NATIONAL ACADEMY OF SCIENCES
OF THE UNITED STATES OF AMERICA
BIOGRAPHICAL MEMOIRS
VOLUME XXII—NINTH MEMOIR

BIOGRAPHICAL MEMOIR

OF

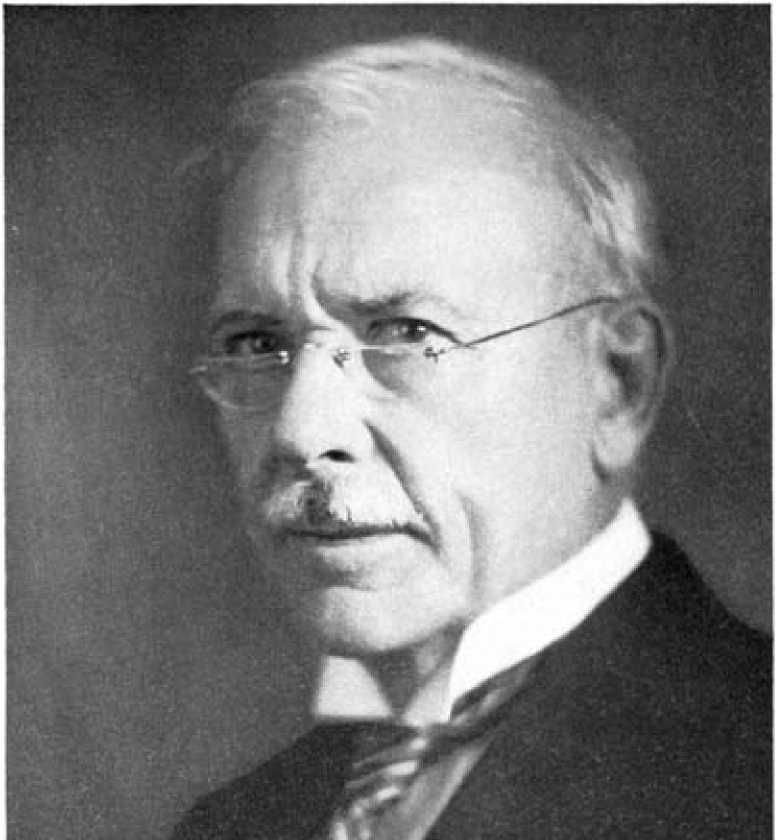
CARL BARUS

1856–1935

BY

R. B. LINDSAY

PRESENTED TO THE ACADEMY AT THE AUTUMN MEETING, 1941



Carl Barus

CARL BARUS

1856–1935

BY R. B. LINDSAY

I. *Biographical Sketch* [1]

When the history of the progress of physics in the United States during the late nineteenth and early twentieth centuries is written the name of Carl Barus will of necessity occupy an important place. When he began his scientific career with the United States Geological Survey in 1880, American physicists and physical laboratories were relatively few in number; when he ended his professional career as Hazard Professor of Physics in Brown University in 1926, the United States had achieved an eminent position in this field of human activity. In this development, Barus' own contributions were not inconsiderable.

Carl Barus came of German stock. His father, Carl Barus, Sr., settled in this country in 1849 and found work in Cincinnati, Ohio, as a musician, though he had been trained primarily as an engineer. His mother, Sophia Möllmann by birth, was the daughter of a German clergyman who came to the United States in 1835. Carl Barus, their first child, was born on February 19, 1856 in Cincinnati where he spent the first eighteen years of his life, culminating with his graduation from the Woodward High School there in 1874.

If we may judge from Barus' unpublished autobiographical memoir [2] his boyhood was a normal, healthy one in a cultured but not wealthy family where hard work was the expected thing and luxury was unknown. There are the usual stories of the pranks of the neighborhood boys, but it does not appear that

---

[1] This memoir is divided into three parts: (1) a biographical sketch, (2) a review of Barus' scientific research, and (3) a bibliography of Barus' scientific publications which, so far as is known, is complete.

[2] This is the chief source of information about the personal details of Barus' life. It is an engagingly written account which makes much easier the task of even a biographer who knew him intimately. The present writer has been able to supplement this material by the recollection of numerous conversations and other associations with Professor Barus during the period from 1918-1935. The writer also wishes to acknowledge his indebtedness for interesting suggestions by Prof. W. G. Cady of Wesleyan University and Prof. Ernest Merritt of Cornell University.

the future physicist was uncommonly mischievous. On the contrary he evidently developed early the habit of systematic application which was such a conspicuous feature of his later scientific career. He speaks, for example, of ten years of faithful service as organ pumper in the churches at which his father acted as musical director. Even before his high school years, Barus showed more than a passing interest in scientific experiments, particularly in chemistry. He also took advantage of the opportunity presented by a boyhood acquaintance to learn the use of the lathe and other machine tools and was soon deep in the mystery of tempering steel. It is clear that he combined natural curiosity with considerable initiative and was not at all backward in letting people know of his existence. In school he was a conscientious student and got few thrashings—the standard method of imparting education in the sixties as well as later. He admits reading Shakespeare, Milton, Byron, Schiller and part of Goethe before the age of fifteen. Small wonder he developed a literary style unusual for a scientist! His musical education also naturally began at an early age and though he had the normal boy's detestation of piano practice he kept at the thing intensively enough to become ultimately an accomplished musician.

Barus had an astonishingly good memory and in 1923 wrote a long letter to the Founder's Day Committee of the Woodward High School in Cincinnati giving a wealth of detail about his experiences at the school some fifty years earlier. Here he was a classmate of the late ex-President and Chief Justice William Howard Taft. The standards of instruction at Woodward were exceptionally high and Barus rose nobly to the occasion, graduating in 1874 with the silver medal for outstanding work in mathematics. It seems probable, however, that he learned as much out of school as in it, for he was forever dabbling with amateur chemistry, astronomy and botany, to say nothing of attempts at poetry, playwriting and musical composition. People had not heard of "thwarted" youth in his day.

The normal expectation of a lad of Barus' financial status was that high school would complete his formal education and it was at first intended that he should get a job with a wholesale chemical house in Cincinnati. By a happy chance, however, a former schoolmate returned from his freshman year at the Columbia School of Mines full of enthusiasm for the course of study there and the professional opportunities being opened up by the great mine booms then being exploited. The Barus family were much impressed and though their means were decidedly restricted, decided to strain a point and send their son to Columbia. Two able classmates went with him.

Life in New York was largely a peregrination from boarding house to boarding house with the usual vicissitudes in those days of uncertain plumbing and sharp landladies. But there is no question that on the whole Barus enjoyed his two years at the School of Mines. His interest in the purely engineering aspects of the course was by no means comparable with his growing enthusiasm for pure science and the physicist Professor Ogden N. Rood was his favorite teacher. There was no undergraduate physical laboratory at that time and experiments had to be done at home with simple apparatus or followed from the demonstrations of the professor who maintained an instrument maker (William Grunow) in the attic above his lecture room—very dingy quarters according to Barus' account. Here the young student was able to see fine physical equipment in the process of construction, for many well-known physicists came there to have apparatus made, among them Henry, Langley, Rowland and Michelson. Barus speaks very highly of the faculty of the School of Mines of that day, but it is clear that he was not cut out for an engineer. At the end of his second year the realization that his chief interest lay in pure physics prompted him to leave Columbia.

In 1876 Johns Hopkins University was founded and the new physical laboratory was opened under the presiding genius of H. A. Rowland. This provided an attractive opportunity for an embryonic physicist and Barus was strongly tempted to take it. There still exists a letter in Rowland's hand dated October 5, 1876, expressing his willingness to have the Columbia student work in his laboratory. Barus' father, however, was more favorable to a European training if his son were really determined to become a physicist, and Professor Rood recommended enthusiastically Würzburg and Professor Friedrich Kohlrausch, who had just then completed his well known treatise on practical physics. So Barus took up residence in the old Bavarian university town and remained there for the next four years, taking his doctor's degree summa cum laude in 1879. He entered with zest into both the social and intellectual life of Würzburg, perhaps at first over-emphasizing the former, at any rate by his own confession. He became a member of the Arminia fraternity and engaged in its activities with the same thoroughness he showed in everything else he undertook. Duelling took much of his time and left a permament mark on his cheek. In fact one gathers that during his first year of residence the fraternity saw more of him than the physics lecture room. Finally the money began to run low and conscience to prick; intellectual zeal returned with a rush after the proposal by Kohlrausch of a doctoral research on the relation of magnetization to the hardness of steel. This was modified by Barus to a study of the thermoelectric properties and electrical conductivity in their relation to hardness. His thesis was published in the Annalen der Physik in 1879, having been reported to the physical-medical society in Würzburg in January of that year. The physical laboratory facilities at Würzburg during most of Barus' stay were rather crude and uncomfortable. Apparatus building for graduate students was largely a matter of cobbling together equipment out of wood, cork, glass, rubber and wax with metal foil, wire and solder. Nevertheless the apparatus served its purpose. Each generation will not cease to wonder at the remarkable results achieved by the meager tools of the previous one. During Barus' residence the Bavarian government built for Kohlrausch a new physical laboratory and Barus helped in the process of moving and settling. At Kohlrausch's invitation he decided to stay for a time after receiving his degree and act as assistant in the new laboratory. Here he continued his research work on steel with the collaboration of a Czecho-Slovakian colleague, Vincent Strouhal. The pair gathered material for a number of papers which appeared in the Annalen der Physik from 1880-1883. By 1880, Barus' father was anxious to have him return to America and a good opportunity developed with the possibility of a position under Clarence King, the director of the United States Geological Survey, who was looking for a man in geophysics. So the young Ph.D. from Würzburg returned to begin a professional career in this country.

After a short stay with his family in Cincinnati he received his appointment as physicist in the Geological Survey and was ordered to Nevada to make electrical measurements on ore bodies as a member of the staff of Dr. G. F. Becker, the geologist. Here he spent the better part of a year in a rather adventurous existence delving into gold and silver mines and more or less roughing it in the wilds of a section made famous about that same time by Mark Twain. Barus worked both in the famous Comstock lode in Virginia City and at Ruby Hill near Eureka. As an interesting commentary on the serious conscientiousness with which the young physicist took his work it may be noted that after he had returned to Cincinnati to work out his report, he was assailed with doubts whether certain experimental allowances had been properly made. So seriously did he feel this that he went back to Nevada to check this single point. It turned out that the return trip was unnecessary. Nevertheless the incident stamped Barus as a serious and cautious scientist and augured well for the future.

The next phase in Barus' connection with the Geological Survey came with the establishment of a rather elaborate geophysical laboratory, first (and for a short time only, i.e., December 1881-November 1882) in the American Museum of Natural History in New York and later in a private dwelling house in New Haven. In this work it was planned that he would be assisted by his former colleague at Würzburg, Dr. Strouhal, and the latter did actually help considerably in purchasing in Europe the much needed apparatus which it was practically impossible to procure in America at that time. However, an offer of the professorship of physics at the Czech University of Prague overturned Strouhal's plans to join Barus and the latter had to look elsewhere. He finally found an able collaborator in another American, William Hallock, who had also just then taken his degree with Kohlrausch. He was a Columbia man and remained with the Survey until 1891, ultimately becoming professor of physics and head of the department at Columbia. The two young physicists set up what must have been a well-appointed laboratory for those days at 310 Dixwell

Avenue in New Haven. The location was apparently chosen with a view to the possibility of collaboration with the Yale faculty, and Barus and his colleague received a very kind reception from the Yale scientists. They embarked on an elaborate geophysical program which first involved a thorough calibration of the platinum thermocouples which were to be used for high temperature measurements. However, it appears that little of a definite nature was accomplished. The lure of social activity was still too strong for such youngsters to resist and the Yale acquaintances were probably too kind. Then, too, Clarence King, on whose initiative the whole research project had been undertaken, had been absent from the country for a considerable time and was no longer director of the Survey. The new director, Major J. W. Powell, did not take kindly to the New Haven laboratory and ordered it dismantled in 1884 and the removal of the apparatus to Washington, D. C., where new quarters were provided in the National Museum.

Barus remained in Washington for the next ten years. His work for the Geological Survey continued until 1892 and was a period of intense scientific activity. His colleague Hallock left him and he worked alone on a great variety of fundamental researches in geophysics, including a thorough study of the viscosity of steel in various stages of hardness, and a continuation of the high temperature thermometry begun in New Haven. Such preliminary experiments were necessary before proceeding to the main geophysical research, which began to be tackled about 1888 and included a determination of the volume expansion of rock in the transition from the solid to the liquid state as well as the change in the specific heat during the transition. The behavior of bodies under very high pressure was also studied. The importance of this work will be noticed further on in the review of Barus' scientific achievements. Suffice it to say that the basis of his scientific reputation was laid in this work with the Survey. It led to his election to the National Academy of Sciences in 1892. It also undoubtedly played an important part in establishing the method of his research: for the rest of his life his most significant work was done without collaborators. It had both the advantage of encouraging independence and the disadvantage (which indeed showed itself later) of encouraging queerness in notation and making his papers rather difficult to read. It was in Washington also that Barus began his married life. He was married on January 20, 1887, to Annie Gertrude Howes, a graduate of Vassar College in the class of 1874. Two children were born of this marriage, Maxwell Barus and Deborah Barus, of New York and Boston respectively. Mrs. Barus, who later become an active and nationally recognized worker in sociological and educational fields, died in 1928.

Though government scientific salaries were low, Barus enjoyed his work thoroughly. He was an independent worker, content to let the results of his labors speak for themselves without the trumpet blowing of extra-laboratory activities. In this he was probably unwise, since in his sincere confidence in Major Powell he made no attempt to build favor for himself outside of the Survey. Moreover there was no civil service protection then. Hence when Powell lost his grip with Congress, several of his staff were unceremoniously dismissed, among them Barus. This was in 1892 and marked the end of his association with the U. S. Geological Survey. To make the shock greater and the gloom more dismal the geophysical equipment which had been laboriously constructed over a period of nearly a dozen years was constitutionally classified as "old junk" and was carted off to the Department of the Interior to be disposed of as such. The only silver lining in the cloud was provided by the apparatus originally lent to Barus by Clarence King. This alone remained after the house-cleaning. Curiously enough it stayed with Barus to the end of his life and some of it still remains in the Physical Laboratory at Brown University.

As a physicist with a laboratory and some scientific equipment but minus a job, Barus felt himself doomed to cut a sorry figure. If he had known of the ups and downs which the next three years were to hold in store for him, he would have felt even worse. At the moment, however, a saviour appeared in the shape of Professor Mark W. Harrington, who had just been called from Michigan to head the remodeled U. S. Weather Bureau, recently transferred to the Department of the Interior. Harrington decided to put a little physics into the Bureau and organized a sub-department of meteorological research in which Barus was made Professor of Meteorology in September, 1892. Showing considerable versatility he threw himself into the new field with great vigor and soon had a program underway to look into the condensation of atmospheric moisture. However, even here trouble arose over the "anomaly" of a research under the auspices of the Weather Bureau being carried on in the National Museum! So Barus had to find new quarters. It was Alexander Graham Bell who came to the rescue in the spring of 1893 with the offer to rent a house in Georgetown for the project until the Bureau could take care of it. However, Barus' peace of mind was short-lived, for the incoming Cleveland administration made short work of his new post and in the summer of 1893 he was again without a job, though he still had a laboratory.

Barus had previously attracted the favorable attention of S. P. Langley, the Secretary of the Smithsonian Institution, and in August, 1893, accepted the latter's offer to become scientific consultant at the Institution. The salary was small compared with his previous stipends, but it was better than nothing and kept him in the field of physics. Two projects were to be worked on; first, the connection between radiation and temperature (the field in which Langley made probably his greatest contribution) and second, aerodynamical researches. Barus was not too enthusiastic over the latter, but it appears that of the two he had to spend more time and energy on this than on the former. Langley was an indefatigable experimenter and in those days experiments with airplanes were very disappointing. When the history of aeronautics is written, the hours Barus spent trying to make Langley's models fly certainly ought to receive attention. In his memoirs he states frankly that he did not enjoy the work. Finally early in 1895 he gave it up entirely. His stay at the Smithsonian had not been a total loss, however, for there he had a chance to meet many celebrated visiting physicists and to conduct some of the multifarious scientific correspondence inevitably associated with such an institution.

Life must have looked rather blue for a time. Here was a mature physicist in his late thirties, already recognized by the

American Academy and the National Academy and with many colleagues fully acquainted with the value of his work, but without a job! For a few months Barus set up as a consulting physicist and actually patented some devices which, however, developed into nothing. A few nibbles had come from some educational institutions but they like the inventions came to naught. Finally in March of 1895 a letter came from his old teacher Professor Rood of Columbia, stating that Rood's brother-in-law, Professor Eli Whitney Blake, was about to retire from the Hazard Professorship of Physics at Brown University and conveying the suggestion that Barus should become a candidate for the vacant position. Rood took upon himself the position of "campaign manager" and proved eminently successful in this capacity, for Barus ultimately received the appointment in May, 1895, after many weeks of letter writing, interviewing, etc. There were probably some who felt considerable doubt about entrusting the position to a man who had had no teaching experience whatever, even though his professional attainments were vouched for by half a dozen of the most famous physicists in the country.

The opportunity at Brown must have seemed like a haven of refuge to the much buffeted physicist. But Barus by no means rested on his oars. He entered into the business of learning how to teach with the same thoroughness and enthusiasm he had shown in his scientific research. Evidently he wrote to his predecessor Blake for advice in connection with the general elementary course, for a letter still exists from Blake to Barus cautioning him not to expect too much of his sophomores. His over-optimism about the amount of physics which can be stuffed into college undergraduates was soon tempered by experience. His lectures could not have been unpopular for the enrollment in elementary physics increased steadily during the first years of his stay. Much time went into the devising of effective lecture demonstrations and many such pieces with elaborate charts, etc., are still extant to testify to Barus' thoughtful attention to pedagogical matters. Disillusionment came, as it undoubtedly does to all who teach. In Barus' case it came on an occasion when he announced to his class that due to the necessity of attending a scientific meeting he would be forced to absent himself from the next class meeting. He expressed regret, but the class responded with applause! Most of us sooner or later learn not to take ourselves too seriously in the business of teaching.

The rest of Barus' active career was spent at Brown University, where he held the Hazard Professorship until his retirement at the age of 70 in 1926. In 1903 it was deemed desirable to put graduate instruction on a somewhat more systematic basis and a graduate department was established with Barus as Dean. He served in this capacity also until his retirement and witnessed great growth in graduate study. In 1926 the "department" had grown large enough to be made into a separate school of the University—a tribute to the efforts Barus had made toward its evolution. His annual reports as Dean were a definite contribution to post graduate higher education in America, for he had the uncanny power to separate the essential from the unessential.

As a classroom teacher Barus followed the European lecture system with perhaps a somewhat more careful regard for the time schedule. Promptly at the last stroke of the college bell he would stride into the classroom and with no preliminaries launch directly into his discourse. No questions were tolerated during the lecture—students might beard the professor in his den afterwards if they chose (or dared). The lectures were clear and in the elementary course, at any rate, rather lavishly illustrated with demonstrations, simple in construction but having the merit of usually working. Occasionally a flash of humor would emerge, but this was rare and for that reason all the more keenly appreciated. The pace set, particularly in the intermediate and advanced courses, was rather severe and demanded close attention on the part of the auditor. Some students found it simpler to use the lectures as suggestions for what should be studied outside class and not as a systematic course in themselves. This occasionally led to embarrassment when the week's notebook, handed in for inspection, did not seem to have much connection with the week's lectures. One comment in a case of this sort is worth recording. Barus wrote at the end of a screed more than usually irrelevant to what he had been trying to talk about: "I set a given week's work and you hand me in return a tragedy of Euripides." The notes were always corrected but not always severely enough. A representative of a well-known scientific instrument company has told the writer that he remembers climbing out of the lecture room window while Barus was scribbling on the blackboard (after attendance had been taken, of course). Such stories could be duplicated at any number of college campuses during the first decade of this century. Physics lecture rooms today are not so easy to leave surreptitiously!

There seems little doubt that Barus' real heart was in his research, which he kept at almost continually winter and summer until his retirement. When Commencement came and the college community largely dissolved until fall, Barus shipped his family off to the seashore but went on working in his basement laboratory. He was a prolific writer on scientific subjects and believed in describing the results of experiments with considerable detail and in frequent reports, as a glance at the appended bibliography amply indicates. During his tenure at Brown alone he found time to bring out some 300 publications, a record of productivity scarcely equalled in American physics. He worked almost entirely alone and made nearly all his own apparatus, on which the financial expenditure was usually rather meager. Very rarely has so much been accomplished with so little. Although an assessment of Barus' scientific contributions will be found in the second part of this memoir, something should be said here about the style of his writing. For a scientist he possessed an unusual grasp of language and evidently keenly enjoyed putting words on paper. He had a very witty way of bringing out essential points which makes his book reviews and general articles on the progress of physics a pleasure to read even today when the physical ideas in them have often long since passed into the realm of the historic. His address at the International Congress in St. Louis in 1904, for example, was a masterly summary of the whole evolution of physics during the 19th century and still repays study both for content and style. That his powers of graphic delineation did not wane with age is evident from his Honor's Day address at Brown in 1926 on "Three Phenomenal Ages of Cultural Advance." Those who corresponded with Barus will recall what a delightful letter writer he was and how he could invest even the simplest topics with a whimsical significance.

For the first fifteen years of his connection with Brown, Barus occupied a very prominent place in the activities of American physicists and the list of his dignities and high offices is impressive. In 1897 he was a Vice-President of the American Association for the Advancement of Science and Chairman of the Section on Physics at the Detroit meeting of that year. His address on this occasion concerned long range variables in temperature and pressure measurement. In 1898 he visited England as guest of Cambridge University on the occasion of the Stokes Jubilee and was made an honorary member of the Royal Institution of Great Britain. He took this occasion to travel extensively in France and Germany, renewing old friendships and making new ones. In 1899 Barus was a member of a committee which founded the American Physical Society, in whose fortunes he took for many years an active part. He was the fourth president of the society, holding that office in 1905-1906. He comments that his presidential address in New York on December 30, 1905, describing his work on condensation nuclei, was twice as long as it should have been. On reading it one can only marvel at the patience and capacity of the physicists of that day. Barus served as a member of the council of the Physical Society until his death. Naturally in his later years he was forced to give up active participation in the affairs of the society.

In 1900 the American Academy of Arts and Sciences awarded Barus its Rumford Medal for his researches in heat. In the same year he contributed a paper on high temperature measurement to the International Congress of Physics in Paris. In 1902 he was invited by President Gilman of Johns Hopkins to join the advisory council of the Carnegie Institution of Washington, in which he served with Woodward and Michelson as the committee for physics. The plan for the administration of the funds of the Institution which Barus drew up and the committee recommended was not finally adopted. Nevertheless he himself did some of his research under Carnegie grants and many of his later research reports appeared as Carnegie publications.

In 1903 came election to the American Philosophical Society and his appointment as Dean of the Graduate Department at Brown University. The next year saw the International Congress of Arts and Sciences in St. Louis and Barus gave the principal address for physics, taking as his subject the progress of the science during the nineteenth century.

For many years Barus was an active member of the National Academy of Sciences and attended meetings faithfully. When the National Bureau of Standards was founded he worked hard to get the Academy to endorse the project. Later, when the Proceedings of the Academy was established as a journal, Barus became a frequent contributor. In 1900 the Academy met at Brown and Barus received the congratulations of his fellow members for the thoroughness with which the arrangements had been carried through.

Barus received two honorary degrees, an LL.D. from Brown in 1907 and a similar degree from Clark in 1909. In 1911 he traveled in Europe and attended the Portsmouth meeting of the British Association for the Advancement of Science.

During the first World War the National Research Council was formed by Hale and Millikan, and Barus was a member. He gave a good deal of time to certain instrument problems though it is clear that he was not enthusiastic over the particular work within the scope of his resources, and glad when the end of the war enabled him to drop it. The war years were not happy ones for a pure scientist and Barus labored under the extra handicap of carrying a German name.

After the war Barus' courses suffered a considerable slump in attendance and he finally gave up elementary teaching shortly after reaching 60. Though he emphasizes in his memoirs his love of teaching, it is clear that by 1918 the spontaneity had departed and his elementary instruction had grown mechanical and uninspiring. He began to confine himself to his Deanship, his research (which continued unabated) and his advanced courses, the most successful of which was that in vector analysis which actually amounted to an introduction to theoretical physics. As a matter of fact he continued to teach this course with unfailing zest after he became professor emeritus and indeed up to the very year of his death.

After 1920 traveling became a hardship and Barus rarely if ever attended scientific meetings. He tended more and more to withdraw into himself and those who wished to see him had to visit him in his laboratory. At the same time he withdrew also from active participation in the affairs of his own department, leaving the details to his colleague and successor, Professor A. deF. Palmer. During most of his tenure the department consisted of the two professors and it does not appear that Barus made any serious attempt to increase it; if he did he was singularly unsuccessful. This is rather curious since during this whole period, physics departments in other institutions headed by men of his caliber made great strides. Possibly this is another indication that Barus' real zest was for his own research, also emphasized by the fact that he directed almost no students for the doctorate. Administrative procedure as such was distasteful to him, though he performed faithfully, systematically and efficiently that which he was called upon to do.

In 1926 Barus attained the compulsory retiring age of 70 and became professor emeritus. The Corporation of Brown University extended to him the privilege of laboratory space and for a time he continued to carry on his investigations. But the effort was rather taxing and the old fire was burning low. He still came to the laboratory every day, read widely to keep himself informed on the progress of physics, and enjoyed thoroughly his lectures in vector analysis. As the slackening of research provided more time he mellowed considerably in his attitude toward casual visitors and would talk by the hour with visiting colleagues about his reminiscences, which were a delight to listen to. When he was in the mood he was a brilliant conversationalist. His interests in the world about him continued to be wide and deep to the very end of his life. At the age of 60 he had taken up the study of Greek and Italian and maintained a zeal for literature until his death. His skill in music has already been referred to. Besides playing the piano very well he also mastered in adult life the violin, flute, clarinet, oboe, cornet, trumpet and trombone. Moreover the number of his musical compositions reached 40. Many of his former students well remember how he used to write music while proctoring elementary tests. It will never be quite clear just what the nature of the artistic inspiration was on such occasions!

In personal appearance, Carl Barus was tall with a sparely knit frame. In later life he walked with a slight stoop but had a good stride. As he walked across the campus with the cane he invariably used he was a dignified figure that even an undergraduate would stop twice to look at. Though not particularly athletic he enjoyed swimming, boating and bicycling. In fact swimming formed his chief recreation in the summers he spent on Cape Cod during the last seven or eight years of his life. Barus used to remark that smoking was his only vice. He pursued it methodically. One rarely visited him in his laboratory without finding him pipe in mouth. To avoid the nuisance of matches, a small gas flame burned continually within easy reach. The empty tobacco cans formed useful containers for small physical apparatus, and the usual thoroughness was also displayed in the carefully kept accounts of the weekly consumption, which were found among his papers after his death.

Though Barus suffered considerably from insomnia in later life, possibly connected with his tremendous mental energy, he was rarely ill in the usual sense of the word and maintained a reasonably good state of health until the summer of 1935 when he had to undergo a serious operation. Progress was very slow and he had just begun to show signs of definite recovery at his home in Providence when death came suddenly with a cerebral hemorrhage on September 20, 1935. With him there passed away one of the ablest men ever to occupy a chair in Brown University and one of America's distinguished scientists.

II. *Scientific Research (1879-1929)*

A complete assessment of Barus' contributions to physics is beyond the scope of the present memoir but it seems desirable to provide a brief summary of his principal scientific achievements. For convenience his research career may be divided into three main periods: (1) geophysical research during his service with the U. S. Geological Survey, probably his most significant work; (2) investigation of condensation and ionization in the atmosphere begun with the U. S. Weather Bureau and continued during the early years at Brown University; (3) development and application of optical interferometry to a variety of problems in light, electricity, gravitation and acoustics, carried out during the latter part of his career at Brown. It will be impossible here to do justice to the great many side branches into which his insatiable curiosity led him from time to time.

As has already been indicated Barus' first geophysical work consisted of a study of the electrical activity of ore bodies in Nevada. So far as is known this represents the first physical research conducted by the Survey and is a tribute to the perspicacity of Clarence King in recognizing the importance of physical methods in geology. Barus set out to determine the possibility of locating the presence and approximate position of ore bodies by measurements of electrical potentials in the surface. On the whole the measurements were successful and represent a definite advance over other work of similar nature done earlier in the nineteenth century. The investigations were not pursued further, for Barus' interests were always in fundamental things and not so much in applications. It is interesting to note, however, that the problem and its mathematical ramifications have been taken up again seriously by geophysicists during the past decade. Even before leaving Nevada, Barus carried out in collaboration with G. F. Becker a series of observations on the kaolinization produced by the action of hot water on feldspar. In later years he returned to this problem in the consideration of the compressibility of hot water in glass vessels in which the solution of the glass in the water was a source of considerable difficulty, but nevertheless led to interesting results having a bearing on volcanic action.

Clarence King was very much interested in dynamical geology and particularly in the age of the earth from the standpoint of the thermal conductivity of rock. With his usual thoroughness Barus mapped out an elaborate program for the study of the thermal behavior of rock material both in the liquid and solid states. He soon found it necessary, however, to precede this with an investigation of high temperature measurement. In 1886 he completed the first rigorous comparison of platinum-iridium and other platinum alloy thermocouples with the air thermometer over a range of some 1000°C. This fully confirmed the validity of thermoelectric pyrometry and established the method as one of the greatest utility in high temperature measurement. Here Barus definitely anticipated Le Chatelier, who usually receives the credit for thermoelectric calibration. Unfortunately the report of Barus' work in Bulletin 54 of the Geological Survey, a book of 313 pages, did not see the light until 1889, by which time much of Le Chatelier's work was well known. The latter part of the report is devoted to the description of investigations of high temperature viscosity of gases and its possible use in precision pyrometry. This was a bit of pioneering work which was not followed up.

An allied problem investigated at length at the same time was the viscosity of solids. This followed appropriately from Barus' thesis investigation at Würzburg on the properties of steel in their dependence on hardness. Various workers in different countries had studied the subject but there was considerable confusion due to divergence in notation. Barus' investigation was an elaborate attempt to obtain precise results and to unify the field. He succeeded in showing the essential validity of Maxwell's theory of viscosity and in particular established the significant metallurgical result that the phenomena associated with temper in steel, considered as of the nature of a strain, follow at once from Maxwell's theory. Barus was also led to attempt the distinction between the various states of matter on the basis of viscosity, which under fixed conditions of temperature, pressure and strain remains constant in time for fluids, but which for solids increases steadily under the application of constant stress. All this was pioneer research of the highest order and first importance in the field of metallurgy. Much of it was reviewed later in his Clark University lectures in 1909 on the physical properties of the iron carbides.

The effect of high pressures also came into the picture, and Barus busied himself much in the late eighties with devising means for the production and accurate measurement of such pressures, which he finally succeeded in carrying out up to 2000 atmospheres. With this and his high temperature equipment he was able to embark on a long series of researches on the thermodynamics of liquids. This would undoubtedly have been extended to more specific geological problems had not Barus' tenure in the Survey been abruptly terminated in 1892. As it was, his achievements in geophysics attracted international attention, being favorably commented on by Lord Kelvin, among others.

To the period of Barus' association with the Survey belongs also some fundamental research on the nature of colloids. In a paper with E. A. Schneider "Über die Natur der kolloidalen Lösungen" (Zs. für Physikalische Chemie," 8, 278, 1891), he and his colleague definitely established that colloidal silver solution consists of an aggregate of extremely small particles of actual silver. This marked an important forward step in the study of colloids.

Though Barus worked for the Weather Bureau for only one year the studies begun during this engagement initiated a program which, after an interruption of several years, formed his major scientific interest from 1900-1910. The problem was to study the condensation of water vapor in its dependence on the size of the nuclei precipitating it. In particular the plan involved gradually decreasing the size of the nuclei until they approached the diameter of the water molecule itself, i.e. condensation taking place in completely dust free air. Presumably Barus was the first person ever to try deliberately to condense water vapor on its own molecules. For this purpose he employed a carefully controlled steam jet and estimated the size of the water particles by means of the colors produced in the light scattered by the particles. He definitely understood that the cooling involved in the condensation is adiabatic, in its first stages at any rate, and he seems definitely to have anticipated the important work of C. T. R. Wilson in his famous paper of 1896. It is unfortunate that he had to break off his experiments so abruptly, as he clearly had his hands on one of the most important tools of twentieth century physics. When he returned to the subject around 1900 the cream had been removed by the English investigators. The cloud chamber had already been invented by Wilson and was being increasingly used to study condensation as affected by various ionizing means. Nevertheless, Barus was still fascinated by the use of light scattering (coronas) in studying condensation and determined to follow up this field. For this purpose he found it advisable to use the fog chamber rather than the cloud chamber. This is a vessel about 50 centimeters long and 15 centimeters in diameter. It is connected through a short but wide pipe to a large tank, which in turn is pumped to a pressure about 30 centimeters below atmospheric pressure while the fog chamber itself is kept at atmospheric pressure by means of a large stopcock. On opening the stopcock suddenly the result is adiabatic expansion of the air in the chamber. The fog produced is looked at against a bright source of light illuminating the chamber transversely and the "fog limit" is estimated from the first appearance of the diffraction rings. Moreover, the number of condensation nuclei formed or the extent of the nucleation can be estimated from the size of the rings. With apparatus of this type Barus investigated over a period of several years nucleation in the free atmosphere as a function of season and discovered some interesting periodicities. The effect of ionizing agents like X-rays and radioactive materials was also studied. The first stages of this research were reported at length in Barus' presidential address to the American Physical Society at the end of 1905. This work was rather roughly handled in "Nature" by C. T. R. Wilson, who might be expected to display small sympathy for systematic research with an instrument like the fog chamber when he had developed in the cloud chamber one of so much greater precision. His criticisms of Barus' results provoked a controversy which was probably taken a little too seriously by the American. In addition to the experimental uncertainties of the fog chamber, it is a fact that Barus paid rather too little attention to the role of ionization in nucleation. Along this route the great discoveries in atomic physics were being made. It is perhaps unfortunate that a physicist of Barus' stature was unwilling to throw his research energy into the cooperative venture which culminated in the modern theory of the constitution of matter. It is clear, however, that already in the early years of the new century, Barus was satisfied to play a lone hand. This is reflected in the make-up of his papers. In contrast to earlier procedure he began to omit all but the most cursory reference to the work of other previous and contemporary researchers, and his chief publications began to assume more and more the appearance of progress reports of his own experiments without adequate summaries of the essential results and their relation to those of other workers in the same or allied fields. They thus became increasingly difficult to read with discernment, even though there might be no question about the manipulative and interpretative skill of the experimenter. The writer is willing to hazard the guess that very few have ever made a really careful study of Barus' four memoirs on nucleation published under the auspices of the Carnegie Institution from 1906-1910. Certainly one finds very few references in present day literature to them, in marked contrast to his earlier research on high temperature and high pressure and their effects on the properties of matter. Yet a study made in the Brown Physical Laboratory in 1936 indicates that the fog chamber with certain simple improvements *can* be made to give reliable results.

The year 1910 may for convenience be taken to mark the beginning of the third and last stage of Barus' scientific activity. He then largely relinquished his work on condensation and embarked on a program of miscellaneous research suggested by the development of an ingenious displacement interferometer. In its early simple form this consisted of a plane transparent diffraction grating backed with a mirror. When light incident on and reflected from the front surface of the grating (after passing through the grating and being reflected by the mirror) is examined in a telescope, interference fringes are observed whose position is very sensitive with respect to any displacement of the mirror. Later the apparatus was modified in such a way that light from a single source reflected from two mirrors (more or less as in the conventional Michelson interferometer) is examined after passing through a plane transparent grating. A displacement of one of the mirrors produces a shift in the fringe system which can be used as a measure of the displacement.

With this instrument in various stages of modification and improvement over a period of some fifteen years, Barus investigated an astonishingly large range of physical phenomena involving very small linear or angular displacements. Thus, as if he were unwilling entirely to tear himself away from his condensation problem, he applied his interferometer to the measurement of the size of fog particles. Later he used the same instrument for the measurement of ordinary and extraordinary indices of refraction of doubly refracting crystals as well as magneto-striction elongations in iron. There followed in rapid succession (around 1914) the estimation of acoustic displacements of telephone diaphragms, the index of refraction of air at high temperatures, the accurate comparison of screws of any length, a precision quadrant electrometer, the measurement of changes of angular inclination of a pendulum as small as 3×10^{-4} seconds of arc, etc.

The interferometer was later applied by means of an open mercury manometer to precise pressure measurement, the precision stated by Barus being of the order of a few hundred thousandths of a centimeter of mercury per fringe displacement. This at once suggested the exploration of acoustic radiation fields by means of a pin-hole probe connected to the interferometer pressure gauge. This is probably the most precise non-electrical method of measuring acoustic pressure which has ever been devised. Unfortunately it was never followed up on a large scale by Barus and has been more or less neglected by others. Barus' unwillingness to embark on pretentious projects involving large financial layout and the use of numerous assistants, also had much to do with the failure of his attempt to apply displacement interferometry to a re-determination of the Newtonian constant of gravitation. For a number of years around 1920 he experimented with this problem and undoubtedly had in his hands an extremely precise method, but the disadvantages of his laboratory situation, with inevitable and largely uncontrollable temperature gradients, made his results illusory.

It is perhaps worthy of note that the displacement interferometer has more recently been made by C. E. Bennett [3] into a high precision instrument for the measurement of the dispersion of gases as a function of pressure.

[3] C. E. Bennett, Phys. Rev. **37**, 263, 1931; **45**, 200, 1934; **58**, 263, 1940.

It is difficult to avoid the feeling that practically all the scientific work of Barus during the last dozen years culminating in 1929 was of purely exploratory character, dictated by his own fancies and interests and with little effort toward the more precise development of his ideas. There can be no question that he profoundly enjoyed what he was doing and that it brought him more satisfaction than his teaching and administrative work. But he had reached the stage where he was unwilling to go at things in a large way and seek financial support for elaborate equipment. His autobiography indicates a growing feeling through the twenties that he was out of touch with the main trends of contemporary physics and that his scientific career was about over. He must have realized with growing misgivings that few persons any longer read his papers with clear appreciation of what he was doing. It is futile to quarrel with individual idiosyncrasies but one may be pardoned for expressing the regret that during his long teaching career Barus made little or no effort to build up graduate study in physics, so that a succession of doctoral students could have profited by his ingenuity and been stimulated by his drive. This would have insured much greater attention to his later scientific research and would have put the research itself on a firmer basis with a more adequate exploitation of its features of ultimate value. Such regrets are, of course, vain in the face of the record. The holder of this record will go down in scientific history as a great American physicist. That, with his insatiable curiosity, unusual intuitive powers, extraordinary experimental skill, and incredible capacity for work, he should have become an even greater figure lies strictly outside the province of an admiring biographer to stress.

BIBLIOGRAPHY

KEY TO ABBREVIATIONS

A. A. A. S., Proc. = American Association for the Advancement of Science, Proceedings.
Amer. Acad., Proc. = Proceedings, American Academy of Arts and Sciences.
Amer. Chem. Soc., Journ. = American Chemical Society Journal.
Amer. Hist. Rev. = American Historical Review.
Amer. Inst. Mining Eng. = American Institute of Mining Engineers.
Amer. Journ. Meteor. = American Journal of Meteorology.
Amer. Journ. Sci. = American Journal of Science.
Amer Phil. Soc. Proc. = American Philosophical Society Proceedings.
Ann. d. Physik = Annalen der Physik.
Ann. d. Physik u. Chemie = Annalen der Physik und Chemie.
Journ. Phys. Chem. = Journal of Physical Chemistry.
Nat. Acad. Sci. Proc. = National Academy of Sciences Proceedings.
Phil. Mag. = Philosophical Magazine.
Phys. Rev. = Physical Review.
Phys. Zeits. = Physikalische Zeitschrift.
Rev. Amer. Chem. Res. = Review of American Chemical Research.
Smithson. Contrib. Know. = Smithsonian Contributions to Knowledge.
Terr. Mag. = Terrestrial Magnetism.
U. S. Geol. Surv. Bull. = U. S. Geological Survey Bulletin.
U. S. Geol. Surv. Mono. = U. S. Geological Survey Monographs.
Verh. d. Physik. Med. Gesell. Würzburg, N. F. = Verhandlungen der Physikalische-Medizinische Gesellschaft, Würzburg.
Zeits. f. Phys. Chem. = Zeitschrift für Physikalische Chemie.

1879

Die Thermo-electrische Stellung und das Electrische Leitungsvermögen des Stahls in ihres Abhängigkeit von der Hartung. (Thesis) Ann. d. Physik u. Chemie, **7**, 383-414. Translation in Phil. Mag. (3) **8**, 341-368.

1880

Ueber eine einfache Methode der galvanischen Calibrirung eines Drahtes. (With V. Strouhal) Ann. d. Physik u. Chemie, **10**, 326-330.

Ueber Anlassen des Stahls und Messung seines Hartezustandes. (With V. Strouhal) Ann. d. Physik u. Chemie, **11**, 930-977.

Anlassen des Stahls und Messung seines Hartezustandes. (With V. Strouhal) Verh. d. Physik. Med. Gesell., Würzburg, N. F. **15**, 7.

1881

Ueber der Aenderung der Thermo-electrischen Stellung des Eisens und des Stahls durch Magnetisirung. (With V. Strouhal) Ann. d. Physik u. Chemie, **15**, 54-61.

1882

Geology of the Comstock Lode and the Washoe District with Atlas. By George F. Becker. Dr. Barus wrote Chapter IX "On the thermal effect of the action of aqueous vapor on feldspathic rocks," pp. 290-308; and Chapter X "On the electrical activity of ore bodies," pp. 309-367. Dr. Barus and F. R. Reade carried out many of the computations involved in the discussion of the increment of heat contained in this monograph. U. S. Geol. Surv. Mono. **3**.

1883

Ueber den Einfluss der Harte des Stahls auf dessen Magnetisirbarkeit. (With V. Strouhal) Ann. d. Physik u. Chemie, **20**, 621-662.

Ueber den Einfluss des Anlassens auf die Haltbarkeit der Magnete. (With V. Strouhal) Ann. d. Physik u. Chemie, **20**, 662-684.

Ueber den galvanischen Temperatur-coefficienten des Stahls, des Stab und Gusseisens. (With V. Strouhal) Ann. d. Physik u. Chemie, **20**, 525-536.

1884

Das Wesen der Stahlhartung vom elektrischen Standpunkte aus betrachtet, besonders im Anschluss an das entsprechende Verhalten einiger Silberlegirungen. (With V. Strouhal) Abhandlungen der kongl. böhm. Gesell. der Wissen. 6 Folge, **12**, 1-27. Prag.

Ueber die Definition des Stahls auf Grundlage des Electrischen Verhaltens des Eisens beim Wachsenden Kohlenstoffgehalt. (With V. Strouhal) Abhandlungen der kongl. böhm Gesell. der Wissen. 6 Folge, **12**, 1-25.

On the thermal effect of the action of aqueous vapor on feldspathic rocks (Kaolinization). School of Mines, Quarterly, **6**, 1-24.

Time, temper, and color of oxide films on steel. U. S. Geol. Surv., Bull. **27**, 51-61.

1885

The electrical activity of ore bodies. Amer. Inst. Mining Eng., **13**, 417-477.

The electrical and magnetic properties of the iron carburets. (With V. Strouhal) U. S. Geol. Surv., Bull. **14**, 1-238.

The relation between electrical resistance and density, when varying with the temper of steel. (With V. Strouhal) U. S. Geol. Surv., Rept. Div. Chem. and Phys., Bull. **27**, 1-51.

1886

On the strain effect of sudden cooling exhibited by glass and steel. (With V. Strouhal) Amer. Journ. Sci., **31**, 439-452; **32**, 181-192.

Hydro-electric effects of temperature in case of steel. (With V. Strouhal) Amer. Journ. Sci., **32**, 276-283.

The viscosity of steel and its relation to temperature. (With V. Strouhal) Amer. Journ. Sci., **32**, 444-466.

Physical properties of the iron carburets. (With V. Strouhal) U. S. Geol. Surv., Bull. **35**, 1-61.

Subsidence of fine solid particles in liquids. U. S. Geol. Surv., Bull. **36,** 1-53.

The effect of sudden cooling exhibited by glass and by steel considered both chemically and physically. (With V. Strouhal) U. S. Geol. Surv., Rept. Div. Chem. and Phys., Bull. **42,** 99-131.

Note on the structure of tempered steel. (With V. Strouhal) Amer. Journ. Sci., **31,** 386.

1887

The viscosity of steel and its relation to temperature. (With V. Strouhal) Amer. Journ. Sci., **33,** 20-36.

The viscosity of steel and its relation to temperature. Amer. Journ. Sci., **34,** 1-19.

The effect of magnetization on the viscosity and the rigidity of iron and steel. Amer. Journ. Sci., **34,** 175-186.

1888

Notes on the viscosity of gases at high temperatures and on the pyrometric use of the principle of viscosity. Amer. Jour. Sci., **34,** 407-410.

Maxwell's theory of the viscosity of solids and certain features of its physical verification. Amer. Journ. Sci., **36,** 178-208.

Certain generic electrical relations of the alloys of platinum. Amer. Journ. Sci., **36,** 427-442.

Secular annealing of cold hard steel. Phil. Mag., **26,** 397-403.

1889

Die Zähigkeit der Gase im Gebiete hoher Temperaturen. Ann. d. Physik u. Chemie, **36,** 358-398.

The subsidence of fine solid particles in liquids. Amer. Journ. Sci., **37,** 122-129.

The electrical resistance of strained glass. Amer. Journ. Sci., **37,** 339-351.

The energy potentialized in permanent changes of molecular configuration. Amer. Journ. Sci., **38,** 193-198.

The viscous effects of strains mechanically applied as interpreted by Maxwell's theory. Phil. Mag., **27,** 155-177.

On the thermo-electric measurements of high temperatures. U. S. Geol. Surv., Bull. **54,** 1-313.

1890

Fluid volume and its relation to pressure. Amer. Journ. Sci., **39,** 478-511.

The effect of pressure on the electrical conductivity of liquids. Amer. Journ. Sci., **40,** 219-222.

The pressure variations of certain high temperature boiling points. Phil. Mag., **29,** 141-159.

The change of the order of absolute viscosity encountered on passing from fluid to solid. Phil. Mag. **29,** 337-355.

The isometrics of liquid matter. Phil. Mag., **30,** 338-361.

The hydro-electric effect of stretching metals. Amer. Chem. Soc., Jour., **12**, 1-13.
A method of obtaining and measuring very high pressures. Amer. Acad., Proc., **25**, 93-108.
The molecular stability of metals, particularly of iron and steel. Nature, **41**, 369-371.
Note on the absolute viscosity of solids, liquids, and gases. Amer. Journ. Sci., **39**, 234.

1891

Compressibility of hot water and and its solvent action on glass. Amer. Journ. Sci., **41**, 110-116.
The chemical equilibrium of solids in its relation to pressure and temperature. Phil. Mag., **31**, 9-35.
Note on the pressure coefficients of the voltaic cell. Amer. Acad., Proc., **25**, 259-261.
Note on the continuity of solid and liquid. Amer. Journ. Sci., **41**, 325-326.
A comparison of the Bourdon, the Tait, and the Amagat high pressure gauges. Phil. Mag., **31**, 400-406.
The continuity of solid and liquid. Amer. Journ. Sci., **42**, 125-147.
Über die Natur der kolloidalen Lösungen (with E. A. Schneider). Zeits. f. phys. Chem., **8**, 278-298.
The viscosity of solids. U. S. Geol. Surv. Bull. **73**, 1-139.
Note on the variation of molecular pressure. Amer. Acad., Proc., **26**, 313-325.
The contraction of molten rock. Amer. Journ. Sci., **42**, 498-499.
The solution of vulcanized India rubber. Amer. Journ. Sci., **42**, 359-369.

1892

The relation of melting-point and pressure in case of igneous rock fusion. Amer. Journ. Sci., **43**, 56-57.
The dependence of viscosity on pressure and temperature. Amer. Acad., Proc., **27**, 13-18.
The volume lag and its bearing on molecular constitution. Amer. Chem. Soc., Journ., **14**, 191-202.
Note on the change of heat conductivity in passing isothermally from solid to liquid. Phil. Mag. **33**, 431-432.
Note on the relative position of high temperature melting and boiling points. Amer. Acad., Proc., **27**, 100.
The change of heat conductivity in passing isothermally from solid to liquid. Amer. Journ. Sci., **44**, 1-15.
The fusion constants of igneous rocks, I. Phil. Mag., **34**, 1-18.
Note on the change of electrical conductivity observed in rock magmas of different composition on passing from liquid to solid. (With J. P. Iddings.) Amer. Journ. Sci., **44**, 242-249.
Thermal variation of viscosity and of electric resistance. Amer. Journ. Sci., **44**, 255.

Thermoelectrics of platinum iridium and of platinum rhodium. Phil. Mag., **34**, 376-381.

Die phys. Behandlung und die Messung hoher Temperaturen. Leipzig, J. A. Barth, I-IV; 1-92.

The compressibility of liquids. U. S. Geol. Surv., Bull. **92**, 1-96.

The mechanism of solid viscosity. U. S. Geol. Surv., Bull. **94**, 1-138.

The volume thermodynamics of liquids. U. S. Geol. Surv., Bull. **96**, 1-100.

1893

Isothermals, isopiestics, and isometrics relative to viscosity. Amer. Journ. Sci., **45**, 87-96.

Preliminary note on the colors of cloudy condensation. Amer. Journ. Sci., **45**, 150-151. (Cf., Phil. Mag., **35**, 315.)

The colors of cloudy condensation. Amer. Journ. Meteor., **9**, 488-521.

The fusion constants of igneous rock, II. The contraction of molten igneous rock on passing from liquid to solid. Phil. Mag., **35**, 173-190.

The fusion constants of igneous rock, III. The thermal capacity of igneous rock, considered in its bearing on the relation of melting-point to pressure. Phil. Mag. **35**, 296-307.

Ueber das verhalten des colloidalen Silbers gegen den electrischen Strom. (With E. A. Schneider.) Ann. d. Physik, **48**, 327-337.

Colored cloudy condensation as depending on air temperature and dust contents, with a view to dust counting. Amer. Journ. Meteor., **10**, 12-34.

Mr. McGee and the Washington symposium. Science, **22**, 22.

Criticism of Mr. Fisher's remarks on rock fusion. Amer. Journ. Sci., **46**, 140-141.

High temperature work in igneous fusion and ebullition, chiefly in relation to pressure. U. S. Geol. Surv., Bull. **103**, 1-57.

1894

Spiral goniometry in its relation to the measurement of activity. Amer. Journ. Sci., **48**, 1-10.

An elementary expression in thermoelectrics. Amer. Journ. Sci., **47**, 366-371.

Colored cloudy condensation as depending on the temperature and on dust contents of the air. Phil. Mag., **38**, 19-35.

Contributions to Landolt and Börnstein's Phys. Chem. Tabellen, Berlin, J. Springer.

The colors of cloudy condensation. Nature, **49**, 363.

Remarks on colloidal silver. Amer. Journ. Sci., **48**, 451-454.

The present status of high temperature research. Amer. Journ. Sci., **48**, 332-336.

A simple chronograph pendulum. Amer. Journ. Sci., **48**, 396-397.

Note on the telephonic measurement of electromotive force. Amer. Journ. Sci., **48**, 346.

Telephonic measurement of electromotive force. Phil. Mag., **38**, 558-567.

1895

Report on the condensation of atmospheric moisture. U. S. Weather Bureau, Bull. **12**, 1-104.

Standards for electrical measure. Committee Report, National Academy of Sciences, February 20, 1-9.

The significance of certain experiments of Professor E. W. Blake. Brown Magazine, **7**, 41-48.

1896

The lecture experiment with liquid carbon dioxide. Amer. Journ. Sci., **2**, 1-4.

A curve-tracing top. Science, **4**, 444-446.

1897

The blackboard treatment of physical vectors. Science, **5**, 171-175.

Preliminary trial of an interferential induction balance. Amer. Journ. Sci., **3**, 107-116.

Note on the excursions of the diaphragm of a telephone. Amer. Journ. Sci., **3**, 219-222.

On a possible development of the idiostatic electrometer. Phys. Rev., **4**, 400-404.

Effects of hardness on the electrical and magnetic constants of steel, etc. Terr. Mag., **2**, 1-10.

Review of Helmholtz's "Electromagnetic theory of light." Journ. Phys. Chem., **1**, 537.

Clamp for fragile glassware. Science, **6**, 31.

Long range temperature and pressure variables in physics. Vice-Presidential address. A.A.A.S., Proc., **46**, 1-30; Science, **6**, 333; Nature, **56**, 528.

The saecular softening of cold hard steel, with remarks on electrical standards. Phil. Mag. **44**, 436-483.

1898

Combination tones of the siren and an organ pipe. Amer. Journ. Sci., **5**, 88-92.

On a method of obtaining pores or capillary canals of a specified diameter. Phys. Rev. **6**, 52-54.

Review of "Vorlesungen ueber die prinzipe der mechanik," Pt. I, Ludwig Boltzmann (Barth, Leipzig, 1897). Journ. Phys. Chem., **2**, 53-54.

The mathematical theory of the top. Science, **8**, 470-474.

Curious inversion of the wave mechanism of the electromagnetic theory of light. Amer. Journ. Sci., **5**, 343-348.

Ballistic galvanometry with a counter-twisted torsion system. Phys. Rev., **7**, 10-18.

The compressibility of colloids, with applications to the jelly theory of the ether. Amer. Journ. Sci., **6**, 285-298.

Remarks on colloidal glass. Amer. Journ. Sci., **6**, 270.
Inertia as a possible manifestation of the ether. Science, **8**, 681-685.

1899

The thermodynamic relations of hydrated glass. Amer. Journ. Sci., **7**, 1-3.
The objective presentation of harmonic motion. Science, **9**, 385-406.
Review of "Die moderne entwicklung der electrischen prinzipen," F. Rosenberger (Barth, Leipzig, 1898). Journ. Phys. Chem., **3**, 48.
The aqueous fusion of glass, its relation to pressure and temperature, I. Phil. Mag. **47**, 104-109.
The aqueous fusion of glass, its relation to pressure and temperature, II. Phil. Mag., **47**, 461-479.
"The Laws of Gases." Memoirs by R. Boyle and E. A. Amagat. Translated and edited by Carl Barus. 107 pp. New York, American Book Co., 1899. (Harper's Scientific Memoirs, No. 5.)
Review of "A treatise on the kinetic theory of gases" (S. H. Burbury, Cambridge Univ. Press 1899). Journ. Phys. Chem., **3**, 605-606.
Die Einwirkung des Wassers auf heisses Glas. Phys. Zeits., **1**, 3-5.

1900

Review of "Kanon der physik," Felix Auerbach (Veit, Leipzig, 1899). Journ. Phys. Chem., **4**, 42-43.
Review of "Cinematique et mechanismes; potentiel et mecanique des fluides," Henri Poincare. (Carre et Naud, Paris, 1899). Journ. Phys. Chem., **4**, 137.
Review of "Strahlung und temperatur der sonne," J. S. Scheiner. (Engelmann, Leipzig, 1899). Phys. Rev., **10**, 126-127.
Review of "Mesure des temperatures elevees," H. Le Chatelier et O. Boudouard. Bibliotheque de la Revue Generale des Sciences. (Carre et Naud, Paris, 1900). Journ. Phys. Chem., **4**, 394-395.
Review of "Vorlesungen über hydrodynamische fernkräfte, nach C. A. Bjerknes' Theorie," V. Bjerknes. Vol. I. (Barth, Leipzig, 1900). Journ. Phys. Chem., **4**, 395-396.
Motion of a submerged index thread of mercury in the lapse of time. Amer. Journ. Sci., **9**, 201-206.
On the absorption of condensation-producing atmospheric dust by solid nuclei and surfaces, and on the diffusion velocity of supposedly non-ionized dust particles. Science, **11**, 201-206.
Hot water and soft glass in their thermodynamic relations. Amer. Journ. Sci., **9**, 161-175.
On a method of studying diffusion of air through water, and on a method of barometry. Amer. Journ. Sci., **9**, 397-400.
Review of the scientific papers of J. W. Strutt, Lord Rayleigh Science, **11**, 550-585.
The transmission of the ionized exhalation of P through air and other nuclei. Phys. Rev., **10**, 257-267.

Rapport sur les progres de pyrometrie. Translated by D. Berthelot. Paris, Congres International de Physique, 1-30.

The interferences observed on viewing one coarse grating through another, and on the projection of one piece of wire gauze by a parallel piece. Science, **12**, 617-627.

Torsional magnetostriction in strong transverse fields and allied phenomena. Amer. Journ. Sci., **10**, 407-418.

The rates of a rocking watch. Phil. Mag., **50**, 595-604.

Review of "A Treatise on the Theory of Screws," Sir Robert Stawell Ball. (Univ. Press; Cambridge, Macmillan, New York, 1900) Science, n.s. **12**, 1001-1003.

1901

Review of "Handbuch der Spectroscopie," H. Kayser. Vol. I. (Hirzel, Leipzig, 1900) Journ. Phys. Chem., **5**, 66-68.

Hysteresis-like phenomena in torsional magnetostriction and their relation to viscosity. Amer. Journ. Sci., **11**, 47-110.

Certain stroboscopic phenomena in the end or projection of a wave. Science, **13**, 128-129.

The projection of ripples by a grating. Science, **13**, 297-298.

Note on the number of particles in the saturated phosphorescent emanation. Science, **13**, 501-503.

On the behaviour of the phosphorus emanation in spherical condensers. Amer. Journ. Sci., **11**, 310-314.

Reminiscent remarks on the top. Science, **13**, 852-853.

The general equations of rotation of a rigid body. Science, **13**, 914-915.

On the stability of vibrations. Science, **14**, 403-405.

On the change of the colors of cloudy condensation with the number of available nuclei, and the effect of an electric field. Phil. Mag., **1**, 572-578.

Absorption of the ionized phosphorus emanation in tubes. Phil. Mag., **2**, 40-49.

On the transmission of the ionized emanations of phosphorus through air and other media. Phil. Mag. **2**, 391-403.

On the simultaneous volumetric and electric graduation of the steam tube with a phosphorus ionizer. Phil. Mag. **2**, 477-488.

Experiments with ionized air. Smithson. Contrib. Know. **24**, Publication 1309. i-x, 1-93.

Effect of temperature and moisture on the emanations of phosphorus and on a distinction of nuclei and ions. Amer. Journ. Sci., **12**, 327-346.

Temporary set as associated with magnetostriction. Phys. Rev. **13**, 283-306.

Greenhill's mathematical theory of the top. Science, **14**, 973-975.

Review of "Handbuch der spectroscopie," H. Kayser. Vol. 1. (Hirzel, Leipzig, 1900). Journ. Phys. Chem. **5**, 66-68.

1902

Behavior of the phosphorus emanation in spherical condensers. Phil. Mag. **3**, 80-91.

The sizes of water particles producing the coronal and the axial colors of cloudy condensation. Phil. Mag. **4**, 24-29.

On spontaneous nucleation and on the nuclei produced by shaking solutions. Phil. Mag. **4**, 262-269.

Graded condensation in benzine vapor, as evidenced by the distorted coronas and marked axial colors attending cloudy condensation. Science, **15**, 175-178.

On geometric sequences of the coronas of cloudy condensation and on the contrast of axial and coronal colors. Amer. Journ. Sci., **13**, 81-94.

Flowerlike distortion of the coronas due to cloudy condensation. Amer. Journ. Sci., **13**, 309-312.

An American journal of physics. Science, **15**, 629-630.

Certain properties of nuclei. Science, **15**, 912-914.

Note on the possibility of a colloidal state of gases. Amer. Journ. Sci., **13**, 400-402.

On a method of hygrometry. Science, **16**, 33-34.

On the structure of the nucleus. Science, **16**, 633-636.

The variation of atmospheric nucleation. Science, **16**, 948-952.

On the velocity and structure of the nucleus. Amer. Journ. Sci., **13**, 225-233.

1903

Data with a possible bearing on the cause of lightning. Science, **17**, 32.

Ionization of water nuclei, I. Amer. Journ. Sci., **15**, 105-120.

Ionization of water nuclei, II. Amer. Journ. Sci., **15**, 217-223.

Apertures of coronas in relation to the number of nuclei and their size. Amer. Journ. Sci., **15**, 335-341.

Atmospheric nucleation during cold weather. Phys. Rev., **16**, 193-198; 246.

The structure of the nucleus. Smithson. Contrib. Know., **29**, Publication 1373, 1-173.

Ionization and nucleation of the phosphorus emanation. Phys. Rev., **16**, 247.

The relation of ionization to nucleation in the case of phosphorus. Phys. Rev., **16**, 287-299.

Diffusion of vapor into nucleated air. Amer. Journ. Sci., **15**, 472-476.

Review of "Lehrbuch der kosmischen Physik," Svante August Arrhenius, Vol. 1 and Vol. 2. (Hirzel, Leipzig, 1903), Journ. Phys. Chem., **7**, 467-469.

Bemerkung über die Schmidt'scher Theorie der Phosphoremanationen. Ann. d. Physik, **11**, 1142-1144.

Experiments with a Holtz machine and the ratio of the velocities of the ions. Phys. Rev., **16**, 247.

Absence of electrification in cases of sudden condensation and of evaporation. Phys. Rev., **16**, 384.

Nuclei produced chemically by mixture of coal gas and of air. Phys. Rev., **16**, 385.

Ions and nuclei. Nature, **69**, 103.

The coronal method of estimating atmospheric nucleation. Phys. Rev., **17**, 233-244.

Note on the constants of coronas. Amer. Journ. Sci., **16**, 325-327.

Review of "Vorlesungen über hydrodynamische Fernkräfte nach C. A. Bjerknes' Theorie," V. Bjerkens. Vol. II. (Bath, Leipzig, 1902), Journ. Phys. Chem., **7**, 219-220.

Review of "Handbuch der Spectroscopie," H. Kayser. Vol. 2. (Hirzel, Leipzig, 1902), Journ. Phys. Chem., **7**, 300-302.

1904

Periodic color distribution in relation to the coronas of cloudy condensation, with a revision of coronas. In "Festschrift Ludwig Boltzmann Gewidmet," (Barth, Leipzig, 1904), 204-214.

On the numbers of nuclei produced by shaking different liquids. Amer. Journ. Sci., **17**, 81-84.

Direct micrometric photography of fog particles. Amer. Journ. Sci., **17**, 160-170.

Review of "Vorlesungen über theoretische Physik," H. von Helmholtz. Band VI, Theorie der Wärme. (Barth, Leipzig, 1903). Journ. Phys. Chem., **8**, 56-59.

Ions and nuclei. Rev. Amer. Chem. Res., **10**, 87-89.

Photography of fog particles. Nature, **69**, 494.

On the denucleating effect of air stirred over water. Amer. Journ. Sci., **17**, 392-394.

1905

Preliminary results with an objective method of showing the distribution of nuclei produced by X-rays, for instance. Amer. Journ. Sci., **19**, 175-184.

Note on the variation of the sizes of nuclei with the intensity of the ionization. Science, **21**, 275-276.

Address given in honor of Professor A. S. Packard. Science, **21**, 404-406.

Penetrating radiation associated with X-rays. Science, **21**, 563-566.

Alternations of large and small coronas, etc. Amer. Journ. Sci., **19**, 349-356.

Review of "An Introduction to the Theory of Optics," Arthur Schuster. (Arnold, London, 1904). Journ. Phys. Chem., **9**, 420.

Review of "Vorlesungen über die Prinzipe der Mechanik," Ludwig Boltzmann. Zweiter Teil, enthaltend: "Die Wirkungs-prinzipe, die Lagrangeschen Gleichungen und deren Anwendungen." (Barth, Leipiz, 1904). Journ. Phys. Chem., **9**, 420.

Review of "Radioactivity," E. Rutherford. (Cambridge, University Press, 1904). Science, ns. **21**, 697-698.

Note on fleeting and on persistent nuclei. Phys. Rev., **112**, 52-56.

Properties and distributions of nuclei. International Congress of Radiology and Ionization, Liege, 1-42.

Groups of efficient nuclei in dust-free air. Amer. Journ. Sci., **20**. 297-300.

Relations of ions and nuclei in dust-free air. Amer. Journ. Sci., **20**, 448-453.

Eigenschaften von Kondensationskerner und ihre atmospherische Vertheilung. Phys. Zeits., **6**, 718-726.

Progress of physics in the nineteenth century. Science, **22**, 363-369; 385-397.

1906

Professor Gills on physical geology. Amer. Journ. Sci., **21**, 461-462.

Condensation nuclei. (Presidential address.) Phys. Rev., **22**, 82-110.

Review of "Physical Optics," Robert W. Wood. (Macmillan, New York, 1905). Journ Phys. Chem., **10**, 221-222.

Review of "Les Quantites elementaries d'Electricite: Ions, Electrons, Corpuscles. Memoires reunis et publies par Henri Abraham et Paul Langevin. (Soc. Française de Physique: Collection de Memoires relatifs a la Physique.) (Gauthier-Villars, Paris, 1905). Journ. Phys. Chem., **10**, 301-302.

Review of "Radio-activity," E. Rutherford. 2nd ed. (Cambridge, University Press, 1905). Science, n.s. **23**, 262.

A continuous record of atmospheric nucleation. Smithson. Contrib. Know., **34**, Publication 1651, 1-226.

The nucleation of the uncontaminated atmosphere. Carnegie Publications, **40**, x-xii; 1-152.

Proprietes des noyaux de condensation dans l'air. Translated by E. Bloch. Le Radium, **3**, 18-20.

Eye anomalies. Science, **23**, 390-391.

Distribution of colloidal nuclei and of ions in dust-free CO_2. Phys. Rev., **23**, 31-36.

Note on the computed drop in pressure in adiabatic expansion. Amer. Journ. Sci., **22**, 81.

Corpuscular radiation from cosmical sources. Science, **23**, 952.

Time variation of the initial nucleation of wet dust-free air. Science, **24**, 180-181.

Colloidal nuclei and ions in dust-free air saturated with alcohol vapor. Amer. Journ. Sci., **24**, 136-142.

Actual drop of pressure in the fog chamber. Amer. Journ. Sci., **22**, 339-341.

New method of standardizing coronas. Amer. Journ. Sci., **22**, 342-343.

Vulcanism. Science, **24**, 400-403.

Water precipitation per cubic centimeter in the fog chamber. Phys. Rev., **23**, 444-446.

Note on the change of colloidal nuclei of wet dust-free air in the lapse of time. Amer. Journ. Sci., **22**, 541.

1907

Condensation of vapor as induced by nuclei and ions. Carnegie Publications, **62**, i-x, 1-164.

Polarization and interference phenomena with white light. Science, **25**, 348-350.

Changes of colloidal nuclei of wet dust-free air in the lapse of time. Amer. Journ. Sci., **23**, 202-210.

Distribution of ions and nuclei in dust-free air. Phys. Rev., **24**, 232-236.

Equations of the fog chamber. Phys. Rev., **24**, 383-384.

Efficiency of the plug cock fog chamber. Phil. Mag., **13**, 357-364.

Review of "Les Origines de la Statique," P. Duhem. Vol. 2. (Hermann, Paris, 1906). Journ. Phys. Chem., **11**, 422.

Review of "Radioactive Transformations," E. Rutherford. (Scribner's, New York, 1906). Journ. Phys. Chem., **11**, 423.

Review of "Electrons, or the Nature and Properties of Negative Electricity," Oliver Lodge. (Macmillan, New York, 1906). Journ. Phys. Chem., **11**, 497-498.

Review of "Essais de Jean Rey, Docteur en Medecine." (Hermann, Paris, 1907). Journ. Phys. Chem., **11**, 498.

On the distribution of nuclei in dust-free air. Amer. Phil. Soc., Proc., **46**, 70-79.

Sun spots. Science, **25**, 972-973.

Vapor nucleation in the lapse of time. Amer. Journ. Sci., **23**, 342-344.

Review of "Vorlesungen über theoretische Physik," H. von Helmholtz. Band IV., "Vorlesungen über Elektrodynamik und Theorie des Magnesismus." (Barth, Leipzig, 1907). Journ. Phys. Chem., **11**, 574-575.

Review of "Die Kathodenstrahlen," G. C. Schmidt, second ed. (Vieweg, Braunschweig, 1907). Journ. Phys. Chem., **11**, 575.

Specification of diagrams in applied geometry. Science, **26**, 149-151.

On a method for the observation of coronas. Amer. Journ. Sci., **24**, 277-281.

On successive cycles of coronas. Amer. Journ. Sci., **24**, 309-312.

The decay of ionized nuclei in the fog chamber. Amer. Journ. Sci., **24**, 419-425.

The flying machine. Science, **26**, 672-673.

Über die Vertheilung der Kondensationskerne in Staubfrei Luft, etc. Ann. d. Physik, **24**, 225-242.

Note on volcanic activity. Amer. Journ. Sci., **24**, 484.

Lodge's ether and Huyghen's gravity. Science, **26**, 875.

Condensation nuclei from the evaporation of fog particles. Phys. Rev., **25**, 391-398.

1908

Pendulum coincidences determined by shadow reinforcement. Phys. Rev., **26,** 299-301.

Axial colors of steam jet and coronas. Amer. Journ. Sci., **25,** 224-226.

The behavior of nuclei of pure water. Amer. Journ. Sci., **25,** 409-412.

Regions of maximum ionization due to radiation. Science, **28,** 26-28.

Standardization of the fog chamber by aid of Thomson's electron. Amer. Journ. Sci., **26,** 87-90.

Thomson's constant e found in terms of the decay constant of ions within the fog chamber. Amer. Journ. Sci., **26,** 324-328.

Condensation of vapor as induced by nuclei and ions, III. Carnegie Publications, **96,** i-v, 1-139.

1909

Coronas with mercury light. Amer. Journ. Sci., **27,** 73-81.

Absence of polarization in artificial fogs. Amer. Journ. Sci., **27,** 402.

Adjustment for plane grating similar to Rowland's for concave grating. Amer. Phil. Soc., Proc., **48,** 166-176.

The electron method of standardizing the coronas of cloudy condensation. Amer. Phil. Soc., Proc., **48,** 177-188.

Electronic measurement of voltaic potential. Amer. Phil. Soc., Proc., **48,** 189-193.

Saecular softening of hard steel. Phys. Rev., **29,** 516-524.

Historical graphics. Science, **30,** 372-373.

1910

Sur les phénomènes de condensation dus aux ions. Congrès international de Radiologie et d'Électricité, Bruxelles, 1910. (Abstract) Le Radium, **7,** 240.

Probability of an inherent relation of the electrical resistance and the hardness of steel. Phys. Rev., **30,** 347-349.

Condensation of vapor as induced by nuclei and ions, IV. Carnegie Publications, **96,** Pt. II, i-vii, 1-84.

Interference of reflected-diffracted and diffracted-reflected rays on a plane transparent grating and on an interferometer. (With Maxwell Barus.) Science, **31,** 394-395.

On the general use of the grating with the interferometer. Science, **32,** 92-93.

Interference of the reflected-diffracted and the diffracted-reflected rays on a plane transparent grating. (With Maxwell Barus.) Phil. Mag., **20,** 45-59.

The use of the grating in interferometry. Amer. Journ. Sci., **30,** 161-171.

Variations graphically. Science, **31,** 867-868.

The grating interferometer. (With Maxwell Barus.) Phys. Rev., **31,** 591-598.

Interferometry and a new interferometer. Eastern Association of Physics Teachers. Report of the Fifty-Sixth Meeting, Providence, 13-21.

The compression of solid colloids. In, "Gedenkboek aangeboden aan J. M. van Bemmelen," 303-307. (De Boer.)

1911

Elliptic interference in connection with reflecting grating. Science, **33**, 113.

On an adjustment for plane grating similar to Rowland's for concave gratings, etc. (With Maxwell Barus.) Amer. Journ. Sci., **31**, 85-95.

Interferometry with the aid of a grating. Phil. Mag., **21**, 411-434.

Der Gang der Luft durch eine Wasserwand. Ostwald's Kolloidal Zeits., **8**, 286-291.

Transpiration of air through water. Amer. Phil. Soc., Proc., **50**, 117-124.

Elliptic interference with reflecting gratings. Amer. Phil. Soc., Proc., **50**, 125-138.

Elliptic and other interferences with reflecting gratings. Phil. Mag., **22**, 118-129.

Independence of coronas of the thickness of fog layer. Amer. Journ. Sci., **31**, 564-566.

Über sedimentation. Ostwald's Kolloidal Zeits., **9**, 14-16.

The production of elliptic interferences in relation to interferometry. Carnegie Publications, **149**, i-vi; 1-77.

The production of elliptic interferences in relation to interferometry, Part II. Carnegie Publications, **149**, Pt. 2, i-vi; 79-168.

1912

The diffusion of gases through water. Report of the Eighty-first Meeting of the British Association for the Advancement of Science, Portsmouth, 1911. Murray, London, p. 357.

Certain physical properties of the iron carbides, together with inferences deducible therefrom. *In,* Clark University, Lectures delivered at the celebration of the twentieth anniversary of the foundation of Clark University . . . Worcester, Mass., 128-161.

Rate of decay of different sizes of nuclei. Amer. Journ. Sci., **33**, 107-108.

Displacement interferometer adapted for high temperature measurement, adiabatic transformation of gas, etc. Amer. Journ. Sci., **33**, 109-119.

The rectification of the spectrum in relation to the shift of ellipses in displacement interferometry. Phil. Mag., **23**, 942-955.

Comparison of two screws. Amer. Journ. Sci., **34**, 333-337.

Viscosity of gases and Bunsen flame. Science, **36**, 320.

Interferometry of ionized air. Amer. Journ. Sci., **34**, 101-116.

Growth of air bubbles on the walls of a beaker, etc. Amer. Journ. Sci., **34**, 304.

The indices of doubly refracting crystals detected by displacement interferometry. Phil. Mag., **24**, 827-837.

1913

On a simple screw micrometer. Amer. Journ. Sci., **35**, 267-269.

Resolution of interference fringes. Amer. Journ. Sci., **35**, 308-310.

The *diffusion of gases through liquids and allied experiments.* Carnegie Publications, **186**, I-VI; 1-88.

Scattering in case of regular reflection, etc. Nature, **92**, 451.

1914

Electrometer with displacement interferometry. Amer. Journ. Sci., **37**, 65-86.

The *production of elliptic interferences in relation to interferometry.* Carnegie Publications, **149**, Pt. 3, I-VI; 169-273.

An application of the displacement interferometer to the horizontal pendulum. Amer. Journ. Sci., **37**, 501-513.

Note on mutual repulsion of rigid parallel plates separated by film of air. Amer. Journ. Sci., **37**, 350-351.

Contractions of the order of the Lorentz-Fitzgerald. Amer. Journ. Sci., **38**, 352-354.

The mathematician in modern physics. Science, **40**, 721-727.

1915

Mutual repulsion of rigid parallel plates. Amer. Journ. Sci., **39**, 93-104.

The use of compensators bounded by curved surfaces in displacement interferometry. Amer. Journ. Sci., **40**, 299-308.

Trains of beating light waves. Science, **42**, 350.

Interferences of crossed spectra, etc. Amer. Journ. Sci., **40**, 486-498.

Experiments with the displacement interferometer. Carnegie Publications, **229**, I-VI; 1-113.

Interferences with two gratings. Science, **42**, 841.

1916

Interferences of the direct spectra of two gratings. Phys. Rev., **7**, 587-598.

The interferences of reversed spectra. Amer. Journ. Sci., **41**, 414-434.

Distance between two parallel transparent plates. Phys. Rev., **7**, 79-86.

An apparent lateral reaction between identical pencils of light crossing each other at small angles. Science, **43**, 282-284.

Note on the interference of parallel and crossed rays. Science, **43**, 345-436.

Channeled grating spectra obtained in successive diffractions. Nat. Acad. Sci., Proc., **2**, 378-380.

Rotation of interferometer fringes. Amer. Journ. Sci., **42**, 63-73.

The interferometry of reversed and non-reversed spectra. Carnegie Publications, **249**, 1-158.

Interferometer methods based on the cleavage of the diffracted ray. Nat. Acad. Sci., Proc., **2**, 475-478.

The interferences of spectra both reversed and inverted. Nat. Acad. Sci., Proc., **2**, 576-578.

Methods in reversed and non-reversed spectrum interferometry. Amer. Journ. Sci., **42**, 402-420.

Path differences within which spectrum interferences are observable. Nat. Acad. Sci., Proc., **2**, 609-613.

Non-reversed spectra of restricted coincidence. Nat. Acad. Sci., Proc., **2**, 614-617.

1917

Methods in reversed and non-reversed spectrum interferometry. Amer. Journ. Sci., **43**, 145-162.

Refractivity determined irrespective of form by displacement interferometry. Nat. Acad. Sci., Proc., **3**, 117-122.

Note on complementary Fresnellian fringes. Nat. Acad. Sci., Proc., **3**, 432-436.

The displacement interferometry of large distances. Nat. Acad. Sci., Proc., **3**, 436-437.

The measurement of small angles by displacement interferometry. Nat. Acad. Sci., Proc., **3**, 412-415.

The interferometry of reversed and non-reversed spectra. Part II. Carnegie Publications, **249**, Part II, 1-146.

Experiments with the Foucault pendulum. Induction pendulum. Science, **45**, 265-270.

Displacement interferometry in connection with U-tubes. Nat. Acad. Sci., Proc., **3**, 334-339.

Theoretical relations in the interferometry of small angles. Nat. Acad. Sci., Proc., **3**, 563-565.

Note on interferometer methods of measuring the elastics of small bodies. Nat. Acad. Sci., Proc., **3**, 693-696.

Transverse displacement interferometry. Nat. Acad. Sci., Proc., **3**, 360-365.

The interferometry of small angles, etc. Methods by direct and reversed superposed spectra. Nat. Acad. Sci., Proc., **3**, 665-672.

1918

Types of achromatic fringes. Nat. Acad. Sci., Proc., **4**, 132-133.

Interference of pencils which constitutes the remote divergences from a slit. Nat. Acad. Sci., Proc., **4**, 134-136.

Note on methods of observing potential differences induced by the earth's magnetic field in an insulated moving wire. (With Maxwell Barus.) Nat. Acad. Sci., Proc., **4**, 66-70.

On the equations of the rectangular interferometer. Nat. Acad. Sci., Proc., **4**, 13-19.

Polarization of moving electrodes. Science **48**, 253-254.

Hygrometry in terms of the weight of a film of gelatine. Science, **48**, 374-376.

The interferometry of vibrating systems. Nat. Acad. Sci., Proc., **4**, 328-333.

Gravitational attraction in connection with the rectangular interferometer. Nat. Acad. Sci., Proc., **4**, 338-342.

The rectangular interferometer with achromatic displacement fringes in connection with the horizontal pendulum. Nat. Acad. Sci., Proc., **4,** 349-354.

1919

Note on a contact lever, using achromatic displacement fringes. Nat. Acad. Sci., Proc., **5,** 39-43.

Interferential contact lever experiments relating to the elastics of small bodies. Nat. Acad. Sci., Proc., **5,** 44-49.

Note on the self-adjusting interferometer in relation to the achromatic fringes. Nat. Acad. Sci., Proc., **5,** 53-58.

An adjustment in relation to the Fresnel coefficient. Nat. Acad. Sci., Proc., **5,** 120-125.

On Herschell's fringes. Science, **49,** 385-386.

Spectrum phenomena due to moving motes. Science, **49,** 72-74.

Displacement interferometry by the aid of the achromatic fringes. Part III. Carnegie Publications, **249,** Part III, 1-100.

Displacement interferometry by the aid of the achromatic fringes. Part IV. Carnegie Publications, **249,** Part IV, 1-122.

An electrodynamometer using the vibration telescope. Nat. Acad. Sci., Proc., **5,** 211-217.

The elongation due to magnetization. Nat. Acad. Sci., Proc., **5,** 267-272.

The interferometry of rapid vibrations, chiefly in relation to telephone currents. Nat. Acad. Sci., Proc., **5,** 331-340.

On the pressure variation of specific heat of liquids. Nat. Acad. Sci., **5,** 340-344.

The motion of a gravitating needle. Science, **50,** 214-216.

The interaction of gravitating and radiant forces. Science, **50,** 29-82.

The displacement of the gravitating needle in its dependence on atmospheric temperatures. Nat. Acad. Sci., Proc., **5,** 547-550.

1920

An example of torsional viscous retrogression. Nat. Acad. Sci., Proc., **6,** 1-3.

On spiral nebulae. Science, **52,** 112-113.

L'interferometrie et les appareils interferentiel. Revue Generale des Sciences, **12,** 401-409.

Notes on a pneumatic method of measuring variations of the acceleration of gravity. Nat. Acad. Sci., Proc., **6,** 495-498.

Note on torsional measurement of variations of the acceleration of gravity by interference methods. Nat. Acad. Sci., Proc., **6,** 498-502.

Compression of a sound wave. Science, **52,** 586-588.

1921

Adjustable embouchure. Science, **53,** 47-48.

Acoustic pressure and acoustic dilatation. Science, **53,** 489-494.

An analogy between the theories of natural selection and electrolysis Science, **54,** 53.

Pneumatic paradox in acoustics. Science, **54**, 155-156.
The energy content of the diapason. Nat. Acad. Sci., Proc., **7**, 47-50.
The open mercury manometer read by displacement interferometry. Nat. Acad. Sci., Proc., **7**, 71-75.
The diffusion of air through water in the lapse of years. Nat. Acad. Sci., Proc., **7**, 133-134.
Acoustic pressure distributions, chiefly in reservoirs and in pipes. Nat. Acad. Sci., Proc., **7**, 207-213.
The U-tube absolute electrometer. Nat. Acad. Sci., Proc., **7**, 242-244.
Displacement interferometry applied to acoustics and to gravitation. Carnegie Publications, **310**, i-viii, 1-149.

1922

Experiments with the vacuum gravitation needle. Nat. Acad. Sci., Proc., **8**, 13-15.
On summaries of recent advances in physics. Science, **55**, 19-20.
Acoustic topography in a room. Science, **55**, 321-326.
Periods and logarithmic decrement of the gravitation needle under high exhaustion. Nat. Acad. Sci., Proc., **8**, 63-66.
Plane reflection of sound, as exhibited by the pinhole resonator. Nat. Acad. Sci., Proc., **8**, 66-69.
Acoustic topography varying with the position of the organ pipe. Nat. Acad. Sci., Proc., **8**, 96-100.
Cylindrical distribution of nodal strength around the pipe normal. Nat. Acad. Sci., Proc., **8**, 119-123.
Positive and negative pinhole resonators. Nat. Acad. Sci., Proc., **8**, 163-165.
Static deflections of the vacuum gravitation needle. Science, **56**, 451-453.
Static deflection, logarithmic decrement and first semi-period of the vacuum gravitation needle. Nat. Acad. Sci., Proc., **8**, 313-316.
On a comparison of the relative sensitiveness of telephones. Nat. Acad. Sci., Proc., **8**, 326-327.
The equilibrium positions of the vacuum gravitation needle in 1921 and 1922. Nat. Acad. Sci., Proc., **8**, 327-330.

1923

Glue bubbles. Science, **57**, 151-153.
Gaseous viscosity measured by the interferometer U-tube. Nat. Acad. Sci., Proc., **9**, 71-72.
Sparkless sparks. Science, **57**, 420-421.
The displacement of the capillary electrometer, for progressive dilutions of the electrolyte. Nat. Acad. Sci., Proc., **9**, 156-158.
Note on equations for tortuosity in Thomson and Tait's "Natural Philosophy." Science, **57**, 562.
Interferometer experiments in acoustics and gravitation, II. Carnegie Publications, **310**, Part II, I-VIII; 1-113.

The vibration of air in tubes capped at both ends. Nat. Acad. Sci., Proc., **9**, 263-65.

The vibration of the air filament in quill tubes capped at both ends. Nat. Acad. Sci., Proc., **9**, 266-268.

Achromatic and superchromatic fringes with a calcite rhomb. Nat. Acad. Sci., Proc., **9**, 373-376.

Vibration of the air filament in quill tubes. Single telephonic exciter. Nat. Acad. Sci., Proc., **9**, 376-378.

1924

Vibration in spark-blown closed quill tubes. Electric oscillation. Nat. Acad. Sci., Proc., **10**, 1-3.

Exhibit of telephonic excitation of acoustic pressure. Nat. Acad. Sci., Proc., **10**, 96-99.

Density and diffusion of gases measured by displacement interferometry. Nat. Acad. Sci., Proc., **10**, 153-155.

The hodograph of Newtonian hyperbolic reflection. Science, **59**, 260.

Sensitive flames and apparent flame pressure. Science, **59**, 137-138.

Density and diffusion measurement by displacement interferometry in extreme cases. Nat. Acad. Sci., Proc., **10**, 349-351.

The diffusion of hydrogen into air, measured by the interferometer U-gauge. Nat. Acad. Sci., Proc., **10**, 447-452.

Review of Pierre Curie, By Madame Curie. Translated by Charlotte and Vernon Kellog . . . Macmillan, New York, 1923. Amer. Hist. Rev., **29**, 601.

1925

Review of Histoire de la nation francaise. Dirigee par Gabriel Hanotaux. Tom. XIV. Histoire des sciences en France, v. 1. Plon-Nourrit et Cie., Paris, 1924. Amer. Hist. Rev., **30**, 589-91.

Pinhole probe measurements of the phase change of the telephonic end plates, acting on a closed cylindrical air column in longitudinal acoustic vibration. Nat. Acad. Sci., Proc., **11**, 260-264.

The effect of commutation of impedances on the acoustic pressure, produced by paired telephonic systems. Nat. Acad. Sci., Proc., **11**, 494-498.

Inductance treated acoustically by differential telephones. Nat. Acad. Sci., Proc., **11**, 408-412.

The acoustic pressure in tubes capped by high resistance telephones vibrating in different phases. Nat. Acad. Sci., Proc., **11**, 581-584.

Telephonic coupling of acoustic and electrical oscillations evidenced by the pinhole probe. Nat. Acad. Sci., Proc., **11**, 728-732.

Interferometer experiments in acoustics and gravitation, III. Carnegie Publications, **310**, Part III, i-ix; 1-165.

1926

Resonant acoustic and electric oscillations released by the relatively slow spring break. Nat. Acad. Sci., Proc., **12**, 137-140.

Mutually counteracting pinhole probes. Nat. Acad. Sci., Proc., **12**, 223-227.

Acoustic pressures in case of soap bubbles. Nat. Acad. Sci., Proc., **12**, 480-482.

Acoustic pressure promoted by coöperating quill tubes without pinholes. Nat. Acad. Sci., **12**, 482-486.

Three phenomenal ages of cultural advance. Honor's Day address. Brown University Papers, IV.

1927

Pinhole probe record of the closed organ pipe. Nat. Acad. Sci., Proc., **13**, 52-56.

Pinhole probe experiments with massive air columns. Nat. Acad. Sci., Proc., **13**, 87-91.

Pinhole probe measurements with massive cylindrical air columns. Nat. Acad. Sci., Proc., **13**, 223-227.

Linear elements of the electromagnetic pinhole graphs. Nat. Acad. Sci., Proc., **13**, 313-315.

Reciprocating acoustic vibration on opposite sides of the pinhole in long quill tubes. Nat. Acad. Sci., Proc., **13**, 579-583.

Efficiency of pinhole probes. Science, **65**, 329-331.

The electric wind pressure phenomenon. Science, **65**, 448-450.

Mucronate electrode with micrometer. Nat. Acad. Sci., Proc., **13**, 457-460.

Pressure phenomena of the mucronate anode. Nat. Acad. Sci., Proc., **13**, 503-505.

Graphic treatment of Euler's equations. Science, **66**, 114-115.

The convective spark discharge of the mucronate electrode. Science, **66**, 358-359.

Acoustic experiments with the pinhole probe and the interferometer U-gauge. Carnegie Publications, **383**, i-x, 1-158.

Change of convective to spark discharge. Science, **66**, 658-659.

1928

Experiments with modified mucronate electrodes. Nat. Acad. Sci., Proc., **14**, 188-191.

Anode and cathode sparks differentiated by the mucronate electrode. Nat. Acad. Sci., Proc., **14**, 248-251.

Sparks of the induction coil between mucronate electrodes. Nat. Acad. Sci., Proc., **14**, 465-469.

Little circle of reference. Science, **67**, 530-531.

Telescopic observations of cathode and anode points. Science, **67**, 248-249.

Reminiscences over fifty years. Columbia Alumni News, **31**, 57.

The repulsion between electric currents and their induced eddy currents in parallel. Nat. Acad. Sci., Proc., **14**, 542-544.

The displacement interferometry of barometric pressure. Nat. Acad. Sci., Proc., **14**, 641-645.

Diagrams relative to Hamilton's canonical equations. Science, **48**, 276-277.

Further experiments in microbarometry. Nat. Acad. Sci., Proc., **14**, 771-773.

The interferometer U-gauge with closed auxiliary reservoirs. Nat. Acad. Sci., Proc., **14**, 855-857.

Chemical reaction in the interferometer U-gauge. Nat. Acad. Sci., Proc., **14**, 939-943.

1929

Adiabatic expansion in case of vanishing increments. Nat. Acad. Sci., Proc., **15**, 22-25.

Euler's tensor and Hamilton's cubic. Science, **69**, 248.

Adiabatic expansion in case of vanishing increments, II. Nat. Acad. Sci., Proc., **15**, 237-241.