the artificial production of frazil ice, together with measurements of the temperature conditions in the water. *Trans. Roy. Soc. Canad.* (2), **10**, Sec. III, 29
1904. (With A. S. B. Lucas.) The growth of ice crystals in the Bunsen ice calorimeter. *Trans. Roy. Soc. Canad.* (2), **10**, Sec. III, 33.
1904–1905. (With E. Rutherford.) Heating effect of the γ-rays from radium. (1) *Nature, Lond.* **71**, 151. (2) *Phil. Mag.* (6), **9**, 621.
1905. (With E. H. Archibald & D. McIntosh.) Molecular weight determinations by means of platinum thermometers. *J. Amer. Chem. Soc.* **24**, 47.
1905. Formation of anchor ice and precise temperature measurements. *Trans. Amer. Soc. Mech. Engrs*, p. 558.
1906. (With C. H. McLeod.) Further notes on the difference of temperature McGill College grounds and Mount Royal, Montreal, Canada. *Trans. Roy. Soc. Canad.* (2), **12**, Sec. III, 141.
1906. (With C. H. McLeod.) Records of the difference of temperature McGill College Observatory, and a method of local temperature forecasting. *Mon. Weather Rev.* November, p. 1.
1906. (With T. A. Starkey.) Deficient humidity of the atmosphere. *Trans. Roy. Soc. Canad.* (2), **12**, Sec. III, 203.
1906. Temperature records of nocturnal radiation. *Trans. Roy. Soc. Canad.* (2), **12**, Sec. III, 127.
1906. Anchor-ice formation from the standpoint of the radiation theory, together with some early memoirs on ground-ice. *Trans. Roy. Soc. Canad.* (2), **12**, Sec. IV, 65.
1907. Equilibrium between ice and water. *Trans. Roy. Soc. Canad.* (3), **1**, Sec. III, 29.
1907. Further notes on the difference of temperature McGill College grounds and Mount Royal. Local temperature forecasting. *Trans. Roy. Soc. Canad.* (3), **1**, Sec. III, 3.
1907. (With R. W. Boyle.) Heat of dilution of sodium amalgum (in MS.).
1908. (With G. W. Shearer.) A hydrogen peroxide cell. *J. Phys. Chem.* **12**, 155.

1908. (With G. W. Shearer.) Production of hydrogen peroxide from aluminum zinc. *J. Phys. Chem.* **12,** 468.
1908. A simple continuous electric calorimeter for students' use. *Science* (n.s.), **27,** 698.
1908. Measurement of temperature for industrial purposes. *J. Soc. Chem. Ind.* (Canad. Section), **27,** 3.
1908. (With C. H. McLeod.) Local temperature forecasting by differences in temperature between Mount Royal and McGill College Observatory. *Trans. Roy. Soc. Canad.* (3), **2,** Sec. III, 157.
1908. (With T. A. Starkey.) Deficient humidity in the atmosphere. Comparisons of various forms of hygrometers. *Trans. Roy. Soc. Canad.* (3), **2,** Sec. III, 187.
1909. The physical constants of ice. *Trans. Roy. Soc. Canad.* (3), **3,** Sec. III, 3.
1909. The absolute value of the mechanical equivalent of heat, in terms of the international electrical units. *Proc. Roy. Soc.* A, **82,** 390.
1909. (With A. N. Shaw.) A phenomenon connected with the discharge of electricity from pointed conductors (with a note by John Zeleny). *Proc. Roy. Soc.* A, **82,** 336.
1910. Ice formation. *J. New Eng. Water Works Assoc.* **14,** 576.
1912. Influence of ice on water power development. Presented to Canad. Electrical Assoc., Ottawa.
1912. The rise of temperature associated with the melting of icebergs. *Canad. Engr,* **23,** 887.
1912. The so-called thermoid effect and the question of superheating of a platinum-silver resistance used in continuous-flow calorimetry. *Proc. Roy. Soc.* A, **86,** 330.
1913. (With C. H. McLeod.) Records of differences of temperature between Mount Royal and McGill College Observatory, Montreal. *Trans. Roy. Soc. Canad.* (3), **7,** Sec. III, 151.
1913. Notes of a trip across the Atlantic on board the R.M.S. *Victorian* on which a micro-thermometer had been used. *Supplement to the 45th Annual Report of the Dept. of Marine and Fisheries (Canada) for the fiscal year,* 1911–1912. Sessional paper no. 21c, 3 George V A, 1913.
1914. (With C. H. McLeod.) Records of differences of temperature between Mount Royal and McGill College Observatory, Montreal. *Trans. Roy. Soc. Canad.* (3), **8,** Sec. III, 73.
1914. (With J. W. Hayward and N. McLeod.) The expansive force of ice. *Trans. Roy. Soc. Canad.* (3), **8,** Sec. III, 29.
1914. The Dawson isothermal layer of low temperature in the Gulf of St Lawrence. *Trans. Roy. Soc. Canad.* (3), **8,** Sec. III, 75.
1915. (With H. M. MacKay.) The crushing strength of ice. *Trans. Roy. Soc. Canad.* (3), **9,** Sec. III, 83.
1915. Effect of strain on the coefficient of expansion of quartz. *Trans. Roy. Soc. Canad.* (3), **9,** Sec. III, 147.
1916. Production of ring ice and hoar frost in pipes. *Trans. Roy. Soc. Canad.* (3), **10,** Sec. III, 93.
1917. The buoyancy of frazil crystals in water. *Trans. Roy. Soc. Canad.* (3), **11,** Sec. III, 61.
1917. On Stokes' law for spheres moving through water. *Trans. Roy. Soc. Canad.* (3), **9,** Sec. III, 55.
1926. The St Lawrence River levels and ice conditions. *Shipping register and travel guide, Montreal,* **8,** 1. (Lecture given to Montreal Board of Trade and the Shipping Federation of Canada.)
1926. Theory and use of thermit heat units in relieving ice conditions. *J. New Eng. Water Works Assoc.* **40,** 312.
1926. Engineering features in breaking the Allegheny Ice Gorge. *Engng J.* (*Engng Inst. of Canad.*).
1926. Some physical properties of icebergs and a method for their destruction. *Proc. Roy. Soc.* A, **114,** 161.
1927. Thermit and icebergs. *J. Franklin Inst.* **203,** 611.

Books and pamphlets

1904. Tory-Barnes pyrometer. U.S. Patent Office. Pat. No. 769364. 16 September.
1906. *Ice formation.* New York, John Wiley & Sons.
1909. (With L. V. KING.) Report on ice formation in the St Lawrence River, *and* a Report on the influence of icebergs on the temperature of the sea as shown by the use of a micro-thermometer in a trip to Hudson Strait and Bay in July 1910. *Sessional Paper no.* 21*b*, *Supplement to* 43*rd Annual Report of the Dept. of Marine and Fisheries, Canada, for the fiscal year* 1909–1910.
1912. Icebergs and their location in navigation. Pamphlet pub. by Roy. Inst. of Gr. Britain. 31 May. *Also* with additions in Smithsonian Rep. 717–740.
1928. *Ice engineering*, Montreal, Renouf Publishing Co.