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GEORGE ELLERY HALE

1868–1938

BY

WALTER S. ADAMS

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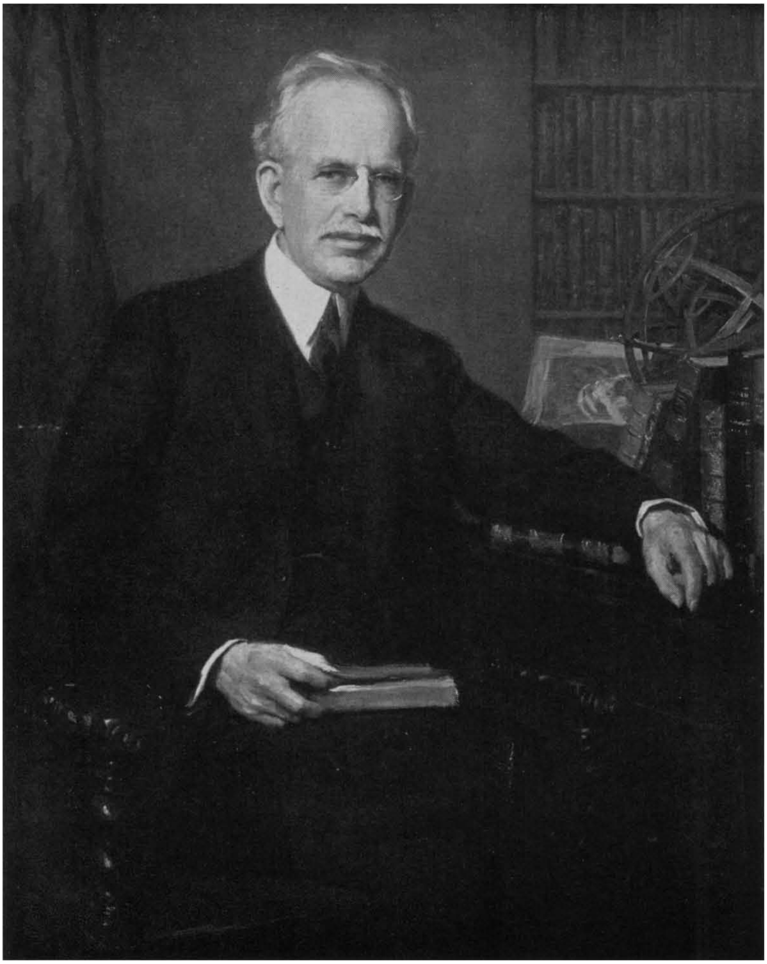

George E. Hale

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George Ellery Hale, distinguished scientist and for many years one of the leading members of the National Academy of Sciences, was born in Chicago on June 29, 1868. His family can be traced backward to Thomas Hale, a farmer of some property who lived at Watton-on-Stone, Hertfordshire, England. He died in 1630 and his son, also named Thomas, emigrated to America about 1640 and settled at Newbury, Massachusetts. Later he moved to Haverhill and must have been active in town affairs, since in 1646 he was chairman of the Board of Selectmen. Successive generations of sons lived in Newbury and vicinity and were numbered among the merchants, carpenters, and weavers of that slowly growing New England community.

The great-grandfather of George Hale, Benjamin by name, moved to Boston and kept the Eastern Stage House, an inn frequented by sea-faring folk and mentioned in King's Handbook of Boston. His son, Benjamin Ellery, was born in 1809 and became a Congregational minister, occupying pastorates in several Massachusetts towns. He became greatly interested in the cause of temperance, delivering many lectures on the evils of alcohol; and when he later moved to Hartford, Connecticut, and gave up the ministry owing to failing eyesight, he organized an insurance company which limited its risks to people of temperate habits. In 1854 he went to Beloit, Wisconsin, and took a position with the Rock River Paper Company. When this concern moved to New York he went with it and lived for some time in Brooklyn. He died in 1882.

Benjamin Ellery Hale was married twice and of the six children of his first marriage William Ellery, father of George, was born on April 8, 1836. He received his early education in the public schools of Hartford, Connecticut. A few years after his parents moved to Beloit he went to Chicago as agent for the Rock River Paper Company and became interested in that rapidly developing city. He erected a building at the corner of State and Washington Streets which was destroyed in the great fire of 1871. During its reconstruction the possibilities of hydraulic elevators attracted him greatly, and in partnership with his brother George W. Hale he established the firm of William E. Hale and Company to manufacture and install passenger elevators under patents purchased from Cyrus W. Baldwin. The firm prospered, and when some 20 years later the two brothers sold their interests to the Crane Company, each had acquired a considerable fortune.

In 1862, at about the time William E. Hale came to Chicago, he married Mary Browne, daughter of Dr. Gardiner S. Browne of Hartford, Connecticut. Five children were born of the marriage and of these three survived: George Ellery, born June 29, 1868; Martha Davis, born July 28, 1870; and William Browne, born December 7, 1875. George Hale was born in a house on La Salle Street, but a year before the great fire his father moved to the southern part of the city. Here in 1885 he built a stone house of considerable size at the northeast corner of Drexel Boulevard and Forty-Eighth Street.

Although not a college graduate, William E. Hale had a deep appreciation of the value of education to the individual and to society and was generous in its support. He became a trustee of Beloit College and contributed the endowment for a hall of science at that institution. Most interesting of his characteristics, however, and of those of his wife as well, were their ability to recognize the rare intellectual gifts of their son George and the constant encouragement which they afforded him as his mind began to unfold and his interests to develop. In later years Hale referred again and again to the decisive part which his father and mother took in this formative period of his youth.

It is an extremely interesting picture which we can form of Hale in the early years of his life. Born with a quick and active mind and an insatiable curiosity about every fact and process in the physical world about him, he had the constant sympathy and encouragement of a father who helped to develop his natural interest in tools and methods of work and aided him to establish at a very early age an intelligent knowledge of his relations to the community; and of a mother who formed his tastes in reading and opened for him all the delights of the poetry and literature of the past. His fondness for poetry began with the Iliad and Odyssey and developed more and more strongly throughout the years; and to his wide reading during his early life must be ascribed the development of his creative imagination, a characteristic which aided and enriched so greatly his later scientific work.

So we see the young boy transforming his bedroom and later a small hallroom into a little shop, surrounded by his tools, his scroll saw and a simple wood lathe. One Christmas day his father gave him a lathe for turning metal, and these early interests in machinery and the construction of instruments remained with him throughout his life. A small microscope was another of his most highly prized possessions, and with his younger brother and sister he made many a collection of rotifers and infusoria from the stagnant ditches of Kenwood for examination. Already he was learning the fascination of the marvelous worlds hidden from the unaided eye. He delighted in such books as "The Young Mechanics" and "The Boy Engineers", both published in London, and he and his brother were soon led through the father's encouragement to build with their own hands a shop of their own. In a room ten by fifteen feet in size they installed their tools and work benches, built a small horizontal steam engine and finally with the aid of a second-hand boiler had the great joy of operating a power-driven lathe. The building also served the purposes of a tiny physical laboratory.

The use of his first microscope in the study of infusoria had interested the young boy in optics. This interest was greatly deepened by the acquisition of a fine Beck instrument which his father had given him after solemnly submitting him to a successful examination upon the results of his work. He soon obtained a small camera with which he made photographs of microscopic objects, and other possibilities at once began to present themselves. His first telescope he built in his own shop, but the simple lens used naturally failed to give good images. At about this time he became acquainted with S. W. Burnham, who served as stenographer in the Chicago law-courts by day and observed double stars by night. Through Burnham's aid Hale's father purchased a second-hand Clark refractor which was mounted on the roof of the house at Kenwood, and the 14-year-old boy was amazed and delighted with the views of the moon and planets afforded by the excellent lens. He promptly began making photographs, observed a partial eclipse of the sun, and commenced drawings of sun-spots. His feet had entered upon the long road of scientific research.

It is clear from this brief summary of Hale's earliest years that his interests had already become defined. They lay in physics and physical applications, in instruments and experimental methods, and not in the more formal types of observation of classical astronomy. He became an enthusiastic disciple of the youthful science of astrophysics, and his prophets were Huggins, Lockyer and C. A. Young. He soon built a simple spectroscope in his shop, and his interest and excitement in observing the solar spectrum and measuring the principal lines remained in later life as one of the most vivid memories of his boyhood. Up to the time of his death Hale could never look at a high-dispersion solar spectrum without an intense feeling of pleasure and anticipation. During these early years he read avidly all he could find regarding spectra, and the greatly worn copy of Lockyer's "Studies in Spectrum Analysis" still remaining in Hale's library bears witness to the extent to which it was used by the enthusiastic boy. He soon learned of the work of Rutherfurd and Rowland, and in the larger laboratory in the upper story of the new house built by his father in 1885, Rutherfurd's long photographic map of the solar spectrum hung on the wall near the grating spectroscope.

Although this picture of Hale's boyhood emphasizes his interest in science and scientific instruments, he was altogether a normal boy in his pleasures in life. He fished and swam and skated, played tennis, rode a bicycle, and built both a canoe and an ice-boat. He even gave magic performances, building most of the "properties" used in his exhibitions. He read Jules Verne's stories with great enthusiasm and took especial delight in certain tales of adventure laid in California, the mountains of which seemed to attract him even at that time. His summers he nearly always spent at his grandmother's house in Madison, Connecticut, a pleasant old New England village where time had apparently stood still and ox-carts still moved about the streets. The contrast between the busy life of Chicago and the placid life of the inhabitants of the little country town on Long Island Sound interested George Hale greatly, and he often spoke in later life of his satisfaction in having known a little of the Puritan civilization before it had so nearly disappeared.

Not far from his grandmother's home in Madison was the house of the mother of Evelina Conklin and there he met his future wife whose affection and understanding and courage made possible the long and illustrious career which lay before him.

Hale's individualism and his interest in tasks of his own selection he carried with him into his school life. After passing through the Oakland Public School in Chicago he entered Allen Academy where the principal, Ira W. Allen, recognizing the boy's talents, gave him unofficial charge of the very limited physical apparatus and allowed him to serve as assistant in demonstrations before the classes. Courses in elementary chemistry, physics and astronomy supplemented his home reading, and an additional course in shop-work at the Chicago Manual Training School gave him valuable experience in a field in which he was already competent. Meanwhile his reading and activities in directions other than physics and astronomy had widened his interests greatly. "The Origin of Species" affected him profoundly and gave him a lasting desire to apply evolutionary principles to other fields of science. His father had been closely associated in business with the well-known architect Daniel H. Burnham, and through him Hale acquired a knowledge of the principles of architecture and city planning which he put to excellent use in later years. It was on Burnham's advice that in 1886 at the age of seventeen Hale selected the Massachusetts Institute of Technology for his later studies.

1886–1892

The four years at the Massachusetts Institute were exceedingly busy ones. The course of study in physics together with the chemistry and mathematics, which he had selected, occupied his time very fully, but he still found it possible to continue his astronomy at the Harvard College Observatory where Edward C. Pickering allowed him to serve as volunteer assistant. He did much reading of original articles on astronomy and spectroscopy in the Boston Public Library. His interest in art and music developed greatly during this period, and the beginnings of his life-long friendship with his classmate Harry M. Goodwin gave him a companion of similar views and tastes.

Before Hale left Chicago to enter the Institute he had designed a spectroscopic laboratory which was soon built on a lot adjoining the house in Kenwood. The equipment included a heliostat and a spectrograph of ten feet focal length with a Rowland concave grating. This instrument he used during his summer vacations in the study of arc, spark and solar spectra. However, having seen a solar prominence for the first time with C. A. Young's telescope, his active mind began to search for a method of photographing prominences in full daylight and thus obtaining a full and permanent record of these important solar phenomena. This was the beginning of the spectroheliograph. The first instrument, which was used with a horizontal telescope at the Harvard Observatory in the winter of 1889-90, did not give satisfactory photographs because of imperfections in the instrument, lack of guiding mechanism, and distortion of the solar image, but it was clear that the principle and method were fully adequate. When he returned to Chicago his father offered to provide a telescope of sufficient size to carry the spectroheliograph, and a 12-inch refractor with lens by Brashear and mounting by Warner and Swasey was ordered. The building and dome together with a room for a library were erected against the south front of the existing spectroscopic laboratory, and the completed equipment came to form the Kenwood Observatory.

During the period of construction of the telescope Hale worked in his laboratory. A visit to the Lick Observatory, which he had made immediately after his marriage in June 1890, had impressed him enormously with the possibilities of a powerful spectrograph on a large telescope in the hands of such skilled observers as Keeler and Campbell. As a result of Keeler's investigations on the spectra of planetary nebulae, Hale made a study of the bands of magnesium and published his conclusions in a paper in the *Sidereal Messenger*, January 1891. He had previously published several short articles dealing mainly with stellar and solar photography in the *Beacon, Technology*

Quarterly and *Astronomische Nachrichten.* His earliest known publication was in March 1889.

As soon as the new instruments were ready for use in the spring of 1891, Hale began active work with his spectroheliograph. He discovered in the spectra of prominences the remarkable brightness of the H and K lines, which he had found to be due to calcium, and thus had at hand an ideal means of photographing solar phenomena with existing plates. It was not until years later that red-sensitive emulsions made possible the use of the α line of hydrogen as well. He obtained some satisfactory photographs of prominences at this time and as a result of experience designed an improved form of spectroheliograph with two moving slits driven by a clepsydra which was ordered from Brashear. While the instrument was under construction he left for a trip to Europe with Mrs. Hale.

The purpose of this trip was twofold. First, he wished to acquaint himself with many astronomers with whose published work he was familiar and to study their methods and equipment. Secondly, he wished to secure their views and, if these were favorable, their support for the new astrophysical publication which he had in mind—a journal in which physicists and astronomers would find a common meeting ground. In both objects he was remarkably successful. Astronomers and physicists in England and Continental Europe were only too glad to discuss their problems with the brilliant young man whose inventive skill was already well known to them. They also joined heartily in the plans for the new publication, and on his return from Europe with the endorsements of a score of eminent scientific men he started the journal at first known as *Astronomy and Astrophysics.* For three years it represented a combination with the *Sidereal Messenger,* but beginning with 1895 this plan was discontinued and the *Astrophysical Journal* began its long and noteworthy career. Hale and Keeler were its first editors, supported by a strong board of collaborating scientists.

On his return to Chicago, Hale began active work with the new spectroheliograph which proved to be a most successful instrument. Photographs of solar spectra had shown that the H and K lines are bright, not only in the chromosphere and prominences, but also in the vicinity of sun-spots and over irregular regions scattered over the sun's surface. With the spectroheliograph he now succeeded in photographing over the entire sun these calcium clouds to which he gave the name of "flocculi." The systematic study of the flocculi has proved of great importance ever since their discovery, and the probable relationship of rapidly developing and changing flocculi and disturbed areas near sun-spots to magnetic storms on the earth was found by Hale in July 1892. Most of his results are given in publications in *Astronomy and Astrophysics.* The extent of the work at the Kenwood Observatory is indicated by the fact that more than 3000 spectroheliograms were taken by Hale and his assistants, more especially by Ferdinand Ellerman who came to Kenwood in 1892. In addition to his observing Hale found time to organize the astronomical exhibit at the Columbian Exposition in Chicago in 1893, and to act as secretary of the section of astronomy and astrophysics of the international congress held at that time.

1892–1903

Wider plans had begun to develop in Hale's mind by this time. The University of Chicago had recently been founded by John D. Rockefeller, and although it had not yet been formally opened, its wise and far-sighted President, William R. Harper, had already appointed Hale to its faculty. During a meeting in Rochester, New York, of the American Association for the Advancement of Science Hale had met Alvan Clark, who told him of two 40-inch disks of optical glass, originally ordered for the University of Southern California but now, owing to financial difficulties, once more available for purchase at cost. The possibility of securing these for the new University of Chicago at once attracted Hale, and President Harper was in full agreement. Several Chicago business men were appealed to on the subject, and finally Charles T. Yerkes agreed to provide the funds for the purchase of the disks and the completion of the optical work. Soon afterward, influenced by Hale's enthusiasm and persuasiveness, he also promised to provide for the mounting of the telescope. No provision, however, was made for the building and other equipment, and it was only after a long delay, when Hale was again in Europe, that Yerkes finally consented to construct the observatory building. Much of this was designed by Hale in correspondence with Henry Ives Cobb, the University architect.

The second European visit was partly for pleasure but mainly for research and further study. In England he renewed many of the associations he had made on his earlier visit and added greatly to the number of his friends. Especially in the case of Professor Newall of Cambridge, a close friendship was established which lasted throughout Hale's life. At Berlin he attended lectures at the University by Planck, Rubens and others, and with his friend Goodwin attempted some investigations with photoelectric cells. His chief interest, however, lay in the astrophysical work in progress at Potsdam, and in the course of many visits he became intimately acquainted with the investigations of Vogel, Scheiner, and the other members of the able group of that period. Nevertheless, neither the climate nor the German food agreed particularly well with Hale, and at the end of a single semester he and Mrs. Hale started for Italy by way of Vienna.

The change from the cold and darkness of northern Europe to the warmth and sunshine of Italy impressed Hale enormously. As he often said, he was always a true son of the south. He spent a few days in Venice, visited Florence where the Astrophysical Observatory was under construction and where he discussed solar problems with Tacchini and the elder Abetti, and then journeyed down through Rome to Southern Italy and Sicily. At Catania he met a fellow solar physicist in Riccò, and with him planned an ascent of Etna. A year earlier Hale had tried with the spectroheliograph to photograph the solar corona without an eclipse, both at Kenwood and on Pike's Peak, but without success. With the blue skies above the summit of Etna he hoped for better observing conditions. The spectroheliograph was attached to the equatorial telescope of the Bellini Observatory (elevation 9600 feet), and the second slit of the instrument was set on the broad K line for the purpose of reducing the intensity of the sky spectrum near the sun and recording the coronal streamers by means of their continuous spectrum. The results, however, were negative, although the two scientists spent a week in the attempt. In the last years of his life Hale had the great satisfaction of learning of a successful solution of this problem through a somewhat different method by Lyot in France.

On his return to Chicago, Hale became immersed in the difficult financial problems of the Yerkes Observatory. No endowment had been given for equipment or maintenance, and the heavy demands upon the University of Chicago prevented it from devoting more than very limited funds to the operation of the Observatory. Hale was obliged to seek gifts in small amounts from every possible source and to conserve his small resources in every way. With courage and hope, however, he built up a strong staff, bringing Barnard from the Lick Observatory and Wadsworth from Michelson's laboratory at the University. Burnham, who had returned to Chicago from Mount Hamilton, gladly undertook observations of double stars two nights each week, and Ellerman came with Hale from Kenwood. Ritchey, a teacher in the Chicago Manual Training School, was engaged privately for optical work at a somewhat later date. Hale's greatest disappointment was his inability to secure Keeler as stellar spectroscopist, the Directorship of the Lick Observatory having been offered to Keeler at just this time. Edwin B. Frost was engaged for this position not long afterward. All the Kenwood equipment, including the 12-inch telescope and dome and the machine tools, was given to the Yerkes Observatory, the small instrument shop was organized, and little by little additions were made to the limited apparatus available at the beginning.

Hale's scientific work was of necessity considerably interrupted during this period by the many difficult responsibilities which he was carrying, but with the completion of the large Rumford spectroheliograph which he had designed he had a powerful instrument for continuing his solar investigations. With its aid he soon discovered dark hydrogen flocculi and the comparatively rare dark calcium flocculi, and by using different portions of the broad K line was able to study the distribution of calcium vapor at different levels in the sun's atmosphere. These results, combined with measurements of the radial motions of the gases in the flocculi, added much to our knowledge of circulatory processes in the sun. A description of the spectroheliograph, together with a discussion of the observations and many illustrative plates, is found in *Publications of the Yerkes Observatory,* Volume III, Part I. In the same publication Hale also discusses the relative value of various types of investigations in solar physics and formulates some of the principles which governed much of his work in later years.

The spectroscopic study of sun-spots, prominences and the solar chromosphere had always interested Hale greatly. The short-focus grating spectrograph attached to the 40-inch refractor formed an admirable instrument for observations which did not require very high dispersion, and with it he observed widened lines in sun-spots, discovered the bright lines of the green carbon fluting at the edge of the sun, and obtained some excellent photographs of the ultraviolet spectrum of prominences and the chromosphere. It was clear, however, that for much of this work larger and more powerful spectrographs than could be attached to the 40-inch refractor were needed. Accordingly his mind turned to the possibilities of fixed coelostat telescopes which would at the same time provide large images of the sun and make possible the use of spectrographs of any desired length. The results of his thought on this problem were embodied in the horizontal telescope built at the Yerkes Observatory in 1902. This was partially destroyed by fire, but through the gift of Miss Helen Snow of Chicago a larger and more complete instrument took its place. In 1904 the Snow telescope was brought to Mount Wilson and through purchase became a permanent part of the equipment of the new observatory established soon afterward. The development of this instrument into the tower telescope forms an exceedingly interesting illustration of Hale's remarkable appreciation of observational needs and of his resourcefulness in meeting them.

Although primarily interested in solar physics, Hale always realized that the sun is a typical star and was quick to apply to the field of stellar spectroscopy any results found from a study of the sun. Similarly, throughout his life, he was a strong advocate of the value of a spectroscopic laboratory in which to study spectra under controlled conditions and imitate, at least in part, the phenomena found in sun and stars. Several of his most brilliant discoveries of later years were greatly aided by the fact that laboratory resources were available for purposes of test and comparison. It is of interest to note that two of his principal publications while at the Yerkes Observatory illustrate these conceptions most clearly. In his monograph on "The Spectra of Stars of Secchi's Fourth Type" (with Ellerman and Parkhurst) he dealt with a class of stars of low temperature showing certain marked similarities of spectrum to that of sun-spots; and in the paper "The Spectrum of the High-Potential Discharge between Metallic Electrodes in Liquids and in Gases at High Pressures" (with Kent) he made a laboratory study of spectral phenomena which seemed at that time to bear a striking resemblance to certain features of the spectra of stars and especially novae.

In concluding this brief account of Hale's years at the Yerkes Observatory I can fortunately add a brief statement in his own words of the principal ambitions governing his scientific investigations of this period.

(1) To continue the development of the spectroheliograph and learn more of the nature of the flocculi and the possible terrestrial effects of solar eruptions.
(2) To study, under the highest possible dispersion, the spectra of various solar phenomena, especially sun-spots and the chromosphere.
(3) To continue my investigation of stellar evolution and to photograph the spectra of the brighter stars on a scale as great as that of Rowland's photographs of the solar spectrum.

The first two of these desires Hale fulfilled abundantly within the next few years, but the third he was obliged, because of insufficient strength, to leave to others.

1903–1922

The announcement in 1902 of the gift by Andrew Carnegie of ten million dollars to establish an institution devoted to pure research came to Hale quite unexpectedly, but he immediately foresaw the possibilities which it presented. After years of difficult and often disappointing search for funds to equip and maintain the Yerkes Observatory, the possible chance that funds might be available for establishing a solar observatory in the best possible climatic location free from any considerations due to affiliation with an educational institution stirred his mind to the very depths. Here was an opportunity not only to undertake solar research under the most favorable conditions but to plan the equipment to fit the problems in view. His first contact with the Carnegie Institution was as secretary of the Advisory Committee on Astronomy of which Pickering was chairman. Its duties were primarily to survey the field of astronomy and make recommendations for a number of small grants. This function, however, did not entirely satisfy the conceptions of one of the leading members of the Executive Committee, Charles D. Walcott, nor was it altogether in keeping with Mr. Carnegie's own views. Accordingly in a letter to the Committee, Walcott expressed the hope that not only would minor grants and problems be considered but that major projects involving large expenditure be suggested as well. The sole criterion to be considered was the merit of the proposed work. As a result the report of the Advisory Committee contained, in addition to recommendations of appropriations in aid of individual investigations at existing institutions, a proposal for the establishment of a southern observatory with a large reflector for stellar observations, and of a solar observatory at a high altitude in as favorable a climate as possible.

At the meeting of the Executive Committee favorable action was taken upon various individual grants and a special committee, consisting of Lewis Boss, W. W. Campbell and Hale, was appointed to advise on the proposed southern and solar observatories. An appropriation was also made to provide for the study of possible sites in the northern and southern hemispheres by W. J. Hussey of the Lick Observatory. The full report of this committee, together with a detailed statement by Hussey of the results of his investigations of sites, appeared in the Year Book of the Carnegie Institution for 1903. The project of the two observatories was approved in principle by the Executive Committee, and although the income of the Institution was insufficient to provide for the solar observatory as planned by Hale, which was to include a large reflecting telescope for the study of stellar evolution, it was believed that a special gift by Mr. Carnegie would be made for this purpose. Mount Wilson had provisionally been selected as the site and the directorship had been offered informally to Hale.

In the autumn of 1903 Mrs. Hale accompanied by the two children came to Pasadena for the winter. The elder child Margaret had suffered severely from repeated attacks of bronchitis and asthma in the severe climate of Wisconsin and the journey was made in the hope that the milder weather of the Pacific Coast would prove beneficial. Hale, himself recovering from an illness, remained in Chicago, awaiting with deep interest the final action of the trustees of the Carnegie Institution.

The report of the meeting of the trustees came as a severe disappointment. Various grants were made up to the limit of the available income, but no mention was made of the solar observatory or of any additional gift. Hale considered the situation deeply and with characteristic courage and hope decided to join his family in California and to investigate thoroughly the possibilities for solar research on Mount Wilson. He had visited the mountain in the previous June with Hussey and Campbell and had been immensely pleased with the conditions as they then appeared to him. Arriving in Pasadena on December 20, 1903, he soon made his second ascent, taking with him a small portable telescope. Observations with this instrument convinced him of the value of a larger telescope, and partly through personal contributions and partly through gifts from friends, he secured sufficient funds to bring from the Yerkes Observatory a coelostat telescope with a 6-inch lens having a focal length of 60 feet. He also succeeded in interesting John D. Hooker of Los Angeles in the plan for bringing Barnard with the Bruce 10-inch photographic telescope from the Yerkes Observatory to complete a photographic atlas of the Milky Way, and a gift was made by Mr. Hooker for this purpose.

There now began a novel and extremely interesting and enjoyable period in Hale's life. Depression vanished quickly in the brilliant skies of the mountain top, and the isolation and beauty of the natural surroundings made a strong appeal to many of his most deeply seated instincts. Two narrow trails were the only means of access to the mountain, and transportation of supplies and instruments was wholly by pack trains made up of burros and mules of ancient lineage. The only building on the mountain top was an old log cabin, badly out of repair, which the owners of the land on the summit kindly allowed Hale to occupy as a dwelling house. Repairs on this building, the installation of a large fireplace, and the construction of the piers for the coelostat telescope occupied Hale and his able assistant George D. Jones during two of the winter months. This was the beginning of the long connection of Jones with the Observatory: in later years as superintendent of construction he erected nearly every important instrument and building of its extensive equipment. In all this work Hale took an active and enthusiastic part, not hesitating to walk down the 9-mile trail in order to ride his bicycle into Pasadena after some needed supplies which he would then carry on his back up the mountain.

In March of 1904 Hale brought Ellerman from the Yerkes Observatory and together they erected the coelostat and 60-foot telescope. At first the beam of light from the coelostat was enclosed in a long tube of building paper protected by a canvas shield, but it was soon evident that the heating of the air in the tube made the image blurred and indistinct. The top of the tube was then removed and the canvas was stretched as a flat shield to the eastward, preventing direct sunshine from striking the tube. A very marked improvement resulted and on April 11 some excellent direct photographs of the sun were obtained. Hale soon afterward started down the mountain to prepare for his journey to Washington to attend the meeting of the National Academy of Sciences, and the completed negatives were brought to him by Ellerman on the afternoon of the same day. The next morning Hale started for Washington, taking the photographs with him.

In addition to his general desire to be present at the Academy meeting, Hale had two specific objects in mind. The first was to present to the Council of the Academy a plan he had conceived for the organization of the International Union for Cooperation in Solar Research: the second was to interest the trustees of the Carnegie Institution in a plan for bringing the Snow telescope from the Yerkes Observatory to Mount Wilson on an expeditionary basis. Both projects met with a favorable reception. The plan for the International Union was approved by Alexander Agassiz, President of the Academy, and by Simon Newcomb, and was favorably acted upon by the Council. A grant of $10,000 to bring the Snow telescope to Mount Wilson was made by the trustees of the Carnegie Institution, and several of the leading trustees, including J. S. Billings, Walcott and Weir Mitchell, expressed great interest in the project and held out the hope that additional funds might be granted at the annual meeting of the Institution in December. On his return from Washington to Chicago, Ha'e considered the entire situation most carefully and decided to add personally to the Institution appropriation such funds as seemed necessary to carry out his plans. These, however, were still limited to the conception of an expedition from the Yerkes Observatory and did not provide for the construction of the 60-inch telescope.

Early in May, Hale left Chicago for California taking with him two additional members of the Yerkes group, W. S. Adams and G. W. Ritchey. These with Ellerman, who had remained at Mount Wilson, and F. G. Pease who came about a year later, formed for several years the Mount Wilson staff. A small machine shop was established in Pasadena with Ritchey in immediate charge, and on Mount Wilson construction was begun upon the piers and building to support and house the Snow telescope. It was a period of intense physical and mental activity for Hale and one which he enjoyed beyond measure. The quiet and isolation of the mountain top appealed to him enormously and in the thousand details of planning and construction under pioneering conditions he found an interesting opportunity to apply his resourcefulness and inventive skill. He designed a special small horse-drawn truck, steered from either end, for transporting the heavier parts of the Snow telescope up the narrow foot-trail two feet in width; he planned the living-quarters for the staff, the first "Monastery," on a site selected after a strenuous afternoon devoted to cutting trails through the thick brush; he studied the water supply and means for developing it; but most of all he investigated in great detail methods for improving the definition of the sun's image, especially some hours after sunrise when radiation from the heated ground became most injurious. Tests of the "seeing" at different elevations above the ground, the effect of shielding the ground in the neighborhood of the beam incident upon the telescope, stirring with fans of the air traversed by the beam from the coelostat mirrors, and artificial heating of the backs of these mirrors to compensate for the distortion produced on their front surfaces by the sun's heat—all of these matters were studied with great care by Hale, and the conclusions were incorporated into the design of the building for the Snow telescope, and in later years into the design of the 60-foot and 150-foot tower telescopes. Although he felt a deep sense of responsibility at this time for the successful outcome of this development work as affecting his future recommendations to the Carnegie Institution, he always retained his hopefulness and courage and faced all his problems with a joyous light-heartedness which was a constant delight to his associates. The small group on Mount Wilson had been increased by the addition of Barnard who had brought the Bruce photographic telescope from the Yerkes Observatory to photograph the southern Milky Way, and the gatherings around the fireplace at the Monastery on the stormy evenings of the winter of 1904-5 with Hale present form one of the choicest memories of these early years of the history of Mount Wilson.

In the autumn of 1904 Hale went to St. Louis where as chairman of a committee of the National Academy he was making preparations for an international meeting at the Exposition called to organize the International Union for Cooperation in Solar Research. After this meeting he visited New York and Washington where he planned to report to Billings and Walcott, trustees of the Carnegie Institution, upon the results of his study of conditions on Mount Wilson. For this purpose he had much material available in the form of direct photographs of the sun taken with the 60-foot focus telescope, and records of day and night seeing over a period of nearly a year. His interview with Billings was one which Hale looked back upon with considerable amusement in later years, but at the time it seemed far from reassuring. Although, as Billings afterward acknowledged, he had a deep and favorable interest in the Mount Wilson project, he took a somewhat grim and pessimistic attitude toward Hale's detailed statement of his plans which would have disconcerted anyone less enthusiastic and fully convinced of the value of the case he was presenting. Together they visited Mrs. Draper, and Hale then went to Washington to interview Walcott. From him Hale received strong encouragement to revive the original project of a large solar observatory including the 60-inch reflector. The following day, at a meeting of the Executive Committee of the Trustees, Hale on the invitation of Walcott presented two plans, the first providing simply for a continuation of the expedition with the Snow telescope from the Yerkes Observatory, and the second for the establishment of an independent solar observatory and the construction of the 60-inch reflector. It was about two weeks later that Hale, on his way up Mount Wilson, received word over the decrepit single-wire telephone line running to Pasadena that the Executive Committee had acted favorably upon the larger project, had appropriated $150,000 for each of two years, and had authorized Hale to proceed with the immediate execution of the plan.

The establishment of a new observatory as a department of an institution devoted wholly to research came to Hale as the culmination of hopes and wishes held throughout many years. With his usual modesty he doubtless underestimated his capacity as a teacher, but there can be no question that his interest in research was the dominating influence of his life. Even the development and organization of strong departments of graduate study at the universities with which he was associated, made no such appeal to him as did the opportunity of carrying on his individual investigations under the conditions afforded him by the Carnegie Institution. Here he found for the first time the means of planning and building his equipment with a view to the problems in mind just as the physicist in the laboratory sets up his instruments for definite and specific experiments.

The problem of the 60-inch reflector was one of the first to be undertaken. The glass disk, for the purchase of which funds had long before been provided by Hale's father, was brought from the Yerkes Observatory, a new optical and instrument shop was built in Pasadena, and the figuring of the mirror and the design of the mounting and dome were commenced by Ritchey. The transportation of this material up Mount Wilson presented serious difficulty, and after much consideration of various possibilities, including that of a telpher cable line, Hale finally decided upon the widening of the existing foot trail into a road. This work was carried out in 1907 and 1908, the long and somewhat dangerous task of transporting the mounting and mirror on a primitive motor truck, supplemented by mule power, was accomplished successfully, and the first tests of the completed telescope were made in December, 1908. They proved extremely satisfactory, and the way to one of Hale's cherished ambitions, the physical study of stellar spectra and of the evolution of stars, now seemed to lie open before him.

In the meantime the Snow telescope was in regular operation with a large spectroheliograph of special design. To aid in the interpretation of the results found with this instrument, a special study was made of the behavior of the H and K lines over the flocculi and other regions of the sun's surface with an 18-foot spectrograph. Two determinations of the rotation period of the sun were also completed by Hale and his colleagues: the first from the motions of the flocculi (to aid in the measurement of which Hale designed a special projection instrument called the heliomicrometer); and the second, a spectrographic determination based upon the Doppler displacements of lines at opposite limbs of the sun. A more important and, in its future application, extremely fruitful investigation was that on the spectrum of sun-spots which was begun in 1906. Visual observations of widened lines had been made previously at several observatories, but photographic methods were only just beginning to be applied. With the excellent definition often found at Mount Wilson a great amount of new and interesting material became at once available on the photographs, and their study became a major investigation of the next few years.

The Snow telescope with its specially designed house of louvre walls was yielding excellent results, but still Hale was not satisfied with the duration of the good seeing conditions. For some two to three hours after sunrise the sun's image would remain sharp and clear, but then air waves rising from the heated ground and to some extent disturbances within the telescope house would produce blurring and lack of definition. To reduce and at least partially eliminate these effects, and because he had larger spectrographs in mind, Hale conceived the tower telescope, the first of which was built in 1908. In this type of instrument the coelostat on top of the tower receives the sunlight well above the air waves near the ground, and the image-forming lens sends a vertical beam (much less sensitive to disturbances than a horizontal beam) downward to the ground level where the image is produced. A long vertical spectrograph is placed in a deep underground pit and receives the benefit of reasonably constant temperature. Another feature of this telescope was the use of very thick mirrors to resist deformation by the sun's heat. With the marked improvement in the solar definition afforded by this instrument, especially toward the middle of the day, with a 30-foot spectrograph in the vertical pit, and with ease and convenience of operation, the 60-foot tower telescope soon became one of the major solar instruments on Mount Wilson and a model for instruments of similar type in other parts of the world.

Hale had always believed strongly in the great value of affording facilities to astronomers and physicists to undertake special investigations at any location where instrumental or climatic conditions were especially favorable for their work. With this in mind he invited C. G. Abbot in 1906 to undertake measures of the solar radiation at Mount Wilson, E. F. Nichols to study very long-wave radiation in the sun's spectrum, W. H. Julius to investigate anomalous dispersion with the spectroheliograph, and H. G. Gale to undertake spectroscopic work in the small physical laboratory then available on the mountain top. He also gained Kapteyn's assent to becoming a research associate of the Observatory and affording his invaluable advice and judgment regarding problems of stellar research. The result of Hale's policy was to keep the comparatively isolated staff on Mount Wilson in close touch with many of the men and problems which counted for most at this period in the history of astrophysics.

During these years of intense scientific activity, the busiest and probably the most enjoyable of Hale's life, two investigations among the many in which he was engaged stand out with especial prominence. Both had to do with sun-spots, the phenomena of which had fascinated him from childhood. The first of these, in which he had as associates Gale and Adams, resulted in an explanation of many of the chief features of the sun-spot spectrum and the discovery of temperature classes among the lines of the principal elements, and thus laid much of the observational basis for later applications of the theory of ionization and the analysis of spectra according to energy levels in the atom. The results of the investigation when applied by others to stellar spectra led through a few simple steps to the discovery of the relationship between luminosity and certain spectral criteria, and thus to the spectroscopic method of deriving stellar distances.

Comparisons of sun-spot spectra with those of the sun's disk had shown that among the lines of the same element some were greatly strengthened, others but slightly affected, and still others were weakened. These last were recognized as lines which are much more prominent in the spectrum of the electric spark than in that of the arc when studied in laboratory sources and were called "enhanced" lines. They are now known to be due to the radiation of the ionized atom. Since the most reasonable hypothesis was that the temperature of spots is below that of the general surface of the sun, a laboratory investigation was begun in which the temperature of the light-source could be varied and the corresponding spectral changes studied. It at once appeared that the lines fell into distinct classes, some of the lines being greatly strengthened at low temperatures while others were little affected. A comparison showed that just the lines most strengthened at low temperatures in the electric arc were most strengthened in sun-spots, and that the correspondence between the laboratory and the sun-spot behavior was essentially complete.

The investigation was continued, and the discovery of molecular bands in the spectrum of sun-spots confirmed beyond question the assumption of the lower temperatures in spots. On the laboratory side, the study by A. S. King of the spectra of numerous elements under the controlled temperature conditions of the electric furnace led to the accurate classification of the lines according to temperature and provided a collection of data of the utmost value for physical studies of stellar spectra and the quantitative analysis of the spectra of the elements which developed in later years. At about the same time laboratory studies by Gale and Adams showed that the intensity of the enhanced lines is greatly increased by reduction of pressure in the gas surrounding the source of light, and the suggestion was made that this effect might account for the abnormally high intensity of such lines in the spectrum of the solar chromosphere where the density is extremely low. These results thus anticipated some of the conclusions of the ionization theory developed later by Saha. It is probably not too much to say that this investigation of sun-spot and laboratory spectra, originating with Hale, with all its ramifications and applications, has been one of the most fruitful in its results of any in the field of astrophysics and spectroscopy.

One very important feature of the sun-spot spectrum was left unexplained by the study of the influence of temperature upon spectral lines. This was the widening and in some cases doubling of numerous lines, first discovered by Young, measured systematically by visual methods by some English observers, and studied in detail by W. M. Mitchell at the Allegheny Observatory. The explanation of the phenomenon as one of self-reversal did not fully satisfy Hale and he reverted to the problem when sufficiently powerful spectroscopic equipment became available at Mount Wilson. The successive steps by which he was led to what was perhaps his most brilliant discovery, that of magnetism in the sun, form a most interesting story.

Observations with the spectroheliograph had in past years been limited to the use of H and K and one or two of the blue hydrogen lines because of the lack of sensitiveness of photographic emulsions to light of longer wave-length. The development of red-sensitive dyes and their application to plates by R. J. Wallace in 1907 made it possible to use the $H\alpha$ line with the spectroheliograph. This led at once to results of great interest. Bright flocculi were found to be much more numerous and intense than on photographs taken with the blue hydrogen line $H\delta$, large prominences were photographed as dark areas in projection against the sun's disk, and the intensity and contrast of the images were greatly superior to anything obtained previously. Most important of all, these photographs showed clearly the existence of curved and radial structure in the flocculi surrounding spots of such a character as to indicate definitely that spots are centers of attraction for the surrounding hydrogen atmosphere and are associated with cyclonic whirls or vortices. The frequent similarity of the distribution of the hydrogen flocculi around spots to that of iron filings in a magnetic field at once caught Hale's attention, and in his well-known paper on Solar Vortices he referred to the possibility of the circular polarization in opposite directions of the components of the double lines in spot spectra and of his intention of undertaking the necessary observations. In June 1908 when suitable spots were available he obtained satisfactory photographs using a rhomb and Nicol prism and proved conclusively the presence of a magnetic field.

Problems growing out of this remarkable discovery occupied Hale for many years. He undertook extensive and systematic measurements of the strength of field in all available spots; studied the behavior of lines in the spectrum as the spots moved toward the sun's edge and the direction of observation changed from one parallel to one at right angles to the lines of force; he discovered the fact that the preceding and the following spots of a normal group have polarities of opposite sign, and that the spots in each hemisphere of the sun are predominantly of one sign but opposite to that in the other hemisphere; and he carried on with much ingenuity experiments on artificial vortices in an attempt to clarify his conceptions of the vortices in the sun. Extensive investigations of the Zeeman effect, conducted in the Pasadena physical laboratory by King and Babcock, provided much material to supplement and check at many points the solar results. Hale also designed at this time the 150-foot tower telescope, completed in 1910, to provide a larger solar image and a spectrograph 75 feet in length. Most of the solar spectroscopic investigations were then transferred to this instrument, and as the sun-spot activity declined Hale commenced with it the most difficult and exacting research of his life, the attempt to detect a general magnetic field in the sun.

During these years the permanent staff and equipment of the Observatory had increased greatly. The 60-inch telescope required several observers and a program of photometric investigation was planned and put into operation by F. H. Seares, who joined the staff in 1909; Ritchey and Pease carried on direct photography and the spectrographic work was shared by Adams, Babcock, Pease and one or two general assistants. In the physical laboratory King and Babcock were actively engaged in spectroscopic studies, and in the solar department C. E. St. John had begun his long series of investigations, in some of which he was associated with Hale. Many of the problems of stellar spectroscopy had always made a strong appeal to Hale but unfortunately he had found through repeated experience that the strain of night observing placed too severe a burden upon his far from rugged health. Although this was a great disappointment to him, he retained a keen and active interest in stellar observations and contributed greatly to plans for the extension of such work and to the design of apparatus for increasing the efficiency of the observations.

A notable event in the history of the Observatory at this time was the gift of Mr. John D. Hooker in 1906 for the purchase of a 100-inch glass disk for a very large reflecting telescope. Although a telescope of such size necessarily involved many unknown factors, Hale did not hesitate to support the project enthusiastically, feeling confident that the successive problems could be solved satisfactorily as they were encountered. The casting of the disk by the French Plate Glass Company met many difficulties and was long delayed, and the disk when it finally arrived appeared of somewhat questionable quality. A series of tests, however, removed most of these doubts and after some further delay optical work was commenced. Meanwhile a visit by Andrew Carnegie to Mount Wilson in March 1910 had resulted in a further large gift to the Carnegie Institution and the expression of a desire that the 100-inch telescope be carried to completion. The construction of the larger portions of the mounting was delayed by the outbreak of the Great War and the first tests of the finished instrument were not made until October 1917. It was a great satisfaction to Hale, who had been in ill health for several years, to be present on this occasion and to find that his hopes regarding the value of this great telescope were to be so fully realized.

Soon after his discovery of the magnetic field in sun-spots Hale had his first intimation of the severe nervous breakdown which occurred early in 1910. It was doubtless occasioned partly by the extremely intense way in which he always worked, both mentally and physically, and partly by the strain and the sense of responsibility he felt with regard to the justification of the new observatory. The new problem of the design and construction of the 100-inch Hooker telescope also placed a severe burden upon him, and the meeting of the International Union for Cooperation in Solar Research at Mount Wilson in the summer of 1910 and contact with a large number of visiting astronomers had a stimulating but probably somewhat injurious effect. He was obliged to give up all active investigation for more than a year, and a similar attack recurred in 1913. From this time until the end of his life he was at no time completely free from more or less severe effects of brain congestion, sometimes accompanied by considerable pain and frequently by depression with occasional confusion of thought. These symptoms were greatly aggravated when he devoted himself to the scientific researches in which he was most interested, and after repeated courageous attempts he gradually turned to less exciting and exacting work. Life had become a problem of recognizing his physical limitations and of utilizing his abilities to a considerable extent in other fields.

Two investigations of later years, however, should be noted in connection with any description of Hale's scientific activities. Both grew out of his discovery of a magnetic field in sun-spots. The first was the strong evidence produced for the existence of a general magnetic field in the sun; and the second was the remarkable discovery of the reversal of the direction of sun-spot polarities in the two solar hemispheres with the cycle of spot activity. These investigations were constantly in Hale's mind, and up to his last years he devoted his gradually failing energies to the exacting measurements required in the study of the general field and to the invention of new methods of detecting the minute quantities involved.

The observations on the general field were commenced in the spring of 1912 when sun-spot activity had reached a low stage and the disturbing effects of spot fields were relatively slight. The apparatus used consisted of a compound quarter-wave plate and large Nicol prism mounted just above the slit of the 75-foot spectrograph of the 150-foot tower telescope. The photographs, taken usually at the most favorable solar latitude of 45°, showed a series of spectra which passed through successive strips of the quarter-wave plate and hence should reveal slight displacements of the spectral lines owing to the alternate extinction of their red and violet components if a magnetic field were present. It was soon found that any such field must be relatively weak, not more than 25 to 50 gausses instead of 2000 gausses or more as in an average sun-spot. A careful selection was made of lines of suitable quality which were known to have large Zeeman separations, and these lines were measured on a large number of plates with the aid of a machine provided with a tipping glass plate designed by Hale for measuring minute displacements. An immense amount of data was obtained in this way, chiefly through the measures of A. van Maanen, and was discussed by Hale and by Seares in publications appearing in 1913. The results appeared fairly conclusive in indicating a general field of the order of 50 gausses at the sun's pole, although as was pointed out by Hale some observers who measured a few of the plates obtained almost negative results.

A short supplementary series of photographs taken in September 1916 helped to confirm the results, and when combined with the earlier observations gave a value of 31.4 days for the period of revolution of the magnetic axis about the sun's axis of rotation.

The evidence for the existence of the magnetic field may be summarized briefly as follows: (1) the reversal of the algebraic signs of the displacements with the inversion of the quarter-wave plate, or the rotation of a half-wave plate used in its place; (2) the variation of the displacements with solar latitude in close agreement with the theoretical variation for a uniformly magnetized sphere; (3) the existence of lines which show no displacements by the general field, whereas systematic errors should affect all the lines measured; (4) the displacement-curves over a long period of time showing changes of form which indicate an inclination of the magnetic axis to the axis of rotation; (5) the correlation between field-strength and magnetic separation of the lines measured.

These results appeared very convincing but another series of photographs was obtained near the following sun-spot minimum of 1922-23. Although these plates were measured by several observers and by numerous independent methods, including that of tracings with the microphotometer, no absolutely definite conclusion could be drawn from the results. It seems significant, however, that in no case did the mean measures show displacements opposed to those to be expected from a magnetic field as great as those favorable to its presence, a result inconsistent with the assumption of purely accidental errors in the absence of a field. Since the quantities involved are exceedingly small, about 0.001 angstrom at a maximum, it is evident that, in spite of the great amount of observational material, turbulence and slight convection currents in the sun's atmosphere might possibly influence the results appreciably. Or it is even conceivable that the general field may be subject to considerable variations. The final proof of a general magnetic field in the sun may come from quite other sources, such, for example, as its effect upon radiation passing near the sun; but there can be little doubt that in the course of this long and trying investigation Hale showed a degree of skill, conscientiousness, and patience which could serve as a model in scientific research.

The discovery of the reversal of sun-spot polarities with the spot cycle resulted from the systematic study of spots planned and put into operation by Hale soon after his discovery of their magnetic fields. It is well known that at the beginning of a cycle of activity new spots first appear at relatively high solar latitudes and gradually approach the equator as the cycle develops. At sun-spot maximum nearly all spots are found in two zones of latitude a few degrees north and south of the equator, and these zones persist as the activity wanes. After the minimum is passed spots are seen in two noticeably different areas, those of the new cycle beginning to appear in high latitudes, but the occasional spots of the old cycle still remaining in low latitudes.

During the interval 1908-1912 near the time of sun-spot minimum Hale had found that in the great majority of cases the standard strip of the compound quarter-wave plate in his polarizing apparatus transmitted the violet component of preceding spots of bipolar groups in the northern hemisphere and the red component of similar groups in the southern hemisphere.

In the case of the following spots of bipolar groups the transmission was just the opposite. After the spot minimum which occurred in December 1912 new spots began to appear in high latitudes and observations at once showed a reversal of polarity: that is, where the transmission for a preceding spot had been violet in the northern hemisphere and red in the southern, it was now red in the northern hemisphere and violet in the southern. Similarly the polarities of the following spots of bipolar groups had reversed.

These results were so surprising that although Hale and his collaborators published their observations in 1918 the desire for full confirmation and additional data led Hale to delay further discussion until after the next sun-spot minimum of 1922. In a publication (with S. B. Nicholson) written in June, 1925, Hale formulates his well-known polarity law based upon 1735 groups of spots:

"The sun-spots of a new 11½-year cycle, which appear in high latitudes after a minimum of solar activity, are of opposite magnetic polarity in the northern and southern hemispheres. As the cycle progresses the mean latitude of the spots in each hemisphere steadily decreases, but their polarity remains unchanged. The high-latitude spots of the next 11½-year cycle, which begin to develop more than a year before the last low-latitude spots of the preceding cycle have ceased to appear, are of opposite magnetic polarity."

The 23-year interval between the successive appearances in high latitudes of spots of the same magnetic polarity Hale designated as the magnetic sun-spot period, and of its fundamental importance in solar theory there can be no question.

No one can look back upon Hale's scientific life and accomplishments without a feeling of astonishment that in a single individual there could be combined so many qualities essential to the finest type of productive research. Apparently born with a passion for physical science, he entered upon his work with an enthusiasm and joyous optimism that no difficulties could seriously affect. Extraordinarily resourceful and with a wide and accurate knowledge of physical methods and instruments, he could always devise the apparatus to undertake a complicated observational problem. His reading and travel kept him closely in touch with developments in technical and applied science and his mind was always engaged in plans for utilizing such developments in his own researches. Hale made constant use of tentative hypotheses to aid in the interpretation of his scientific results, but he treated them merely as tools and no one was more ready to discard any hypothesis immediately when it came into conflict with observational facts. Few scientists have lived who demanded such complete and incontestable evidence for any conclusion he drew from his results; and few have had in greater measure the rare capacity for the selection of problems which proved fruitful and productive in the highest degree.

The outbreak of the World War found Hale in Pasadena temporarily incapacitated by illness. Although his relations with many German scientists had been most cordial, he had always been suspicious of the plans and aims of their arrogant military rulers, and these views were strengthened during a short visit to Germany in 1913. The war, therefore, came to him as no surprise. Soon after the sinking of the *Lusitania* he suggested to the President of the National Academy of Sciences that the services of the Academy be offered to the President of the United States to assist in preparations for possible war. This question was later raised before the Academy Council and acted upon by unanimous vote of the whole Academy. A committee was appointed to call upon President Wilson, who proved to be favorable to the plan and asked the Academy to begin organization at once. Hale served as chairman of the organizing committee and from 1916 until the spring of 1919 spent most of his time in Washington, making only occasional visits to his home in Pasadena.

This was the origin of the National Research Council of which Hale was the first chairman. As a special organization, established under the national charter of the Academy, it had a wide membership and included representatives of governmental scientific and technical agencies, and of scientific, medical, and engineering bodies throughout the United States. Its value was such that at the close of the war on Hale's recommendation it was perpetuated through an Executive Order of President Wilson. The Council was reorganized on a peace basis, and through a gift from the Carnegie Corporation, which Hale was largely instrumental in securing, a building for the Academy and Research Council and funds for administration became available.

Hale was by nature an internationalist in his views, and his wide acquaintance with European men of science and the obvious opportunities for cooperation in research increased his interest in international organizations planned to promote this aim. Reference has already been made to the International Union for Cooperation in Solar Research, the first plans for which were made by Hale at the St. Louis Exposition in 1904. Its formal organization took place at Oxford in September of the following year. As Foreign Secretary of the National Academy during several years following 1910 Hale had attended meetings of the International Association of Academies but was considerably depressed by its extreme conservatism and lack of activity in promoting research. Later the bitter feelings occasioned by the war made it clear that this organization could no longer function successfully. Accordingly late in 1918 Hale assisted in organizing two meetings, one at the Royal Society in London and the other at the Paris Academy of Sciences, at which the problem was discussed and the decision was reached to establish the International Research Council, later the International Council of Scientific Unions. Originally having a membership of only 12 countries it now includes 40 nations, and the individual International Unions in various branches of science organized by the Council have been most active and effective agencies in furthering international research.

Perhaps no single activity of Hale's life serves as a better illustration of his foresight and breadth of view in educational and cultural developments than the part he took in the establishment of the California Institute of Technology. During the early years of the Mount Wilson Observatory his assistance was asked in planning the future policy of Throop Institute, a Pasadena school with small endowment which had been attempting to meet local needs in education through elementary courses, an art school, manual training, and other scattered facilities. Hale at once advised a concentration of activities upon science and a few branches of engineering together with adequate instruction in the humanities. From his own experience in a school of technology he had found that students usually acquired but little interest in literature, history, and other humanistic subjects, and also that fundamental science was too often neglected in the training for engineering.

Hale's policy was adopted and gradually the transformation of the school into an institution of advanced standing was put into effect. At first students were few in number, but rigorous standards were maintained, endowment funds were raised, and one by one departments were established and organized. Hale succeeded in interesting his friend A. A. Noyes of the Massachusetts Institute of Technology in the development of the new school, and Noyes, who had organized the Research Laboratory of Physical Chemistry at the Institute and had served for two years as Acting President, agreed to spend each winter quarter in Pasadena. Soon after the war he joined permanently the staff of the California Institute of Technology, as the new institution was now named, and his influence and that of Hale went far toward defining its policy in the years to come.

In 1920 the first president, J. A. B. Scherer, was obliged to resign because of ill health, and the critical question of his successor arose. Greatly to the delight of Hale and Noyes they succeeded in prevailing upon R. A. Millikan to accept the directorship of the Norman Bridge Laboratory of Physics and the chairmanship of the Executive Council, the governing body directing the affairs of the Institute. By Millikan's wish the administration of the Institute was conducted no longer through a president but through this Council, composed in part of trustees and in part of representatives of the faculty.

The rapid rise of the California Institute under Millikan's leadership to a very high place among the educational institutions of the country is so well known as to require no comment. Hale continued as a trustee and a member of the Executive Council until the time of his death, and the great success of the institution to which he had given so much thought and which represented so many of his ideals in education was of immense comfort to him throughout these darker years of his life.

Hale's acquaintance with Henry E. Huntington began not long after the establishment of the Mount Wilson Observatory. At this time Huntington had already begun collecting rare books and paintings and the eventual disposal of his collections had commenced to occupy his thoughts. Accordingly he asked Hale's advice upon the subject and gradually Hale evolved the plan which later developed into the establishment of the endowed Huntington Library and Art Gallery with its magnificent treasures of books, manuscripts, and paintings. Two considerations were fundamental in Hale's mind: first, that if these collections were to be accessible to the public their management should be in the hands of a board of competent trustees free from political control; and secondly, that the wealth of material contained in the incunabula, manuscripts, and rare books should be made available for use by scholars for literary and historical research. The conception of a research institution mainly along humanistic lines operating in association with the research organizations in physical science already established in Pasadena appealed greatly to Hale and he lost no opportunity of presenting his views to Mr. Huntington. Late in 1925 a statement of policy following closely Hale's suggestions was approved and signed by Mr. Huntington, and on February 8, 1926, a supplemental trust indenture was executed. Early in 1927 a Director of Research was appointed, and the new institution was established with an adequate endowment. In the quality of its collections and the admirable use which is made of them the Huntington Library and Art Gallery ranks high among the great libraries of the world.

These brief accounts of a few of Hale's major activities outside of his immediate scientific work serve merely to illustrate the wide extent of his interests and accomplishments. In a thousand ways, in his community and nationally and internationally, his fertile mind was constantly engaged in assisting or organizing cultural and scientific agencies, in aiding scholars, and in promoting the free interchange of thought throughout the world. He served upon the Committee on Intellectual Cooperation of the League of Nations in 1922; aided in establishing the National Research Fellowships awarded annually by the Rockefeller Boards; and was active in developing in many directions the efficiency of the National Academy and the National Research Council. In his own community he took part in every important cultural movement, and it was upon his suggestion that the City Planning Commission was organized which has contributed so greatly to the attractiveness of the municipal buildings of Pasadena. The award in 1927 of the Noble Medal for Civic Service by the City of Pasadena was in recognition of some of Hale's many contributions to the welfare of the city in which he lived.

1922–1938

A severe nervous breakdown in 1921 had obliged Hale to take a long rest. In the summer of 1922 he went to England and travelled through portions of western Europe finally reaching Egypt where he spent most of the winter. Here he renewed his friendship of long standing with J. H. Breasted, the archaeologist, and together they visited the tomb of Tutenkhamon before the contents had been removed. Breasted was at this time deciphering the seals on the still unopened doorway of the sarcophagus chamber. Hale and Breasted also visited Florence where Hale found the opportunity of observing the sun and planets with one of Galileo's original telescopes. Unfortunately the rest produced no great improvement in Hale's health, and he reached the decision that he must resign the directorship of the Mount Wilson Observatory. In view of the opportunities for research at an institution developed in accordance with his plans of long standing, and his great love of the mountain top and its natural surroundings, this decision was a most difficult and painful one to make. He faced it courageously, however, in the hope that under conditions of less responsibility and less contact with some of the most exciting aspects of research he might still find it possible to accomplish a part of the work he had in mind. He returned to Pasadena and resigned the directorship in the summer of 1923, retaining at the request of his associates the title of Honorary Director and such part in questions of general policy at the Observatory as his health would permit him to take.

Faced with the problem of adjusting his life and work to his weakened physical condition Hale decided to build a small well-equipped solar laboratory where he could work on problems of the sun as his strength permitted, and could meet from time to time his individual associates under conditions affording quiet and freedom from excitement. A building was erected by Hale at his own expense not far from the grounds of the California Institute of Technology and equipped with a vertical coelostat and spectrograph built in the instrument shop of the Observatory. Through the use of the Cassegrain design with convex mirrors, images of the sun up to 16 inches in diameter could be obtained with the telescope. The spectrograph was placed in an underground pit, as in the case of the Mount Wilson tower telescopes. With his usual generosity Hale made over to the Carnegie Institution as a part of the Mount Wilson equipment both the plant and the instruments, merely asking to be allowed to use them as long as he retained his ability to observe.

Before the Solar Laboratory was completed Hale returned to a problem which had interested him in earlier years. This was to render visible to the eye the bright and dark flocculi which are photographed with the spectroheliograph. His skill and ingenuity were never more clearly shown than in his invention of the spectrohelioscope—a special type of spectroscope with an oscillating slit or rotating prism above the slit. With this instrument the whole surface of the sun can be scanned within a few minutes, and short-lived eruptions which might otherwise pass unrecorded can be detected and measured. The spectrohelioscope has proved extremely valuable for observations of the solar activity, and, through a cooperative plan devised by Hale, the sun is now under nearly continuous observation with instruments of this type located in suitable zones of longitude over the earth's surface.

Observations with the spectrohelioscope, many attempts to improve methods for detecting the general magnetic field of the sun, and studies of sun-spot polarities occupied the limited time which Hale found it physically possible to devote to such work during the years following his retirement from the Observatory. But heavy responsibilities awaited him in connection with a new project, the last and in some respects the greatest of the many with which he had been associated during his life. This was the plan for the 200-inch telescope, and although Hale realized the strain which would be placed upon his frail health by the many problems and decisions which the project involved he accepted the burden gladly. It represented a further great addition to the series of instrumental developments which he had contributed so often to the progress of astronomy.

Before returning to Pasadena in 1923 Hale had devoted considerable time while in London to writing a number of articles for *Scribner's Magazine* on various developments in modern astronomy and astrophysics. He was remarkably successful, for he combined a simplicity and clearness of statement with an unusual ability to select the subjects of especial interest to the general reader. In 1927 he was asked by the editor of *Harper's Magazine* to write a similar article and Hale selected the title "The Possibilities of Large Telescopes." This article appeared in April 1928. Before its publication, however, Hale had written to Wickliffe Rose, President of the General Education Board, with whom he was well acquainted and whose enthusiastic interest in scientific research he well knew, regarding the possibility of financial support for the project of a very large telescope. Hale suggested a joint arrangement with the Carnegie Institution of Washington or with the National Academy of Sciences.

Dr. Rose expressed a keen interest in the plan and after an interview with Hale in New York visited Pasadena and Mount Wilson. As a result of this visit and after several discussions in New York with trustees of the Rockefeller and Carnegie foundations, and in Pasadena with the groups at the California Institute of Technology and the Mount Wilson Observatory, Dr. Rose recommended a grant for the construction of a 200-inch telescope. This recommendation received favorable action by the Executive Committee of the International Education Board on October 18, 1928. After assurance had been received from the President of the Carnegie Institution of Washington of the willingness of the Institution to assist and cooperate in the undertaking the telescope was given to the California Institute of Technology on this cooperative basis. An Observatory Council consisting of Hale as Chairman, Millikan, Noyes, and Robinson was designated by the Board of Trustees of the California Institute to carry out the entire project. At a somewhat later date Adams was added to its membership. J. A. Anderson of the Mount Wilson staff was made Executive Officer of the Council, and several committees were appointed to consider various phases of the project.

Hale continued as Chairman of the Observatory Council until his death, and it was only within the last few months of his life that he found it impossible to give personal attention to the problems under consideration. At that time Max Mason became Vice-Chairman and took over Hale's responsibilities. Up to the very end, however, Hale retained the deepest interest in the progress of the telescope and the construction of the buildings on Palomar Mountain, and his contributions to the success of the project were fundamental. Decisions upon the type of glass to be used in the great disk as well as its structure and support, the form of mounting to be adopted, the location of the telescope, and the auxiliary instruments and buildings to be constructed, were all made under his guidance and advice. Although he could not live to see the completion of his last and greatest telescope, he was able to realize that the vital problems were solved and that its success was with all reasonable certainty fully assured.

The condition of Hale's health had been slowly growing worse since 1927 and after 1934 additional complications set in which reduced his strength rapidly. He died on February 21, 1938, a few months before his seventieth birthday. Although even his closest friends had seen him but rarely during the last year of his life, it was most difficult to realize the fact of his death, such was the strength and vividness of his remarkable personality.

Few American scientists had the degree of recognition at home and abroad which Hale received. He was awarded the Janssen medal of the Paris Academy of Sciences in 1894, at the age of 26; Rumford medal in 1902; Draper medal, 1903; Royal Astronomical Society medal, 1904; Bruce medal, 1916; Janssen medal, 1917; Galileo medal, 1920; Actonian prize, 1921; Cresson medal, 1926; Franklin medal, 1927; Holland Society medal, 1931; Ives medal, 1935; and the Copley medal of the Royal Society, 1932. In addition to membership in many scientific societies in the United States and Europe he was a foreign member of the Royal Society of London, the Royal Society of Edinburgh, the Royal Society of Dublin, Société Hollandaise des Sciences, Philosophical Society of Cambridge, Accademia dei

Lincei, Amsterdam Academy of Sciences, Norwegian Academy of Sciences, Swedish Academy of Sciences, Russian Academy of Sciences, and the Société Imperiale des Naturalistes of Moscow. He was also a foreign associate or honorary member of the Institut de France (Academy of Sciences), Italian Society of Sciences, Royal Academy of Belgium, Royal Astronomical Society, Academy of Athens, Vienna Academy of Sciences, Royal Society of Upsala, the Academies of Catania, Genoa, and Turin, Société de Physique of Geneva, Royal Institution of London, London Physical Society, Société Française de Physique, and of the Franklin Institute.

No brief statement of a few of Hale's major activities can give any adequate picture of the life of this remarkably gifted and many-sided man. His sensitive mind like a delicate musical instrument of many strings responded to every contact with nature or the touch of poetry or music or art. Trained as a physicist and engineer, he was also a humanist and classicist with a profound appreciation of the contributions of the older civilizations to the beauty and values of life. The rare combination of an extraordinary clear and analytical mind with a far-reaching and yet controlled imagination explains better than anything else the extent of his influence upon the development of science during his years of activity and the permanence of his contributions to the intellectual life of the period.

No one could be associated with Hale without falling at once under the charm of his vivid and inspiring personality. With every characteristic of a brilliant and highly-cultured mind he retained a thoughtfulness and sympathy for others and a modesty which endeared him to every colleague. This aspect of a man of great human qualities could not be better illustrated than by the closing words of some unpublished biographical notes written in the later years of his life:

"Whatever I have accomplished has been chiefly due to the friendly support and cooperation of others. The only qualities I can claim are an intense interest in the objects I have sought and a willingness to work to the full limit of my strength to secure their accomplishment. Fortunate beyond words in my family, my friends, and my colleagues, I have received far too much of the credit which more truly belongs to them."

KEY TO ABBREVIATIONS

Amer. Assoc. Proc.—American Association for the Advancement of Science, Proceedings.
Amer. Jour. Sci.—American Journal of Science.
Ap. J.—Astrophysical Journal.
Astron. and Astrophys.—Astronomy and Astrophysics.
Astron. Nachr.—Astronomische Nachrichten.
Atlantic Mo.—Atlantic Monthly.
B. A. A. S.—British Association for the Advancement of Science.
Bull. Amer. Inst. Mining Eng.—Bulletin, American Institute of Mining Engineers.
Bull. Soc. fr. de Physique—Bulletin, Société francaise de physique.
Bull. Soc. Arts—Bulletin, Society of Arts.
Carnegie Inst. Yearbook—Carnegie Institution of Washington Yearbook.
Harper's Mag.—Harper's Magazine.
Jour. Amer. Soc. Mech. Eng.—Journal, American Society of Mechanical Engineers.
Jour. B. A. A.—Journal, British Astronomical Association.
Jour. de physique—Journal de physique.
Jour. Franklin Inst.—Journal, Franklin Institute.
Mem. Spett. It.—Memorie della Società degli spettroscopisti italiani.
M. N.—Monthly Notices, Royal Astronomical Society.
Mt. W. Comm.—Mt. Wilson Communications.
Mt. W. Contr.—Mt. Wilson Contributions.
Nat. Acad. Sci. Rept.—National Academy of Sciences, Report.
Nat. Hist.—Natural History.
Nat. Res. Council Reprint & Circular Series—National Research Council, Reprint and Circular Series.
Obs.—Observatory.
Philos. Soc.—Philosophical Society.
Phys. Zeits.—Physikalische Zeitschrift.
Pop. Astron.—Popular Astronomy.
Pop. Sci. Mo.—Popular Science Monthly.
Proc. Amer. Inst. Elec. Eng.—Proceedings, American Institute of Electrical Engineers.
Proc. Amer. Philos. Soc.—Proceedings, American Philosophical Society.
Proc. Nat. Acad. Sci.—Proceedings, National Academy of Sciences.
Proc. R. Inst.—Proceedings, Royal Institution.
Proc. R. Soc.—Proceedings, Royal Society of London.
Pub. A. A. S.—Publications, American Astronomical Society.
Pub. A. S. P.—Publications, Astronomical Society of the Pacific.
Pub. Astron. and Astrophys. Soc.—Publications, Astronomical and Astrophysical Society of America.
Pub. Yerkes Obs.—Publications, Yerkes Observatory.
Research narratives—Popular research narratives, collected by the Engineering Foundation, N. Y.

Riv. di Astron.—Rivista di Astronomia.
Sci. Amer.—Scientific American.
Sci. Amer. Supp.—Scientific American Supplement.
Scribner's Mag.—Scribner's Magazine.
Sid. Mgr.—Sidereal Messenger.
Smiths. Rept.—Smithsonian Institution Report.
Smiths. Coll.—Smithsonian Institution Miscellaneous Collections.
Sunset Mag.—Sunset Magazine.
Tech Engineering News—Monthly of Massachusetts Institute of Technology.
Tech. Quar.—Technology Quarterly, Massachusetts Institute of Technology.
Tech. Rev.—Technology Review.
Terr. Mag.—Terrestrial Magnetism.
Trans. Int. Astron. Union—Transactions, International Astronomical Union.
Trans. Int. Union Coop. Sol. Res.—Transactions, International Union for Co-operation in Solar Research.
Trans. R. Canadian Inst.—Transactions, Royal Canadian Institute.
Vo. Mag.—Vo-Mag, (Vocational Magazine), Pasadena (Calif.) Junior College.
Yerkes Obs. Bull.—Yerkes Observatory, Bulletin.

BIBLIOGRAPHY OF GEORGE ELLERY HALE

1889

Stellar photography. The Beacon (Chicago), March, pp. 54-57.
The new astronomy. The Beacon (Chicago), July-Aug., pp. 164-165, 176-178.

1890

Note on solar prominence photography. Astron. Nachr., *126*, pp. 81-82.
Photography of the solar prominences. Tech. Quar., *3*, pp. 310-316.

1891

Photographic investigation of solar prominences and their spectra. Amer. Jour. Sci., *42*, pp. 160-166.
Note on solar prominence photography. Astron. Nachr., *127*, pp. 211-214.
On results obtained in photographing solar prominences and their spectra. Astron. Nachr., *128*, pp. 109-110.
The ultra-violet spectrum of the solar prominences. Read at Cardiff meeting, British Association for the Advancement of Science, 1891; Report B. A. A. S., pp. 557-558; Amer. Jour. Sci., *42*, pp. 459-467; Astron. and Astrophys., *11*, pp. 50-59, 1892.
On results obtained in photographing solar prominences and their spectra. Mem. Spett. It., *20*, pp. 140-141.

The ultra-violet spectrum of the solar prominences. Mem. Spett. It., *20*, pp. 154-160.

The Kenwood Physical Observatory. Pub. A. S. P., *3*, 30-34; Sid. Mgr., *10*, pp. 321-323.

Organization of the Chicago Section of the Astronomical Society of the Pacific. Pub. A. S. P., *3*, pp. 79-82.

The system of the stars, by A. M. Clerke (Review). Pub. A. S. P., *3*, pp. 180-194.

Researches on the magnesia fluting in connection with the spectra of the nebulae. Sid. Mgr., *10*, pp. 23-30.

Pending problems in spectroscopy. Sid. Mgr., *10*, pp. 89-94.

Photography and the invisible solar prominences. Sid. Mgr., *10*, pp. 257-264.

1892

The spectroheliograph of the Kenwood Astrophysical Observatory, Chicago, and results obtained in the study of the sun. Amer. Assoc. Proc., pp. 55-56.

The Astro-physical Journal. Astron. and Astrophys., *11*, pp. 17-22.

Recent results in solar prominence photography. Astron. and Astrophys., *11*, pp. 70-78.

Note on recent solar investigations. Astron. and Astrophys., *11*, p. 159.

Progress in solar photography at the Kenwood Observatory. Astron. and Astrophys., *11*, p. 235.

The aurora of February 13, 1892. Astron. and Astrophys., *11*, pp. 237-239.

The eruptive prominence of July 9, 1891. Astron. and Astrophys., *11*, pp. 240-241.

The spectra of sun-spots and the photosphere. Astron. and Astrophys., *11*, pp. 241-243.

The astronomical exhibit at the World's Columbian Exposition. Astron. and Astrophys., *11*, pp. 305-307; Pub. A. S. P., *4*, pp. 123-125.

Spectroscopic observations of the great sun-spot group of February, 1892. Astron. and Astrophys., *11*, pp. 310-314.

Solar photography at the Kenwood Astrophysical Observatory. Astron. and Astrophys., *11*, pp. 407-417; Mem. Spett. It., *21*, pp. 68-74.

The ultra-violet spectrum of the solar prominences, II. Astron. and Astrophys., *11*, p. 602.

Photographs of solar phenomena obtained with the spectroheliograph of the Kenwood Astrophysical Observatory. Astron. and Astrophys., *11*, pp. 603-604.

Photographs of the occultation of Mars by the moon (July 11, 1892), made at Kenwood Astrophysical Observatory. Astron. and Astrophys., *11*, pp. 610-611.

A remarkable solar disturbance. Astron. and Astrophys., *11*, pp. 611-613.

Magnetic disturbances and auroras. Astron. and Astrophys., *11*, p. 617.

The ultra-violet spectrum of solar prominences, II (second note). Astron. and Astrophys., *11*, p. 618.

Chicago Academy of Sciences. Astron. and Astrophys., *11*, pp. 635-636, 846-847.

Progress of solar photography at the Kenwood Observatory. Astron. and Astrophys., *11*, p. 741.

The Yerkes Observatory of The University of Chicago. Astron. and Astrophys., *11*, pp. 790-793; Pub. A. S. P., *4*, pp. 250-252.

Some results and conclusions derived from a photographic study of the sun. Astron. and Astrophys., *11*, pp. 811-815.

The ultra-violet spectrum of the solar prominences, III. Astron. and Astrophys., *11*, pp. 821-822.

On the condition of the sun's surface in June and July, 1892, as compared with the record of terrestrial magnetism. Astron. and Astrophys., *11*, pp. 917-925.

Photographies de la chromosphère, des protubérances, et des facules solaires, à l'Observatoire d'Astronomie physique de Kenwood, Chicago. Comptes rendus, *115*, pp. 106-109.

Photographs of solar faculae and prominences. Knowledge, *15* (n. s., *7*), p. 169. (Photographs only.)

Recherches sur l'atmosphère solaire. Mem. Spett. It., *21*, pp. 77-78; Comptes rendus, *114*, pp. 1406-1407.

1893

Chicago Academy of Sciences, Section of Mathematics and Astronomy. Astron. and Astrophys., *12*, pp. 94-95, 285, 477-478.

On the probability of chance coincidence of solar and terrestrial phenomena. Astron. and Astrophys., *12*, pp. 167-169.

The spectroheliograph. Astron. and Astrophys., *12*, pp. 241-257.

Photography of the solar corona without an eclipse. Astron. and Astrophys., *12*, pp. 260-262.

Photography of the solar corona without an eclipse (Note). Astron. and Astrophys., *12*, pp. 364-365.

Spectroscopic notes from the Kenwood Observatory. Astron. and Astrophys., *12*, pp. 450-455.

Attempt to photograph the corona from Pike's Peak. Astron. and Astrophys., *12*, p. 653.

Spectrum of comet *b* 1893. Astron. and Astrophys., *12*, p. 653.

The Congress of Mathematics, Astronomy and Astrophysics (at the Columbian Exposition). Astron. and Astrophys., *12*, pp. 640-641.

Astronomical exhibits at The Columbian Exposition. Astron. and Astrophys., *12*, pp. 641-645.

The Congress of Mathematics, Astronomy, and Astrophysics, Section of Astronomy and Astrophysics. Astron. and Astrophys., *12*, pp. 746-749.

Photography of the corona without an eclipse. Astron. and Astrophys., *12*, p. 751.

Les raies H et K dans le spectre des facules solaires. Comptes rendus, *116*, pp. 170-172.

La probabilité de coincidence entre les phénomènes terrestres et solaires. Comptes rendus, *116*, pp. 240-243.

Photographie de la couronne solaire, en dehors des éclipses totales. Comptes rendus, *116*, pp. 623-625.

Méthode spectro-photographique pour l'étude de la couronne solaire. Comptes rendus, *116*, pp. 865-866.

The sun as a bright-line star. Knowledge, *16* (n. s., *8*), pp. 192, 232-233.

A remarkable solar disturbance. Mem. Spett. It., *21*, pp. 106-107.

Photographies de la chromosphère, des protubérances et des facules solaires, à l'Observatoire d'Astronomie physique de Kenwood (Chicago). Mem. Spett. It., *21*, pp. 108-109.

The ultra-violet spectrum of the solar prominences. Mem. Spett. It., *21*, pp. 160-161.

Some results and conclusions derived from a photographic study of the sun. Mem. Spett. It., *21*, pp. 165-168.

Photographie de la couronne solaire en dehors des éclipses totales. Mem. Spett. It., *22*, pp. 66-67.

Fotografie solari. Mem. Spett. It., *22*, p. 89.

The solar faculae. Mem. Spett. It., *22*, pp. 198-204.

Remarks on solar phenomena before the Royal Astronomical Society. Obs., *16*, pp. 395-396.

Some recent photographic investigations of the sun. Tech. Quar., *6*, pp. 262-272.

1894

Monsieur Cornu's spectroscopic investigations. Astron. and Astrophys., *13*, pp. 57-58.

Spectroscopy at Stonyhurst College Observatory. Astron. and Astrophys., *13*, pp. 58-59.

New nomenclature for the hydrogen series. Astron. and Astrophys., *13*, p. 63.

Spectroheliograph for the Yerkes telescope. Astron. and Astrophys., *13*, pp. 64-66.

The solar faculae. Astron. and Astrophys., *13*, pp. 113-122.

The spectroscopic investigations of Mr. George Higgs. Astron. and Astrophys., *13*, pp. 151-153.

On some attempts to photograph the solar corona without an eclipse. Astron. and Astrophys., *13*, pp. 662-687.

A collection of astronomical photographs. Astron. and Astrophys., *13*, pp. 693-695.

Dr. Huggins' 1888 photograph of the spectrum of the great nebula in Orion. Astron. and Astrophys., *13*, p. 696.

The Astrophysical Journal. Astron. and Astrophys., *13*, pp. 831-835.

The solar faculae. Knowledge, *17* (n. s., *9*), pp. 18-22.

On the mounting of large telescopes. Knowledge, *17* (n. s., *9*), pp. 145-146.

Sur les facules solaires. Mem. Spett. It., *23*, pp. 110-111; Comptes rendus, *118*, pp. 1175-1177.

Ueber die photographische Erforschung der Sonne. Verhandlungen der Phys. Gesellschaft, Berlin, *13*, pp. 1-3.

1895

Preliminary note on the D3 line in the spectrum of the chromosphere. Astron. Nachr., *138*, pp. 227-230; Mem. Spett. It., *24*, pp. 117-119.

The Astrophysical Journal. Ap. J., *1*, pp. 80-84.

Spectro-bolographic investigations at the Smithsonian Astrophysical Observatory. Ap. J., *1*, pp. 162-166.

Arthur Cowper Ranyard. Ap. J., *1*, pp. 168-169.

Publications of the Lick Observatory, volume 3 (Review). Ap. J., *1*, pp. 180-188.

On a new method of mapping the solar corona without an eclipse. Ap. J., *1*, pp. 318-334.

A large eruptive prominence. Ap. J., *1*, pp. 433-434.

On a photographic method of determining the visibility of interference fringes in spectroscopic measurements. Ap. J., *1*, pp. 435-438.

Note on the exposure required in photographing the solar corona without an eclipse. Ap. J., *1*, pp. 438-439.

Terrestrial helium (?) (Review). Ap. J., *1*, pp. 439-441.

Notes on Schmidt's theory of the sun. Ap. J., *2*, pp. 73-74.

Note on the Yerkes Observatory. Ap. J., *2*, pp. 74-76; Pub. A. S. P., *7*, pp. 225-226.

On the presence of helium in clèveite. Ap. J., *2*, pp. 76-77.

Note on the Huggins method of photographing the solar corona without an eclipse. Ap. J., *2*, p. 77.

Note on the D3 line in the spectrum of the chromosphere. Ap. J., *2*, pp. 165-166.

On the wave-length of the D3 line in the spectrum of the chromosphere. Ap. J., *2*, pp. 384-385.

On some attempts to photograph the solar corona without an eclipse. The expedition to Mount Etna. Mem. Spett. It., *24*, pp. 31-35.

1896

Action of the Editorial Board of the Astrophysical Journal with regard to standards in astrophysics and spectroscopy. Ap. J., *3*, pp. 1-3.

Note on the application of Messrs. Jewell, Humphreys and Mohler's results to certain problems of astrophysics. Ap. J., *3*, pp. 156-161.

Yerkes Observatory, University of Chicago (Yerkes Obs. Bull., No. 1). Ap. J., *3*, pp. 215-219; Astron. Nachr., *140*, pp. 305-306.

The sun, by C. A. Young (Review). Ap. J., *3*, pp. 235-240.

Observations des protubérances solaires faites à l'Observatoire d'Odessa, by A. Kononowitch and others (Review). Ap. J., *3*, p. 241.

The effect of a total eclipse of the sun on the visibility of the solar prominences. Ap. J., *3*, pp. 374-387.

The modern spectroscope. XIX. The objective spectroscope. (With F. L. O. Wadsworth.) Ap. J., *4*, pp. 54-78.

Observations de l'éclipse totale du soleil du 16 Avril, 1893, by H. Deslandres (Review). Ap. J., *4*, pp. 160-166.

1897

On the comparative value of refracting and reflecting telescopes for astrophysical investigations. Ap. J., *5*, pp. 119-131.

Note on the Ranyard mounting for reflecting telescopes. Ap. J., *5*, pp. 148-149.

The Yerkes Observatory of the University of Chicago: I. Selection of the site. Ap. J., *5*, pp. 164-180.

Note on a form of spectroheliograph suggested by Mr. H. F. Newall. Ap. J., *5*, pp. 211-213.

Award of the Gold Medal of the Royal Astronomical Society to Professor Barnard. Ap. J., *5*, pp. 215-216.

Total eclipse of the sun, April 16, 1893, by J. N. Lockyer (Review). Ap. J., *5*, pp. 220-226.

The Yerkes Observatory of the University of Chicago: II. The building and minor instruments. Ap. J., *5*, pp. 254-267.

The Yerkes Observatory of the University of Chicago: III. The instruments and optical shops, and the power house. Ap. J., *5*, pp. 310-317.

Analyse spectrale directe des minéraux, by A. de Gramont (Review). Ap. J., *5*, pp. 362-363.

The Yerkes Observatory of the University of Chicago: IV. The forty-inch telescope, dome, and rising floor. Ap. J., *6*, pp. 37-47.

Dedication of the Yerkes Observatory. Ap. J., *6*, p. 58.

Alvan Graham Clark. Ap. J., *6*, pp. 137-138.

Completion of the 40-inch telescope (Yerkes Obs. Bull., No. 2). Ap. J., *6*, pp. 147-153.

Note on the relative frequency of the H and K lines in the spectrum of the chromosphere. Ap. J., *6*, pp. 157-158.

Dedication of the Yerkes Observatory (Yerkes Obs. Bull., No. 3). Ap. J., *6*, pp. 262-263.

The aim of the Yerkes Observatory. Read at Yerkes meeting, Astronomical and Astrophysical Society of America, 1897; Ap. J., *6*, pp. 310-321.

The dedication of the Yerkes Observatory. Ap. J., *6*, pp. 353-362.

Note on the level of sun-spots. Ap. J., *6*, p. 366.

On the presence of carbon in the chromosphere. Ap. J., *6*, pp. 412-414.

Researches in solar physics. Read at Yerkes meeting, Astronomical and Astrophysical Society of America, 1897; Pub. Astron. and Astrophys. Soc., *1*, p. 39, 1910.

1898

The total solar eclipse. Ap. J., *7*, pp. 304-306.

The new Director of the Lick Observatory. Ap. J., *7*, p. 310.

Astronomical and Physical Conference at the Harvard College Observatory. Ap. J., *8*, pp. 54-55.

Election of Edwin B. Frost as Professor of Astrophysics at the Yerkes Observatory. Ap. J., *8*, p. 59.

The Harvard Conference. Ap. J., *8*, pp. 193-198.

On the spectra of stars of Secchi's Fourth Type. Ap. J., *8*, pp. 237-240.

First annual report of the Director of the Yerkes Observatory for the year ending Sept. 30, 1898. 11 pp.

On the spectra of stars of Secchi's Fourth Type (Abstract). Read at Harvard meeting, Astronomical and Astrophysical Society of America, 1898. Pub. Astron. and Astrophys. Soc., *1*, pp. 53-55, 1910.

On the spectra of stars of Secchi's Fourth Type. Science, n. s., *8*, pp. 455-456.

The function of large telescopes; address given at Fifth Annual Reception, New York Academy of Science. Smiths. Rept. 1898, pp. 123-137; Science, n.s., *7*, pp. 650-662.

1899

Parallax of the Andromeda nebula (Yerkes Obs. Bull., No. 6). Ap. J., *9*, pp. 184-185.

The spectrum of Saturn's rings (Yerkes Obs. Bull., No. 6). Ap. J., *9*, pp. 185-186.

Spectra of stars of Secchi's Fourth Type (Yerkes Obs. Bull., No. 7). Ap. J., *9*, pp. 271-272.

Opportunities for students and research assistants at the Yerkes Observatory (Yerkes Obs. Bull., No. 8). Ap. J., *9*, pp. 272-273.

Comparison of stellar spectra of the Third and Fourth Types (Yerkes Obs. Bull., No. 9). Ap. J., *9*, pp. 273-274.

Period and elongation distance of the Fifth Satellite of Jupiter (Yerkes Obs. Bull., No. 10). Ap. J., *9*, pp. 358-360.

Heat radiation of the stars (Yerkes Obs. Bull., No. 11). Ap. J., *9*, pp. 360-362; Pop. Astron., *7*, pp. 503-504.

The new Allegheny Observatory. Ap. J., *9*, p. 362.

On the spectra of stars of Secchi's Fourth Type. I. (With Ferdinand Ellerman.) Ap. J., *10*, pp. 87-112.

The Third Conference of Astronomers and Astrophysicists. Ap. J., *10*, pp. 211-220.

Some new forms of spectroheliographs. Read at Yerkes meeting, Astronomical and Astrophysical Society of America, 1899; Ap. J., *10*, pp. 288-289 (Yerkes Obs. Bull., No. 12); Science, *10*, p. 795; (Abstract) Pub. Astron. and Astrophys. Soc., *1*, pp. 86-87, 1910.

Annales de l'Observatoire d'Astronomie Physique de Paris, Tome premier (Review). Ap. J., *10*, pp. 369-374.

The Indian eclipse, by E. W. Maunder (Review). Ap. J., *10*, pp. 374-376.

Second annual report of the Director of the Yerkes Observatory for the year ending June 30, 1899. 5 pp.

Carbon in the chromosphere. Read at Yerkes meeting, Astronomical and Astrophysical Society of America, 1899; (Abstract) Pub. Astron. and Astrophys. Soc., *1*, p. 86, 1910.

Comparison of stellar spectra of the third and fourth types. Read at Yerkes meeting, Astronomical and Astrophysical Society of America, 1899; (Abstract) Pub. Astron. and Astrophys. Soc., *1*, p. 87, 1910.

Carbon in the chromosphere. Ap. J., n.s., *10*, pp. 287-288 (Yerkes Obs. Bull., No. 12); Science, *10*, pp. 794-795.

Comparison of stellar spectra of the third and fourth types. Science, n.s., *10*, p. 795.

Report of the Board of Visitors to the U. S. Naval Observatory, October 2, 1899. Govt. Printing Office, Washington, D. C. 77 pp. (Sec. I): Ap. J., *10*, pp. 292-299; Pop. Astron., *7*, pp. 459-465; Science, n.s., *10*, pp. 747-751.

1900

Solar eclipse problems. Ap. J. *11*, pp. 47-66.

Plans of American eclipse parties. Ap. J., *11*, pp. 314-321.

Variable star observations with the 12-inch and 40-inch refractors (Yerkes Obs. Bull., No. 13). Ap. J., *12*, pp. 52-54.

Observations of the total solar eclipse of May 28, 1900, at Wadesboro, N. C. (Yerkes Obs. Bull., No. 14). Ap. J., *12*, pp. 80-89.

James Edward Keeler. Ap. J., *12*, p. 102; Science, n.s., *12*, p. 353.

Photographs of the cluster M 13 Herculis with the 40-inch visual telescope. (Yerkes Obs. Bull., No. 15.) Ap. J., pp. 161-164.

An atlas of representative stellar spectra, by Sir William and Lady Huggins (Review). Ap. J., *12*, pp. 291-297.

On some attempts to detect the solar corona in full sunlight with a bolometer. Ap. J., *12*, pp. 372-375.

Appointment of Professor W. W. Campbell as Director of the Lick Observatory. Ap. J., *12*, pp. 381-382.

Observing stations for the total eclipse, May 28, 1900. Pop. Astron., *8*, p. 295.

1901

The new star in Perseus (Yerkes Obs. Bull., No. 16). Ap. J., *13*, pp. 173-176; Pop. Astron., *9*, pp. 264-267; Science, n.s., *13*, pp. 514-515.

Changes in the spectrum of Nova Persei (Yerkes Obs. Bull., No. 17). Ap. J., *13*, pp. 238-240.

Annals of the Astrophysical Observatory of the Smithsonian Institution, vol. I (Review). Ap. J., *13*, pp. 280-288.

Latitude and longitude of the Yerkes Observatory (Yerkes Obs. Bull., No. 18). Ap. J., *14*, pp. 146-148.

A remarkable disturbance of the sun's reversing layer (Abstract). Read at Washington meeting, Astronomical and Astrophysical Society of America, 1901; Pub. Astron. and Astrophys. Soc., *1*, p. 177, 1910.

1902

Note on the spark spectrum of iron in liquids and in air at high pressures. Ap. J., *15*, pp. 132-135.

Selective absorption as a function of wave-length. Ap. J., *15*, pp. 227-228.

Handbuch der astronomischen Instrumentenkunde, by L. Ambronn (Review). Ap. J., *15*, pp. 347-349.

Solar research at the Yerkes Observatory. Ap. J., *16*, pp. 211-233.

Report of the Director of the Yerkes Observatory for the period July 1, 1899, to June 30, 1902. 32 pp. Also in Pub. A. S. P., *15*, pp. 99-110, 1903.

Report of Advisory Committee on Astronomy. (With others.) Carnegie Inst. Yearbook, No. 1, pp. 87-93.

General plan for furthering special researches in astronomy. Carnegie Inst. Yearbook, No. 1, pp. 94-104.

Progress and present state of certain departments of astrophysical research. Carnegie Inst. Yearbook, No. 1, pp. 128-144.

Stellar evolution in the light of recent research; address delivered before Minnesota Chapter, Society of Sigma Xi, June 5, 1901; Pop. Sci. Mo., *60*, pp. 291-313; Smiths. Rept. 1902, pp. 149-163.

The spectra of stars of Secchi's Fourth Type. (With F. Ellerman and J. A. Parkhurst.) Read at Washington meeting, Astronomical and Astrophysical Society of America, 1902; (Abstract) Pub. Astron. and Astrophys. Soc., *1*, pp. 183-184, 1910.

A remarkable disturbance of the sun's reversing layer. Science, n.s., *15*, p. 297.

1903

Second note on the spark spectrum of iron in liquids and compressed gases. (With Norton A. Kent.) Ap. J., *17*, pp. 154-160.

The new star in Gemini (Yerkes Obs. Bull., No. 19). Ap. J., *17*, pp. 300-305.

The Snow horizontal telescope. Ap. J., *17*, p. 314.

The spectra of stars of Secchi's Fourth Type. (With Ferdinand Ellerman and J. A. Parkhurst.) Decennial publication, University of Chicago, ser. 2, *8*, pp. 251-385; Pub. Yerkes Obs., *2* (Decennial papers), pp. 251-385, 1904.

The Rumford spectroheliograph of the Yerkes Observatory. (With Ferdinand Ellerman.) Pub. Yerkes Obs., *3* (Pt. 1), pp. 1-26.

Abstract of report on grant to Yerkes Observatory. Carnegie Inst. Yearbook, No. 2, p. xx.

Report of Committee on Southern and Solar Observatories. (With Lewis Boss and W. W. Campbell.) Carnegie Inst. Yearbook, No. 2, pp. 5-70.

The spectra of stars of Secchi's Fourth Type. (With Ferdinand Ellerman and J. A. Parkhurst.) Science, n.s., *17*, p. 324.

1904

The development of a new method of research; address delivered before University of Chicago Chapter, Society of Sigma Xi, Nov. 23, 1903; Pop. Sci. Mo., *65*, pp. 5-26.

Calcium and hydrogen flocculi. (With Ferdinand Ellerman.) Ap. J., *19*, pp. 41-52.

Handbuch der Spectroscopie (vol. 2), by H. Kayser (Review). Ap. J., *19*, pp. 296-300.

An expedition for solar research. Ap. J., *19*, pp. 385-386.

Cooperation in solar research. Ap. J., *20*, pp. 306-312; Science, n.s., *20*, pp. 930-932; Trans. Int. Union Coop. Sol. Res., *1*, pp. 11-19, 1906; (Italian translation) Cooperazione internazionale nelle ricerche solari. Mem. Spett. It., *33*, pp. 209-211.

Report of the Director of the Yerkes Observatory for the period July 1, 1902, to June 30, 1904. 8 pp.

Abstract of report on grant for researches at Yerkes Observatory. Carnegie Inst. Yearbook, No. 3, pp. 88-90.

Report on the Solar Observatory on Mount Wilson. Carnegie Inst. Yearbook, No. 3, pp. 94-95.

Experiments on the use of fused quartz for the construction of optical mirrors. Carnegie Inst. Yearbook, No. 3, pp. 127-128.

A study of the conditions for solar research at Mount Wilson. Carnegie Inst. Yearbook, No. 3, pp. 155-177; Ap. J., *21*, pp. 124-150, 1905; Mt. W. Contr., No. 1.

Some examples of solar work in which co-operation would be desirable. Mem. Spett. It., *33*, p. 44.

1905

The Solar Observatory of the Carnegie Institution of Washington. Ap. J., *21*, pp. 151-172; Mt. W. Contr., No. 2.

The work of the Rumford spectroheliograph. Ap. J., *21*, pp. 261-270.

Report of Director of the Solar Observatory, Mount Wilson, California. Carnegie Inst. Yearbook, No. 4, pp. 56-77.

The development of a new observatory (Mount Wilson). Pub. A. S. P., *17*, pp. 41-52.

Tests of the Snow telescope. Pub. A. S. P., *17*, pp. 100-101.

Smithsonian expedition to Mount Wilson. Pub. A. S. P., *17*, pp. 108-109.

Water system for the Solar Observatory. Pub. A. S. P., *17*, p. 109.

1906

Circular sent out by the Committee on Solar Research of the National Academy of Sciences (1904). Trans. Int. Union Coop. Sol. Res., *1*, pp. 1-4.

Standards of wave-length (1904). Trans. Int. Union Coop. Sol. Res., *1*, pp. 7-8.

Work with the spectroheliograph (1904). Trans. Int. Union Coop. Sol. Res., *1*, pp. 76-79.

Spectra of sun-spots (1905). Trans. Int. Union Coop. Sol. Res., *1*, pp. 118-119.

Solar radiation (1905). Trans. Int. Union Coop. Sol. Res., *1*, pp. 103-104.

Spectroheliograph (1905). Trans. Int. Union Coop. Sol. Res., *1*, pp. 107-111.

A program of solar research. Ap. J., *23*, pp. 1-5; Mt. W. Contr., No. 3.

Some tests of the Snow telescope. Ap. J., *23*, pp. 6-10; Mt. W. Contr., No. 4.

Photographic observations of the spectra of sun-spots. (With W. S. Adams.) Ap. J., *23*, pp. 11-44; Mt. W. Contr., No. 5.

The five-foot spectroheliograph of the Solar Observatory. (With Ferdinand Ellerman.) Ap. J., *23*, pp. 54-63; Mt. W. Contr., No. 7.

Reply to recent statements by M. Deslandres. Ap. J., *23*, pp. 92-93.

Sun-spot lines in the spectra of red stars. (With W. S. Adams.) Ap. J., *23*, pp. 400-405; Mt. W. Contr., No. 8.

Latitude and longitude of the Solar Observatory. Ap. J., *24*, pp. 129-132; Mt. W. Contr., No. 9.

The spectroscopic laboratory of the Solar Observatory. Ap. J., *24*, pp. 61-68; Mt. W. Contr., No. 10.

Preliminary paper on the cause of the characteristic phenomena of sun-spot spectra. (With W. S. Adams and H. G. Gale.) Ap. J., *24*, pp. 185-213; Mt. W. Contr., No. 11; (Italian translation) Comunicazione preliminare sulla causa dei fenomeni caratteristici degli spettri delle macchie solari. Mem. Spett. It., *35*, pp. 208-215.

A 100-inch mirror for the Solar Observatory. Ap. J., *24*, pp. 214-218; Mt. W. Contr., No. 13; Pop. Astron., *14*, pp. 557-560; Pub. A. S. P., *18*, pp. 272-274.

Report on the Solar Observatory, Mount Wilson, California. Carnegie Inst. Yearbook, No. 5, pp. 60-86; Pub. A. S. P., *19*, pp. 100-104, 1907.

A program of solar research. Pub. A. S. P., *18*, pp. 59-62.

Some tests of the Snow telescope. Pub. A. S. P., *18*, pp. 73-76.

Photographic observations of the spectra of sun-spots. (With W. S. Adams.) Pub. A. S. P., *18*, pp. 76-77.

Report of the Solar Observatory of the Carnegie Institution of Washington, 1905. Pub. A. S. P., *18*, pp. 156-164.

Height of the hydrogen flocculi. Pub. A. S. P., *18*, pp. 221-222.

Identification of faint lines in the spectra of sun-spots. Pub. A. S. P., *18*, pp. 222-223.

Organization of the computing division of the Solar Observatory. Pub. A. S. P., *18*, p. 223.

The five-foot reflector of the Solar Observatory. Pub. A. S. P., *18*, p. 224.

New members of the staff of the Solar Observatory. Pub. A. S. P., *18*, p. 228.

Smithsonian expedition to Mount Wilson. Pub. A. S. P., *18*, p. 229.

Note on the level of sun-spots. Pub. A. S. P., *18*, pp. 250-251.

A road to Mount Wilson. Pub. A. S. P., *18*, pp. 251-252.

On the cause of the characteristic phenomena of sun-spot spectra. (With W. S. Adams and H. G. Gale.) Pub. A. S. P., *18*, pp. 268-270.

Character and cause of sun-spot spectra. (Abstract) Nature, *75*, pp. 113-114.

Opportunities for solar research. Read at New York meeting, Astronomical and Astrophysical Society of America; Pub. Astron. and Astrophys. Soc., *1*, pp. 287-292, 1910.

1907

A vertical coelostat telescope. Ap. J., *25*, pp. 68-74; Mt. W. Contr., No. 14.

Second paper on the cause of the characteristic phenomena of sun-spot spectra. (With W. S. Adams.) Ap. J., *25*, pp. 75-94; Mt. W. Contr., No. 15.

The heliomicrometer. Ap. J., *25*, pp. 293-299; Mt. W. Contr., No. 16.

A photographic comparison of the spectra of the limb and the center of the sun. (With W. S. Adams.) Ap. J., *25*, pp. 300-310; Mt. W. Contr., No. 17.

Some new applications of the spectroheliograph. Ap. J., *25*, pp. 311-314; Mt. W. Contr., No. 18.

Mount Wilson Solar Observatory (annual report). Carnegie Inst. Yearbook, No. 6, 134-152; Pub. A. S. P., *20*, pp. 107-116, 1908.

Some opportunities for astronomical work with inexpensive apparatus. Lecture delivered at Royal Astronomical Society, London, June 26, 1907. M. N., *68*, pp. 64-80, 1907; Pop. Astron., *16*, pp. 74-80, 167-174, 438-442, 1908; Jour. B. A. A., *18*, 1907-1908, Appendix, pp. 1-18; Smiths. Rept. 1907, pp. 267-285; (German tr.) Einige Gelegenheiten zu Astronomischen Arbeiten mit wohlfeilen Apparaten. Phys. Zeits., *10*, pp. 707-719, 1909.

Solar Observatory work (extract from the Annual report, Mt. Wilson Obs., 1907). Pop. Astron., *15*, pp. 563-566.

Opportunities for solar research. Read before the Astronomical and Astrophysical Society, New York meeting, 1906; Pub. A. S. P., *19*, pp. 27-33; Science, n. s., *25*, pp. 613-617.

Spectra of the limb and center of the sun. (With W. S. Adams.) Pub. A. S. P., *19*, pp. 239-240.

Preliminary photographic map of the sun-spot spectrum. Pub. A. S. P., *19*, p. 240.

Recent progress in the construction work of the Solar Observatory. Pub. A. S. P., *19*, pp. 243-244.

Professor Julius's visit to Mount Wilson. Pub. A. S. P., *19*, p. 244.

New appointments to the staff of the Mount Wilson Solar Observatory. Pub. A. S. P., *19*, pp. 244-245.

A plea for the imaginative element in technical education. 15 pp.

The spectrum of the high potential discharge between metallic electrodes in liquids and in gases at high pressures. (With Norton A. Kent.) Pub. Yerkes Obs., *3*, (Pt. 2), pp. 27-66.

1908

Remarques sur le rapport de la commission sur les travaux à faire avec le spectrohéliographe (1907). Trans. Int. Union Coop. Sol. Res., *2*, pp. 56-62.

Report of Committee on Work with the Spectroheliograph (1907). Trans. Int. Union Coop. Sol. Res., *2*, pp. 181-190.

The measurement of solar photographs made with the spectroheliograph (1907). Trans. Int. Union Coop. Sol. Res., *2*, pp. 191-198.

The Mount Wilson photographic map (1907). Trans. Int. Union Coop. Sol. Res., *2*, pp. 216-217.

The tower telescope of the Mount Wilson Solar Observatory. Ap. J., *27*, pp. 204-212; Mt. W. Contr., No. 23.

Preliminary note on the rotation of the sun as determined from the motions of the hydrogen flocculi. Ap. J., *27*, pp. 219-229; Mt. W. Contr., No. 25.

Solar vortices. Ap. J., *28*, pp. 100-116; Mt. W. Contr., No. 26; Pub. A. S. P., *20*, pp. 203-219.

The Pasadena Laboratory of the Mount Wilson Solar Observatory. Ap. J., *28*, pp. 244-249; Mt. W. Contr., No. 27.

On the probable existence of a magnetic field in sun-spots. Ap. J., *28*, pp. 315-343; Mt. W. Contr., No. 30.

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 7, pp. 146-157; Pub. A. S. P., *21*, pp. 146-159, 1909.

Rotation period of the sun as determined from the motions of the calcium flocculi. (With Philip Fox.) Carnegie Inst. Pub. No. 93; Wash., Carnegie Inst. 54 pp.

The study of stellar evolution; an account of some recent methods of astrophysical research (Decennial publication of University of Chicago, ser. 2, v. 10). Chicago, Univ. Chicago Press. 252 pp.

The relative advantages of various forms of telescopes for solar research; read at April meeting, American Philosophical Society, April 25, 1908. (Not printed.)

A comparative study of the spectra of the limb and center of the sun. (With W. S. Adams.) Pub. A. S. P., *20*, pp. 27-28.

Some tests of the vertical coelostat or "tower" telescope of the Mount Wilson Solar Observatory. Pub. A. S. P., *20*, pp. 35-36.

Solar vortices and the Zeeman effect. Pub. A. S. P., *20*, pp. 220-224.

The Zeeman effect in the sun. Pub. A. S. P., *20*, pp. 287-288.

The hydrogen flocculi, as photographed with the Hα and Hδ lines. Mem. Spett. It., *37*, pp. 99-100; (Fr. tr.) Les flocculi de l'hydrogène photographiés avec les raies Hα et Hδ. Comptes rendus, *146*, pp. 1251-1254.

Note on Sutherland's article. Terr. Mag., *13*, p. 158.

On the probable existence of a magnetic field in sun-spots. (Author's abstract.) Terr. Mag., *13*, pp. 159-160.

1909

Photography of the "flash" spectrum without an eclipse. (With W. S. Adams.) Ap. J., *30*, pp. 222-230; Mt. W. Contr., No. 41.

Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 8, pp. 159-180.

Solar vortices and magnetic fields (published also under the titles: Recent solar research; Sur les champs magnétiques des taches solaires; Sui campi magnetici delle macchie solari). Address given at dedication of Frank Brackett Observatory, Claremont, Calif., Nov. 20, 1908; Société française de Physique (Paris), April 23, 1909; Royal Institution of Great Britain, May 14, 1909; Soc. Italiana di Fisica (Rome), June 2, 1909; Proc. R. Inst., *19*, pp. 615-630; Pop. Astron., *17*, pp. 14-19; Obs., *32*, pp. 311-315; Nature, *82*, pp. 20-23, 50-53; Jour. de physique (4), *8*, pp. 461-475; Bull. Soc. fr. de Physique, pp. 118-132; Riv. di Astron., *3*, October, 1909; Sci. Amer. Supp., *69*, pp. 213-215, 236-237, 1910.

Remarques relatives à la communication de M. Deslandres. Comptes rendus, *148*, p. 1025.

Reconnaissance des couches supérieures du calcium et de l'hydrogène dans l'atmosphère solaire et des mêmes filaments noirs dans les deux couches. Comptes rendus, *148*, pp. 1025-1026.

On the nature of the hydrogen flocculi on the sun; address before Royal Society of London, June 17, 1909. M. N., *69*, pp. 616-617.

Celestial photographs taken at Mount Wilson Observatory, California. M. N., *70*, pp. 175-176.

Recent work of the Mount Wilson Observatory. Science, n. s., *29*, pp. 220-222.

Some recent contributions to our knowledge of the sun; Hamilton lecture of the Smithsonian Institution, delivered April 22, 1908. Smiths. Coll., *52*, pp. 331-360.

In Galileo's footsteps. (With Alexander McAdie and Stanley Du Bois.) Sunset Mag., *22*, pp. 133-143.

Solar cyclones and magnetic fields; address before Society of Arts, Massachusetts Institute of Technology. Bull. Soc. Arts, April, 1909. 9 pp.

Note on the magnetic field in sun-spots. Pub. A.S.P., *21*, pp. 205-208.

1910

The work of the Mount Wilson Observatory; lecture before American Philosophical Society, April 22, 1910. (Never printed.)

Notes on the solar magnetic fields and related phenomena. Pub. A.S.P., *22*, pp. 63-78.

Classification of the hydrogen ($H\alpha$) flocculi. Pub. A.S.P., *22*, pp. 142-143.

Asymmetrical lines in sun-spot spectra. Pub. A.S.P., *22*, p. 145.

Sixth interim report on Mars: Addendum. Jour. B.A.A., *20*, pp. 191-192.

On the nature of the hydrogen flocculi and their structure at different levels in the solar atmosphere. (With Ferdinand Ellerman.) Proc. R. Soc., Ser. A, *83*, pp. 177-188.

Address at opening of Fourth Conference of the International Union for Co-operation in Solar Research (1910). Trans. Int. Union Coop. Sol. Res., *3*, pp. 11-26, 1911.

Great solar storms. Literary Digest, *41*, pp. 978-979.

I canali di Marte. Riv. di Astron., *4*, pp. 113-116.

1911

Spectroheliograph; article in Encyclopaedia Britannica, 11th ed., *25*, pp. 618-619.

1912

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 11, pp. 172-213.

Polarization phenomena of coelostat telescopes. Pub. A.S.P., *24*, pp. 73-75.

A method of testing optical glass. Pub. A.S.P., *24*, pp. 128-129.

The 150-foot tower telescope of the Mount Wilson Solar Observatory. Pub. A.S.P., *24*, pp. 223-226.

A sun-spot hypothesis. Pub. A.S.P., *24*, pp. 226-227.

Preliminary note on an attempt to detect the general magnetic field of the sun. Read at Cleveland meeting, Astronomical and Astrophysical Society of America, 1912; (Abstract) Pub. Astron. and Astrophys. Soc., *2*, 154.

Preliminary note on an attempt to detect the general magnetic field of the sun. Terr. Mag., *17*, pp. 173-178.

1913

The work of Sir William Huggins. Ap. J., *37*, pp. 145-153.

Preliminary results of an attempt to detect the general magnetic field of the sun. Ap. J., *38*, pp. 27-98; Mt. W. Contr., No. 71.

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 12, pp. 195-240.

Preliminary note on an attempt to detect the magnetic field of the sun. Pub. A.S.P., *25*, pp. 28-33.

The general magnetic field of the sun. (With F. Ellerman and A. van Maanen.) Read at Atlanta meeting, American Astronomical Society, 1913; (Abstract) Pub. A.A.S., *3*, p. 9, 1918; Pop. Astron., *22*, p. 137, 1914.

National academies and the progress of research. I. Work of European academies. Science, n.s., *38*, pp. 681-698.

Magnetism of celestial bodies. Sci. Amer. Supp., *76*, pp. 196-198.

Earth and sun as magnets. Address delivered at the Semi-centennial of the National Academy of Sciences, Washington, D. C., May, 1913. Smiths. Rept. 1913, pp. 145-158; Pop. Sci. Mon., *83*, pp. 105-124.

The day's work of the Mount Wilson Observatory. The World's Work, *25*, pp. 568-577.

1914

Report of the spectroheliograph committee (1913). Trans. Int. Union Coop. Sol. Res., *4*, pp. 95-97, 1914.

Preliminary observations of the Zeeman effect, due to the general magnetic field of the sun (1913). Trans. Int. Union Coop. Sol. Res., *4*, pp. 218-221, 1914.

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 13, pp. 241-284, 1914.

Solar magnetic phenomena. Read before American Philosophical Society, April 24, 1914; (Abstract) Proc. Amer. Philos. Soc., *53*, pp. 251-255.

The polarity of sun-spots. (With Ferdinand Ellerman.) Read at Evanston meeting, American Astronomical Society, 1914; (Abstract) Pub. A.A.S., *3*, pp. 81-82; Pop. Astron., *22*, pp. 568-569.

The Zeeman and Stark effects. Pub. A.S.P., *26*, pp. 146-147.

National academies and the progress of research. II. The first half-century of the National Academy of Sciences. Science, n.s., *39*, pp. 189-200.

National academies and the progress of research. III. The future of the National Academy of Sciences. Read at Baltimore meeting, National Academy of Sciences (1913); Science, n.s., *40*, pp. 907-919, 1914; *41*, pp. 12-23, 1915.

The direction of rotation of solar storms. Read before National Academy of Sciences, Chicago meeting (1914); (Abstract) Science, n.s., *40*, p. 771.

1915

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 14, pp. 251-293, 1915.

An attempt to measure the free electricity in the sun's atmosphere. (With H. D. Babcock.) Proc. Nat. Acad. Sci., *1*, pp. 123-127; Mt. W. Comm., No. 3.

The direction of rotation of sun-spot vortices. Proc. Nat. Acad. Sci., *1*, pp. 382-384; Mt. W. Comm., No. 10.

Some vortex experiments bearing on the nature of sun-spots and flocculi. (With G. P. Luckey.) Proc. Nat. Acad. Sci., *1*, pp. 385-389; Mt. W. Comm., No. 11.

The work of a modern observatory. Pub. A.S.P., *27*, pp. 161-178.

The remodeled 60-foot tower telescope. Pub. A.S.P., *27*, pp. 233-235.

Progress of work on the 100-inch telescope. Pub. A.S.P., *27*, pp. 235-236.

National Academies and the progress of research. IV. The Proceedings of the National Academy as a medium of publication. Science, n.s., *41*, pp. 815-817.

Ten years' work of a mountain observatory (Carnegie Inst. Pub., No. 235). Wash., Carnegie Inst. 99 pp.

1916

Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 15, pp. 227-272.

Fotografia spettroeliografica (with A. Riccò). Mem. Spett. It., ser. 2a, *5*, pp. 32-35.
Ancora sulla fotografia solare stereoscopica. Mem. Spett. It., ser. 2a, *5*, pp. 61-63.
The National Research Council of the United States. (With others.) Nature, *97*, pp. 464-465.
Some reflections on the progress of astrophysics; address delivered at the Semi-Centennial of the Dearborn Observatory. Pop. Astron., *24*, pp. 550-558.
The minute structure of the solar atmosphere. (With Ferdinand Ellerman.) Proc. Nat. Acad. Sci., *2*, pp. 102-108; Mt. W. Comm., No. 20.
Preliminary report of the Organizing Committee to the President of the Academy. Proc. Nat. Acad. Sci., *2*, pp. 507-510.
Work for the amateur astronomer. Pub. A.S.P., *28*, pp. 53-61.
The national value of scientific research. Tech. Rev., *18*, pp. 801-817.
The National Research Council: How it proposes to mobilize the nation's science for industrial progress and military efficiency. N. Y. Times, July 26, 1916.
A National Research Council. N. Y. Evening Post, Oct. 9, 1916.

1917

Baxandall's explanation of an "abnormal" solar spectrum. Ap. J., *46*, pp. 291-295; Mt. W. Contr., No. 143.
Mount Wilson Solar Observatory (Annual report). Carnegie Inst. Yearbook, No. 16, pp. 199-235.
The National Research Council: Basis of organization and means of co-operation with state councils of defense. Jour. Franklin Inst., *183*, p. 759.
National Research Council: Research committees in educational institutions. Proc. Nat. Acad. Sci., *3*, pp. 223-227.
The best service of astronomers in time of war. Read at Albany meeting, American Astronomical Society, 1917; Pub. A.A.S., *3*, pp. 313-315, 1918; Pop. Astron., *25*, pp. 652-655.
The intellectual inspiration of Paris; introduction to Science and learning in France, pp. 5-17. Published by Society for American Fellowships in French Universities, 1917.
Second annual report of the National Research Council. Nat. Acad. Sci. Rept. for 1917, pp. 46-70.
How men of science will help in our war. Scribner's Mag., *61*, pp. 721-726.
National Research Council. Southern Calif. Mag., *1*, No. 5, p. 6.

1918

The general magnetic field of the sun: apparent variation of field-strength with level in the solar atmosphere (With F. H. Seares, A. van Maanen, and F. Ellerman.) Ap. J., *47*, 206-254; Mt. W. Contr., No. 148.

Mount Wilson Observatory (Annual report). Carnegie Inst. Yearbook, No. 17, pp. 181-218.

The national engineering societies and the National Research Council. Jour. Amer. Soc. Mech. Eng., *40*, pp. 825-829.

Industrial research and national welfare. Address delivered under auspices Engineering Foundation, New York, May 28, 1918; (excerpts) Science, n.s., *48*, pp. 505-507.

War activities of the National Research Council; address before Engineering Foundation, May 28, 1918. Proc. Amer. Inst. Elec. Eng., *37*, pp. 909-934; Bull. Amer. Inst. Mining Eng., *140*, Supp., pp. xxxix-xlvi.

Third annual report of the National Research Council. Nat. Acad. Sci. Rept. for 1918, pp. 39-112.

1919

The magnetic polarity of sun-spots. (With F. Ellerman, S. B. Nicholson, and A. H. Joy.) Ap. J., *49*, pp. 153-178; Mt. W. Contr., No. 165.

Mount Wilson Observatory (Annual report). Carnegie Inst. Yearbook, No. 18, pp. 217-264.

The national importance of scientific and industrial research. (With others.) Nat. Research Council. Bul., *1*, pp. 1-7.

The 100-inch Hooker telescope of the Mount Wilson Observatory. Pop. Astron., *27*, pp. 635-636.

On the nature of sun-spots. (Abstract) Proc. R. Soc., Ser. A., *95*, pp. 234-236.

Preliminary results of a comparative test of the 60-inch and 100-inch telescopes of the Mount Wilson Observatory. Read at Ann Arbor meeting, American Astronomical Society, 1919; (Abstract) Pub. A.A.S., *4*, pp. 90-93, 1923; Pop. Astron., *27*, pp. 563-566; Pub. A.S.P., *31*, pp. 257-260.

Stereoscopic photographs of the solar atmosphere. (Abstract) Pub. A.S.P., *31*, p. 178.

The responsibilities of the scientist; read at Pasadena meeting, Pacific Division, American Association for the Advancement of Science, 1919; Science, n.s., *50*, pp. 143-146; Throop College Bull., *28*, pp. 17-24, 1919.

Co-operation in research; address before Royal Canadian Institute, April 9, 1919. Trans. R. Canadian Inst., *12*, pp. 339-347; Science, n.s., *51*, pp. 149-155, 1920.

Science as a source of industrial progress; address before members of the Legislature of the Province of Ontario, Toronto, April 10, 1919. (Never printed.)

Plan for the promotion of scientific and industrial research by the National Academy of Sciences and the National Research Council. N. Y., Carnegie Corporation, 1919. 32 + xiv pp.

1920

Mount Wilson Observatory (Annual report). Carnegie Inst. Yearbook, No. 19, pp. 209-265.

Photographs taken with the 100-inch reflector of the Mount Wilson Observatory. M.N., *80*, pp. 240-243.

Some tests of the 100-inch Hooker telescope. Nature, *105*, pp. 266-268.

Note on the 100-inch Hooker telescope. Read at Northampton-South Hadley meeting, American Astronomical Society, 1920; (Abstract) Pub. A.A.S., *4*, pp. 161-162, 1923; Pop. Astron., *28*, pp. 599-600.

The Mount Wilson photographic map of the sun-spot spectrum. (With Ferdinand Ellerman.) Read at Northampton-South Hadley meeting, American Astronomical Society, 1920; (Abstract) Pub. A.A.S., *4*, pp. 162-164, 1923; Pop. Astron., *28*, pp. 600-602; Pub. A.S.P., *32*, pp. 272-273.

Lunar photography with the Hooker telescope. Pub. A.S.P., *32*, pp. 112-115.

The international organization of scientific research. Internat. Conciliation, No. 154, Sept., 1920, pp. 431-441.

Outline of plan for inter-allied research council. No date.

Introduction; Science and War (Chap. 1); War services of the National Research Council (Chap. 2); The Possibilities of Co-operation in Research (Chap. 22); The International Organization of Research (Chap. 23). In Yerkes, The New World of Science.

The new heavens. Scribner's Mag., *68*, pp. 387-402.

1921

Mount Wilson Observatory (Annual report). Carnegie Inst. Yearbook, No. 20, pp. 215-294.

The angular diameter of α Orionis. M. N., *81*, pp. 166-167.

Some astrophysical aspects of the Zeeman effect. Physica, *1*, pp. 250-254.

The probable absence of a measurable electric field in sun-spots. Read at Middletown meeting, American Astronomical Society, 1921; (abstract) Pub. A. A. S., *4*, pp. 262-263; Pop. Astron., *29*, pp. 625-626.

A summary of the year's work at Mount Wilson (1919-1920). Pub. A. S. P., *33*, pp. 18-30.

Note on the combined effect of electric and magnetic fields on the hydrogen spectrum. Pub. A. S. P., *33*, pp. 114-116.

The great sun-spot of May, 1921. (With S. B. Nicholson.) (Abstract) Pub. A. S. P., *33*, p. 208.

A summary of the year's work at Mount Wilson (1920-1921). Pub. A. S. P., *33*, pp. 291-312.

Giant stars. Scribner's Mag., *70*, pp. 3-15.

Cosmic crucibles. Scribner's Mag., *70*, pp. 387-401.

The 100-inch telescope of the Mount Wilson Observatory. London Times, July 26, 1921.

1922

Mount Wilson Observatory (Annual report). Carnegie Inst. Yearbook, No. 21, pp. 198-255.

Invisible sun-spots. M. N., *82*, pp. 168-169.

Invisible sun-spots. Proc. Nat. Acad. Sci., *8*, pp. 168-170; Mt. W. Comm., No. 80.

A fifty-foot interferometer telescope. Nature, *110*, pp. 482-483.

A fifty-foot interferometer telescope. Read at Williams Bay meeting, American Astronomical Society, 1922; (Abstract) Pub. A. A. S., *4*, pp. 358-359; Pop. Astron., *30*, pp. 556-557.

Note on invisible sun-spots. Pub. A. S. P., *34*, pp. 59-61.

A summary of the year's work at Mount Wilson. (With W. S. Adams.) Pub. A. S. P., *34*, pp. 258-274.

A joint investigation of the constitution of matter and the nature of radiation. Address at dedication of Norman Bridge Laboratory, California Institute of Technology; Science, n. s., *55*, pp. 332-334.

Report of President of Commission on Solar Atmosphere. Trans. Int. Astron. Union, *1*, pp. 31-33.

The new heavens. N. Y., Scribners. 88 pp.

The depths of the universe. Scribner's Mag., *71*, pp. 689-704.

A national focus of science and research. Scribner's Mag., *72*, pp. 515-530; Nat. Res. Council, Reprint and Circular Ser., No. 39, 16 pp.

1923

The possibilities of instrumental development. Read at Mount Wilson meeting, American Astronomical Society, 1923; Pub. A. A. S., *5*, pp. 54-60, 1927; Pop. Astron., *31*, pp. 568-574; Smiths. Rept. 1923, pp. 187-193.

Recent discoveries in Egypt. Scribner's Mag., *74*, pp. 34-49.

The work of an American Orientalist. Scribner's Mag., *74*, pp. 392-404.

1924

Sun-spots as magnets and the periodic reversal of their polarity. Nature, *113* (Supp.), pp. 105-112.

The law of sun-spot polarity. Proc. Nat. Acad. Sci., *10*, pp. 53-55; Mt. W. Comm., No. 86.

The spectrohelioscope. Proc. Nat. Acad. Sci., *10*, pp. 361-363; Mt. W. Comm., No. 87; Nature, *114*, p. 628.

The depths of the universe. N. Y., Scribner. 98 pp.

Barnard's dark nebulae. Scribner's Mag., *75*, pp. 81-95.

Sun-spots as magnets. Scribner's Mag., *75*, pp. 527-543.

The periodic reversal of the magnetic polarity of sun-spots. Tech Engineering News, *5*, pp. 50-51, 84.

1925

Law of the sun-spot polarity. (With S. B. Nicholson.) Ap. J., *62*, pp. 270-300; Mt. W. Contr., No. 300; List of errata. Ap. J., *63*, p. 72, 1926.

History of the Royal Society, 1820-1920, ed. by J. L. E. Dreyer and H. H. Turner (Review). Ap. J., *62*, pp. 65-72.

The spectrohelioscope. Nature, *115*, p. 50.

A test of the electromagnetic theory of the hydrogen vortices surrounding sun-spots. Proc. Nat. Acad. Sci., *11*, pp. 691-696; Mt. W. Comm., No. 95.
Nature of the hydrogen vortices surrounding sun-spots. Pub. A. S. P., *37*, pp. 268-270.
The Oriental ancestry of the telescope. Scribner's Mag., *77*, pp. 392-404.
Some recollections of Bertram Grosvenor Goodhue. In Memorial volume, Bertram Grosvenor Goodhue, Architect and Master of many arts. Amer. Inst. Architects, pp. 45-50.

1926

Solar tornadoes. Nat. Hist., *26*, pp. 363-373.
Observations with the spectroheliosope. Nature, *118*, pp. 420-421.
Tribute to Sir Joseph Thomson. Nature, *118*, pp. 880-881.
Some new possibilities in solar research. Nature, *118* (Supp.), pp. 1-8.
The spectrohelioscope. Obs., *49*, p. 372.
Visual observations of the solar atmosphere. Proc. Nat. Acad. Sci., *12*, pp. 286-295; Mt. W. Comm., No. 97.
The spectrohelioscope. Pub. A. S. P., *38*, pp. 96-100.
Beyond the Milky Way. Scribner's Mag., *80*, pp. 276-291.
Beyond the Milky Way. N. Y., Scribner. 105 pp.
Heat from the stars. Scribner's Mag., *79*, pp. 47-58.

1927

The sun as a research laboratory. Presented at meeting of Franklin Institute, May 18, 1927; Jour. Franklin Inst., *204*, pp. 19-28.
The fields of force in the atmosphere of the sun. Nature, *119*, pp. 708-714.
The Huntington Library and Art Gallery: The new plan of research. Scribner's Mag., *82*, pp. 31-43.

1928

Work for the amateur astronomer. II. How to build a small solar observatory. Pub. A. S. P., *40*, pp. 285-302.
An inexpensive solar telescope and spectrohelioscope. Nature, *121*, pp. 676-680.
The Astrophysical Observatory of the California Institute of Technology. Science, n. s., *68*, pp. 435-437.
Solar research for amateurs. *In* Amateur Telescope Making. 2d ed. N. Y., Sci. Amer. Pub. Co., pp. 180-202 (Pt. IX).
Science and the wealth of nations. Harper's Mag., *156*, pp. 243-251.
The possibilities of large telescopes. Harper's Mag., *156*, pp. 639-646.
Exploring the solar atmosphere. Scribner's Mag., *84*, pp. 46-55.
New light from the nebulae on the nature of matter. Research narratives, *3*, pp. 113-116.

1929

The spectrohelioscope and its work: I. History, instruments, adjustments, and methods of observation. Ap. J., *70*, pp. 265-311; Mt. W. Contr., No. 388.

Spectroheliograph: article in Encyclopaedia Britannica, 14th ed., *21*, pp. 178-180.

Solar research for amateurs. I and II. Sci. Amer., *140*, pp. 302-305, 436-438.

Building the 200-inch telescope. Harper's Mag., *159*, pp. 720-732.

1930

The spectrohelioscope and its work: II. The motions of the hydrogen flocculi near sun-spots. Ap. J., *71*, pp. 73-101; Mt. W. Contr., No. 393.

Práce pro astroma-amatéra. Říše hvêzd (Prague), *11*, pp. 1-7, 21-27.

1931

The spectrohelioscope and its work: III. Solar eruptions and their apparent terrestrial effects. Ap. J., *73*, pp. 379-412; Mt. W. Contr., No. 425.

The spectrohelioscope and its work: IV. Methods of recording observations. Ap. J., *74*, pp. 214-222; Mt. W. Contr., No. 434.

Some of Michelson's researches. Pub. A. S. P., *43*, pp. 175-185.

A solar observatory for the amateur. Sci. Amer., *145*, pp. 244-247.

Signals from the sun. Scribner's Mag., *90*, pp. 36-42.

Signals from the stars. N. Y. Scribner. 138 pp.

Article written in accepting the Gold Medal of the Holland Society of New York. Holland Soc., Quarterly circular, "De Halve Maen", *7*, No. 3, pp. 2-4.

1932

Cooperative research with the spectrohelioscope. Third report of Commission appointed to Further the Study of Solar and Terrestrial Relationships, pp. 78-79.

1933

Solar research for amateurs. *In* Amateur Telescope Making, 3d ed. N. Y., Sci. Amer. Pub. Co. pp. 180-214 (Pt. IX).

1934

Deeper into space. Atlantic Mo., *153*, pp. 463-471.

Horizons. Vo-Mag., *2*, p. 16.

1935

Sir Arthur Schuster. Ap. J., *81*, pp. 97-106.

The Astrophysical Observatory of the California Institute of Technology. Ap. J., *82*, pp. 111-139.

The brightness of prominences as shown by the spectrohelioscope. M. N., *95*, pp. 467-468.

Solar magnetism. Nature, *136*, pp. 703-705.

Address of the President (in absentia), International Council of Scientific Unions, Brussels, 1934. Reports of Proceedings, pp. 4-10.

Solar research for amateurs. *In* Amateur Telescope Making. 4th ed. N. Y., Sci. Amer. Pub. Co. pp. 180-214 (Pt. IX).

The magnetic periodicity of sun-spots. Pieter Zeeman Jubilee volume, pp. 63-70.

1936

The Astrophysical Observatory of the California Institute of Technology: The 200-inch reflector. Nature, *137*, pp. 221-228.

Transportation of the 200-inch mirror. Nature, *137*, pp. 1017-1018.

El Observatorio Astrofisico del Instituto de Tecnologia de California. El reflector de 200 pulgadas. Revista Astronomica (Buenos Aires), *8*, pp. 2-6.

The 200-inch telescope. Sci. Amer., *154*, pp. 237-240, 293.

1938

Magnetic observations of sun-spots, 1917-1924. (With S. B. Nicholson.) Wash., Carnegie Inst., 2 v. Papers of the Mount Wilson Observatory, *5*, Pt. 1-2; Carnegie Inst. Wash. Pub., No. 498.