MEMOIR

OF

HENRY DRAPER.

1837–1882.

BY

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BIOGRAPHICAL MEMOIR OF HENRY DRAPER.

MR. PRESIDENT AND GENTLEMEN OF THE ACADEMY:

Of all the marvelous results which have been obtained by what has been felicitously styled the New Astronomy, perhaps none exceed in importance or in value those which have been obtained by the aid of photography. While the older or mathematical astronomy, so called, has had to do with positions and magnitudes and motions essentially, all expressible by the aid of suitable symbols in the form of more or less complex functions, the newer or physical astronomy has concerned itself largely with physical phenomena and appearances, the completest attainable record of which is essential to their successful interpretation. True, the contacts of an eclipse and the path of a transit, when registered by photography, have greatly aided the comparison of theory with observation in mathematical astronomy. But the value of photography here is inconsiderable when compared with that of the record which it can furnish of the lunar and solar surfaces, of the distribution of stars in a group, of the configuration of a nebula, or of the arrangement of lines in a solar or stellar spectrum. Indeed, the facility of reproduction by photographic means so far surpasses that by drawing or sketching, and is, moreover, so much more accurate a method of delineation, that the evidence given by an untouched photograph is everywhere accepted as *primâ facie* proof. Among those who have assiduously devoted themselves to the evolution of astronomical photography in its many-sided relations, none, it will be conceded, has accomplished more, and none, therefore, more richly deserves the reward of full recognition from his fellow-workers, than our late member, Henry Draper, the accomplished investigator, scientist, and teacher, who is the subject of the present sketch.

HENRY DRAPER was born in Prince Edward county, Virginia, on the 7th of March, 1837. His distinguished father, John William Draper, who had come from England to the United States in 1832, had settled first in Christiansville, Mecklenburg county, and had at once begun there an active career of scientific research. In 1835 he entered upon a course of medical study in the University of Pennsylvania, and received the degree of Doctor of Medicine in 1836. Already, however, his original scientific papers had gained for him renown, so that in the fall of the same year he was elected to the chair of chemistry and natural philosophy in Hampden Sidney College, in Prince Edward county. This appointment it was which permitted him, in place of practicing his profession, to devote himself entirely to research; which enabled him, therefore, to continue the scientific investigations which he had begun and of which he was so fond, and which secured permanently to the cause of science in this country an investigator of the highest type. It was while he was thus acting as a professor in Hampden Sidney College that Henry was born. His mother, a daughter of Dr. Gardner, the attending physician of the Emperor of Brazil, Dom Pedro I, and a descendant on her mother's side of a noted Portuguese family, the De Piva Pereiras, was a woman of marked character and ability, and his earliest years were spent in an atmosphere of the highest scientific culture and refinement.

In the year 1839, having accepted the professorship of chemistry in the undergraduate department of the University of the City of New York, Dr. Draper moved thither with his family, Henry being at that time but two years old. As soon as he was sufficiently prepared, he entered the primary school, which was at that time connected with the University, from which he passed into the preparatory school. At the age of fifteen he entered the collegiate department as an undergraduate, where he was distingushed for excellent scholarship. By the advice of his father, however, and partly on account of his not very vigorous constitution, he did not remain to take the bachelor's degree with his class, but left the classical course upon the completion of the sophomore year and entered the department of medicine. Upon the termination of his medical studies in 1857, he passed all his examinations satisfactorily; but, not having attained the age necessary for graduation, his diploma was withheld. Thereupon, in company with his older brother, he went abroad for study and recreation, remaining an entire year. Upon his return in 1858, he received his medical degree, graduating with distinction. While in Europe he was appointed upon the medical staff of Bellevue Hospital, a position which he assumed after his return, and the duties of which he discharged for eighteen months. In 1860, at the age of twenty-three, he was elected Professor of Natural Science in the Undergraduate Department of the University of New York, and in 1866 he was appointed Professor of Physiology in the Medical Department, being made at the same time Dean of the Faculty. This connection with the Medical School he retained until 1873. Subsequently he held the chair of Analytical Chemistry in the Academic Department of the University, and upon the death of his father, in January, 1882, he was chosen to succeed him as Professor of Chemistry, a position which he held, however, only until the close of the current academic year. He then severed entirely his connection with the University.

Reared in direct contact with science and scientific thought as Henry Draper was, it is not surprising that at an early age he developed a decided preference for scientific pursuits. The eminence of his father as a teacher, an author, a philosopher, and an investigator created about him an atmosphere of scientific culture of the highest tone. To live in contact with this genial and learned man was of itself an education of the greatest value. Henry was early taken into his father's confidence in all scientific matters, and was often permitted to assist his father, not only in his lectures, but also in his investigations. The scientific spirit which presses forward unflaggingly in the pursuit of truth and which wrests from nature the profoundest secrets by patient and long-continued application had always been characteristic of the elder Draper; it was now to be fully developed in his son Henry. While yet a student of medicine, he had undertaken a most difficult research upon the function of the spleen; and, conscious of the inaccuracies incident to drawings, he illustrated this memoir—afterward published as his graduating thesis—with photomicrographs of rare perfection for those early days, all of which were prepared and photographed by himself. It was while engaged with the microscope in making these excellent micrographs that he discovered the remarkable power possessed by palladious chloride in intensifying negatives, an observation which subsequently proved of much value in the photographic art. From this period dates his interest in photographic pursuits, in which he attained afterward such eminence.

During his sojourn in Europe in 1857 he attended the meeting of the British Association, which was held at Dublin in the month of August. Upon the adjournment of the meeting he was invited by the Earl of Rosse to join a party made up of the members for the purpose of visiting the six-foot reflecting telescope at Birr Castle, Parsonstown. There he saw not only the great instrument itself, but also the machinery and methods by which it had been produced. The sight of this splendid telescope inspired him with a desire to construct a similar, though, of course, a smaller one, and was thus the means of turning his attention to astronomy and astronomical photography.

Accordingly, in September, 1858, shortly after his return from Europe, he began the construction of a Rosse machine for grinding and polishing a 15½-inch speculum. A preliminary trial on a smaller mirror, 8 inches in diameter and 11 inches in focal length, having proved satisfactory, the large speculum was successfully cast on the 2d or 3d of November. The casting turned out to be very fine, free from pores and of silvery whiteness. It was 2 inches in thickness and weighed 110 pounds. The speculum was to be of 12 feet focal length. Work was begun upon it on the 9th and on the 26th it was sufficiently advanced to permit of a preliminary test. On the 29th Jupiter's moons were seen with it with the naked eye. During the following winter this speculum was mounted as a Newtonian telescope, the flat secondary mirror having been made at the same time. The figure of the large mirror was not satisfactory, however, the machine showing a tendency to polish in rings of different focal lengths. Early in the spring of 1859, therefore, it was reground, this tedious operation being assisted by placing the mirror and grinder in a voltaic circuit, the space between the two being filled with acidulated water and the speculum being made the positive pole. In this way the speculum metal was attacked and removed by the electrolytic action, thus facilitating the grinding. If, however, the current was strong enough to make the operation of material value, it was found that the copper and tin were transferred bodily and were deposited upon the grinder. In consequence of this, another experiment was tried with this mirror. Certain defects having to be ground out, the depressions were covered with a thick layer of Canada balsam; and a thick rim of wax having been made around the edge of the mirror, nitrohydrochloric acid was poured on and the uncovered spaces were, in this way, quickly corroded away. Subsequently an increase of 15 inches in the focal length was secured by attacking the edge zones of the surface with the acid in graduated depths. The grinding and polishing of this speculum continued at intervals until the following summer, when the mirror was found to have a focal length of 11 feet 10½ inches, and to give fair results when tested upon the sun. In February, 1860, this speculum was found split entirely across, the parts forming two nearly equal halves, the result being due to the expansion in freezing of a few drops of water which had found their way into the supporting case.

In June, 1860, Prof. John W. Draper sailed for Europe. While abroad he visited Sir John Herschel, and by his advice wrote to Henry to abandon speculum metal and to make his mirrors of silvered glass, since, for an equal aperture, they were only one-eighth as heavy and at the same time reflected 93 per cent. of the light falling upon them. Accordingly a piece of glass 15¾ inches square and 1 inch in thickness was at once ground and polished. In November it was put into its tube, and during the month ten solar daguerreotypes were obtained with it. The following winter a new grinding-machine was contrived, and experiments were made with three 15½-inch glass disks, as well as with some smaller ones. Three mirrors of the same focal length and aperture, Dr. Draper says, are almost essential in working, for it not infrequently happens that two in succession will be so similar that a third is required for attempting to make any advance beyond them. One of the mirrors thus made was parabolic in figure and bore a power of 1,000, 77 hours and 10 minutes having been expended in grinding and polishing it. The three mirrors were all tested together in October, 1861. Number one was found to be nearly spherical, number two parabolic, and number three hyperbolic in form. Number two resolved ϵ Lyræ, separated the components of 36 Andromedæ, and, as Dr. Draper thought, divided γ^2 Andromedæ. Polaris was divided and stood easily a power of 1,000. After further time spent on these mirrors they were all pronounced good, and were consequently silvered.

The construction of these mirrors greatly interested Professor Joseph Henry, of Washington; and, believing that the practical details worked out so successfully by Dr. Draper would be of great value to others experimenting in the same line, he visited Dr. Draper's laboratory and observatory in the spring of 1863 and arranged with him to write a monograph upon the subject, to be published by the Smithsonian Institution. This paper was issued in July, 1864, as No. 180 of the Smithsonian Contributions to Knowledge. It has become the acknowledged authority on the subject, and has been several times reprinted.

In this memoir Dr. Draper treats of the methods of grinding and polishing the mirrors, the method of mounting them, the best forms of driving-clock, the construction of the observatory, the arrangement of the photographic laboratory, and the modes of photographic enlargement. "It is generally supposed," he says, "that glass is possessed of the power of resistance to compression and rigidity in a very marked manner. In the course of these experiments it has appeared that a sheet of it, even when very thick, can with difficulty be set on edge without bending so much as to be optically worthless. Fortunately in every disk of glass that I have tried there is one diameter on either end of which it may stand without harm." The glass used for these mirrors was such as is ordinarily employed for skylights, and had probably been subjected to a rolling operation when in a plastic state in order to reduce it to a uniform thickness; and hence the peculiarity referred to would seem to result from the structural arrangement of the glass itself. The same peculiarity has been observed, however, both in speculum metal and in optical glass, as has been proved by the observations of Short and by Airy. Many fine mirrors were condemned by Dr. Draper to be repolished before he appreciated the effect of position; mirrors which no doubt would have performed excellently had they been properly set in their mountings.

Again, the effect of temperature-changes upon the perfection of the form of the mirror is very remarkable. "A current of cold or warm air, a gleam of sunlight, the close approach of some person, an unguarded touch, the application of cold water injudiciously will ruin the labor of days." Of this effect he mentions the following example: "A 15½-inch mirror, which was giving at its center of curvature a very fine image of an illuminated pin-hole, was heated at the edge by placing the right hand on the back of the mirror at one end of the horizontal diameter. In a few seconds an arc of light came out from the image. On putting the left hand on the other extremity of the same diameter the appearance was that of two arcs of light crossing each other and having an image at each intersection. The mirror did not recover its original condition for ten minutes. Another person, on a subsequent occasion, touching the ends of the perpendicular diameter at the same time that the horizontal were warmed, caused the image to become somewhat like two of the former at right angles to each other. By unsymmetrical warming still more remarkable forms emerged in succession, some of which were more like certain nebulæ, with their milky light, than any geometrical figure. If the glass after one of these experiments had been immediately put on the polishing machine and repolished the changes in surface would, to a certain extent, have become permanent, as in Chinese specula."

Another propensity of glass was observed in these experiments. If the mirror be truly spherical it could give an image free from distortion only when so set that the object and image are both upon its optic axis. But Dr. Draper polished a large number of mirrors in which an image free from distortion was produced only when oblique pencils fell upon the mirror and the image was returned along a line forming an angle of from two to three degrees with the direction of the object. The explanation of this condition seems to be that the radius of curvature is greater along one of the diameters than along that at right angles. "How it is possible," he adds, "for such a figure to arise during grinding and polishing it is not easy to understand, unless it be granted that glass yields more to heat and compression in one direction than another."

After a description of the emery and the rouge needed for grinding and polishing the mirrors, and of the materials and construction of the tools used for the purpose, Dr. Draper goes on to describe the methods he employed for testing the surfaces produced. His habit was to test his mirrors exclusively at the center of curvature, not putting them in the telescope until parabolic or finished. "The means of trial are so excellent, the indications obtained so precise, and the freedom from atmospheric disturbances so complete that the greatest facilities are offered for ascertaining the nature of a surface." "I do not think," he says, "that anything more is learned of the telescope, even under favorable circumstances, than in the workshop." Two distinct methods of examination were employed, the second of which, due to Foucault, affords by itself a large part of the information required in correcting a concave surface. These are: "1st, observing with an eye-piece the image of an illuminated pin-hole at the focus, and the cone of rays inside and outside that plane; 2d, receiving the entire pencil of light coming from the mirror through the pupil on the retina and noticing the distribution of light and shade and the appearances of relief on the face of the mirror." After having obtained a spherical surface, Foucault moves the luminous pin-hole toward the mirror, at the same time retracting the eye-piece or screen, carrying it through a series of ellipsoidal curvatures and thus advancing step by step toward a paraboloid of revolution. Inasmuch, however, as the focal length of Dr. Draper's mirrors was 150 inches, the use of Foucault's method would require a room more than 25 feet long. But, by studying the gradual increase of deformation produced by the greater and greater departures from a spherical surface as the parabola is approached, he so modified Foucault's method as to use it satisfactorily in a room of ordinary size. The principle of this modified method of testing is thus given: If a 15½-inch mirror of 150 inches focal length were spherical and were used to converge parallel rays, those from its edge would reach a focus 5-100 of an inch nearer the mirror than those from its central parts. If, now, the converse experiment be tried, and a mirror of the same size and focal length, which can converge parallel rays falling on all its parts to one focus, be examined at the center of curvature, it gives there an amount of longitudinal aberration 10-100 of an inch, equal to twice the preceding. This latter, then, is the condition at the center of curvature to which such mirror must be brought in order to converge parallel rays with exactness. This is literally a method of parabolizing by measure, and is capable of great precision when the eye learns to estimate where the exact focus of a zone is.

At the outset the machine employed for grinding and polishing was similar to that of Lord Rosse. Subsequently another machine was constructed based upon the principle of Lassell's grinder. With the experience thus gained, still a third machine was made, which gave better and more speedy results than either. Indeed, no fewer than seven different grinding machines were built and tested in the course of the experiments. The final machine, which was intended to give spiral strokes, was a simplification of Lord Rosse's. In it, however, the lateral motion was absent and a changeable stroke was required. Moreover, the mirror was always uppermost in polishing, and, being uncounterpoised, escaped the effects of irregular pressure to as great an extent as possible. Eventually, however, a method of producing reflecting surfaces by correcting these surfaces by local retouches was adopted as the best of all, the mirrors formed by it being as perfect as can be and yet requiring only a short time for their production. In applying this method, due originally to Foucault, several disks of wood are provided, varying in diameter from 8 inches to half an inch, covered with pitch or resin in squares on one side and having a cylindrical handle on the other. The mirror, already fined, is laid face upward upon several folds of blanket arranged upon a circular table. The large polisher is then moved over the surface in straight strokes upon every chord, the pressure being moderate. As soon as is practicable an examination is made at the center of curvature and the best diameter for support is marked. If the mirror is nearly spherical it is replaced and the polishing is continued for three or four hours, till a fine polish is obtained free from dots like stippling. The next step is to shorten the radius of curvature of the center zones so as to convert the section curve into a parabola. This is accomplished by straight strokes across every diameter of the face—at first with a 4-inch, then with a 6-inch, and finally with the 8-inch polisher. When critically examined, however, a wavy or fleecy appearance could be detected upon the surface, due to the unequal pressure of the hand in polishing; and, further, the change in the focal length became greatest on the edge. In consequence a polishing machine was contrived which entirely overcame these two faults.

For silvering the mirrors the process originally adopted made use of milk-sugar as the reducing agent, and was devised by Dr. Draper himself. Subsequently Foucault's method with oil of cloves was experimented with, and finally this gave place to the Rochelle-salt process, suitably modified. The mirror, warmed to 100° F., is placed in the silvering solution face down, and allowed to remain till the sun's disk appears through the film of a pale-blue tint. When dry it is rubbed with a piece of soft buckskin to condense the surface, and is then polished with rouge on buckskin. The thickness of the layer is about 1-200000 of an inch, the weight of silver on a 15½-inch mirror being less than 4 grains.

The observatory in which the reflecting telescope of Dr. Draper was mounted was constructed during the spring of 1860, on ground belonging to his father's estate, at Hastings-on-Hudson. It is located on the top of a hill, 225 feet above low-water mark, and is in latitude 40° 59′ 25″ N. and longitude 73° 52′ 25″ W., as determined by the Coast Survey. The observatory proper is 17½ feet square, and is two stories in height, one being above the ground, and the other, equal in height, being excavated out of the solid granite upon three sides, the fourth being toward the east and open. To the upper portion and upon the southern side a photographic laboratory, 9 by 10 feet, was attached in 1862. The mounting of the 15½-inch telescope was on the alt-azimuth plan, but arranged (as first suggested by Miss Caroline Herschel) so that the eye-piece or place of the sensitive plate is stationary at all altitudes. An ingenious system of counterpoise levers allowed the telescope to work in a space a little more than its own length across. The mirror rests upon an air cushion, supported upon a disk of oak carried by three flat iron bars secured to the lower end of the telescope tube, the whole being surrounded with a curtain of black velvet. In form the telescope is a Newtonian instrument. For photographic purposes the eye-piece of the telescope was provided with a sliding plate-holder, having a motion in the apparent direction of the moon's path. The advantages of such an arrangement are twofold: In the first place, it gets rid completely of the difficulties arising from the moon's motion in declination; and, in the second, it requires the motion of a mass of scarcely more than an ounce in place of that of the entire telescope—a ton or more. To move the plate-holder, a sand-clock was first employed. The weight in this clock rested upon a column of sand, which could be allowed to run out through an orifice variable at will. Subsequently a form of clepsydra or water-clock was contrived, with which the most satisfactory results were obtained. For solar photographs, an angular spring shutter was used, attached to the eye-piece, and movable past the opening by means of a stout rubber band.

During the winter of 1862 a large number of solar photographs were taken with the new telescope, upon both daguerreotype and tannin plates. In April several photographs of the moon were obtained on dry plates with exposure varying from five seconds to five minutes. In the fall of the same year mirror No. 3 was reground, and twenty hours were spent in polishing it. "It is as good as we know how to make it," he writes. "During the construction of this mirror nearly a hundred other mirrors, ranging in size from ¼ inch up to 19 inches, have been made and polished," he tells us. This mirror separated γ^2 Andromedæ and showed the color of the components. It also showed the companion to Sirius, and the sixth component of θ'Orionis. Debillissima between ε and 5 Lyræ was proved quintuple, the moons of Jupiter gave beautiful disks, and the planet was covered with belts up to the poles. In the summer of 1863 lunar photography was again taken up, and the best photographs of the moon ever taken by any one up to that time were obtained during the first week in August. In all about 1,500 negatives of the moon were taken with this telescope. They were about an inch and a quarter in diameter and bore enlargement to three feet, and in one case to fifty inches, with excellent results.

In the fall of 1867 Dr. Draper began the construction of a glass mirror of 28 inches aperture and 12½ feet focal length, which was to be mounted as a Cassegrainian telescope. Upon this work much of his spare time was spent for eighteen months, the mirror having been ground and polished 41 times up to the first of April, 1869. In June, after 17¼ hours of polishing, it was completed and tested. The edge-focus was outside of the center-focus about 5-32 of an inch, so that its figure was about parabolic. Its focus was found to be 148 inches, that of the smaller and secondary mirror being 29. The latter was to be placed 33 inches inside of the focus of the large mirror. During the summer of 1869 another dome was added to the Hastings observatory, and toward the close of August the new mirror was mounted in it. The secondary mirror was silvered, and Saturn and Arcturus were observed with a power of about 120. In October the mirror was supported on a cushion of rubber, and although unsilvered it showed the companion to Polaris. During the following winter the driving clock was completed, and in July, 1871, the large mirror was successfully silvered by Browning's process. On August 1st the first photograph was taken with the new mirror. It was of the moon, the image being five inches in diameter. In September the equatorial clock was attached, and proved so perfect that Saturn could be examined with a power of 2,000. The defining power of the 28-inch mirror not being equal to that of the 15-inch, it was concluded to repolish it, and this was done the following winter, so that in March it was regarded as virtually perfect. The accessories were then finished, and by the end of June, 1872, the large telescope was pronounced to be in complete working order. Twenty or more photographs of the moon were subsequently taken, requiring an exposure of ten seconds for the full moon and of twenty-five seconds when the moon was five days old. These photographs also were five inches in diameter. Shortly afterwards a flat secondary mirror of 16 inches diameter was constructed for use with the large mirror, in order to reduce the magnifying power.

In 1873 this telescope was used part of the time as a front view or Herschelian and part of the time as a Newtonian. With the former arrangement the full moon was photographed with an exposure of one-quarter second, and the image of Mars appeared quite round and free from tails. During August the moon was photographed on every clear night with an exposure of one second, and the pictures obtained were regarded as in every way the equals of those taken with the 15½-inch mirror. With the Newtonian arrangement Saturn, ε Lyræ, and α Lyræ were examined and the two doubles were satisfactorily seen, as well as the five components of Debillissima. The work done with this telescope consisted (1) of photographs of spectra of the midday and setting sun to determine the atmospheric lines in the photographic spectrum, the result of which was negative; (2) of a repetition of J. W. Draper's experiments showing protection at the upper as well as the lower portion of the spectrum, using a quartz lens of 14 inches focus and one or two quartz prisms of 60° (the protected portion appeared to come down into the photographic region proper); (3) of an examination of the spectrum and a photograph of Coggia's comet; and (4) of a study of Saturn and his system in conjunction, first, with Professor Newcomb and afterwards with Professor Holden. In 1874 the reflector was changed again to the Cassegrainian form. Inasmuch as it had never been ascertained whether or not this mirror had a best diameter of support, it was taken to New York in 1876 and tested. This was found to be no easy matter, as the least pressure in the way of wedging deformed the mirror more than turning it round, and great care was necessary in centering it. After three nights of measurement Dr. Draper was satisfied that such a diameter existed. In two positions a single image was given, while in two others at right angles to these a completely double image was produced. In consequence of these results a system of support by means of back levers was decided upon. Dr. Draper concludes: 1st, that he is fully satisfied that there is an axis of maximum rigidity, and that the nature of the support influences the direction in which it should be placed; 2d, that even with the best India-rubber band support there is not as good definition as when the weight of the upper part of the mirror is supported by edge levers; and, 3d, all things considered, Lassell's plan of independent systems of levers is the most feasible. The general idea was to cement 18 squares of glass to the back of the mirror, to drill a round hole through each, and to put in each hole the end of a lever whose fulcrum shall be in the terminus of a tertiary back lever. Suitable weights on the rear ends of these edge levers will carry the weight of the mirror. This apparatus was completed in the spring of 1876, and in July the photographic stellar spectrograph was attached to the reflector and several spectra of Vega were taken with it. "By the word spectrograph," he says, "we indicate the apparatus for photographing stellar spectra. It consists of a box about 3 feet long, which screws into the back of the reflector, and contains in the order from before backwards the following parts: 1st, a slit about 1 inch long, the same that I used for my diffraction photography. Close behind this is the brass tube of the Browning direct vision spectroscope, which contains either 3, 6, or 9 prisms, at will. Behind this and at a distance of 14 inches from the slit is the 7-inch Voigtlander portrait lens; behind this comes an ordinary pocket camera." Various photographs of the moon and of Jupiter were also taken with the 28-inch mirror. In July, 1880, it was again silvered, this time by Martin's process, and a series of comparative experiments was made in taking various stellar spectra and in securing photographs of the moon. At Professor Henry's request, Dr. Draper began the preparation of a description of this telescope and the methods employed in its construction, to be published as a supplement to his early memoir on reflecting telescopes; but this paper was never completed.

Desiring to compare the performance of a large refractor with the 28-inch reflector, Dr. Draper ordered from Alvan Clark & Sons, in the winter of 1875 (February 25), a refractor of 12 inches' clear aperture. In September the object glass was received, and soon afterward was mounted on the same axis with the 28-inch reflector, the eye-pieces at the same level. About the middle of October eleven photographs of the moon were taken upon the same evening, nine with the refractor and telescope clock and two with the reflector and lunar clock. The exposure was 20 seconds for the reflector, the secondary mirror being somewhat dull; the exposure in the refractor was less than 5 seconds. Since the areas of the pictures were as 9 to 1, that of the objectives being as 5 to 1, the time of exposure, assuming that the reflector reflects as much as the refractor transmits, should be about as 2 to 1. They were, in fact, as 4 to 1. The photographs were about equal in goodness; the terraces in Copernicus and the multiple cones were visible in both. By means of a Browning-Huggins spectroscope the distance of the actinic focus outside of the visual in the refractor was determined by the method of Rutherfurd and found to be, in the neighborhood of G, 62-100 of an inch. The focus for H was an inch outside the focus for C. The difference between the spectrum of a star in the two kinds of instrument is also noted. In the reflector the star-spectrum is parallel-sided, while in the refractor it is parallel only from about D to F, and above and below these points it spreads out into a brush. In June following comparisons were instituted between the two instruments on Venus and Jupiter. Venus in the reflector was without color and Jupiter appeared silvery white, the belts being of a brownish or brownish-yellow tint. In the refractor the claret color and green shown upon Venus are stated to be very annoying, and the belts of Jupiter appeared to be dusky upon a pinkish background. In July the refractor was furnished with a silvered Rutherfurd-grating spectroscope and the solar and lunar spectra were examined, as well as those of Jupiter, Vega, etc. The solar protuberances were also examined, one of these observed on July 26 being 1′ high. In August, 1877, the satellites of Mars were observed by Dr. Draper and Professor Holden with the refractor. In the spring of 1880 this refractor was exchanged for an 11-inch achromatic, made by the Clarks for the Lisbon Observatory. This instrument was rendered additionally valuable by the fact that it was provided with a photographic corrector. The new telescope was mounted in the place of the 12-inch instrument, and in 1880 the first photograph of the nebula of Orion was taken with it.

The scientific reputation of Henry Draper, in all probability, will rest chiefly upon his photographic investigations:—First, upon the diffraction spectrum of the sun; second, upon stellar spectra; third, upon the existence of oxygen in the sun; and, fourth, upon the spectra of the elements.

Because of the much greater suitability of the diffraction spectrum for the most accurate scientific work, Dr. Draper deemed the preparation of a trustworthy map of those parts of the solar diffraction spectrum which can be photographed on collodion the most suitable introduction to his investigation upon the spectra of the fixed stars, especially if to such a spectrum an accurate scale were attached for reading directly the wave lengths of the rays. Until the researches of J. W. Draper upon the diffraction spectrum, it had been supposed that three distinct and different types of energy existed in three different but overlapping spectrum regions. Heat was supposed to lie principally at the less refrangible end, light in the middle, and actinism at the more refrangible end. The elder Draper, however, showed that this error has arisen in part from using prismatic spectra for investigation—spectra in which the red end is unduly condensed and the violet unduly dilated, in consequence of which the rays are not presented in the true order of wave lengths; and also in part from the nature of our ordinary photographic substances. The power of chemical decomposition he proved not to belong to the violet end of the spectrum as such, but to exist in every part of it. Bromide and iodide of silver, however, the substances which are used in collodion photography, turn out to be more readily decomposed by vibrations of certain periods than of others, and hence the excess of action seen at the violet end is a function of certain silver compounds and not of the spectrum. The solar beam is, therefore, not compounded of three distinct forms of energy—light, heat, and actinism; it is a series of æther vibrations, which may give rise to any one of these manifestations, depending on the surface on which it falls. Hence the normal character of the diffraction spectrum, in which no portion is unduly extended or compressed and in the two symmetrical halves of which, as J. W. Draper himself first proved, the energy is precisely the same. Distance in such a spectrum is almost exactly proportional to wave length.

The earliest photograph of a diffraction spectrum was taken by J. W. Draper in 1843. The earliest work in diffraction spectra by Henry Draper was in the fall of 1869, when he adjusted his lathe so as to rule steel and speculum metal gratings with 3,600 and 7,320 lines to the inch. In January following he ruled a concave speculum of 18 inches in focus, so that the rays themselves, without telescope or lens, might form an image; and found it to work well. In the fall of 1872 he renewed his experiments; and, having secured from Mr. L. M. Rutherfurd three of his superb glass gratings, ruled, respectively, with 4,320, 6,480, and 12,960 lines to the inch, he began a series of experiments to determine the best conditions of adjustment and of accessory apparatus. The sunlight was reflected from the secondary mirror of a heliostat upon a slit about 1-50 of an inch in width. Behind this, at a distance of 14 feet, the 6,480 grating was placed, the divided side turned from the slit. Then close to the grating came an achromatic lens of 5 inches aperture and 78 inches focus, set perpendicular to the mean ray; and, finally, the sensitive plate, about 12 inches long, in order to take in the spectrum from G to O. The violet rays came to a focus about 2 feet nearer to the grating than the red ones. In order to adjust the position of the plate he made many experiments, and finally found that the plane of the plate must be parallel to the plane of the grating when the lens is perpendicular to the outcoming beam. The spectrum of the third order was employed, and by these adjustments he had a plate in focus from G to P, and visually *b* of the third and fourth spectra in one plane. The spectrum of the third order was selected for the photographs because of two conspicuous advantages which it possesses. In the first place, it is dilated to such an extent as to give a long image, and yet not one too faint to be copied by a reasonable exposure of the sensitive plate; and, in the second place, the spectrum of the second order overlaps it in such a way that D falls nearly upon H and *b* upon O. These coincidences are of service in determining the true wave lengths of all the rays.

In order to provide against an excess of action in certain parts of the spectrum, a system of diaphragms was introduced in the vicinity of the sensitive plate and removed at suitable times during the exposure. The region from wave length 4,000 to 4,350 requires only about one-tenth of the time demanded by that from 3,440 to 3,510. In one of the best of the photographs taken, the line O had an exposure of 15 minutes, while G had 2½ minutes; and yet the former is underexposed. If these exposures seem exceptionally long for a wet collodion plate, it must be remembered that the slit was only 1-110 of an inch wide, and that the grating gives an almost complete circle of spectra round itself, this thin band of light being divided between these spectra. A beam 1-110 inch wide, therefore, is spread out in this case into a streak about 78 feet long.

Accompanying Dr. Draper's memoir is a plate of the diffraction spectrum of great excellence, transferred from the original negative directly to glass and printed as from a lithographic stone. Being absolutely free from retouching it represents faithfully the work of the sun itself. In the upper portion of the plate a spectrum is shown giving all the lines from G to O; *i. e.*, from wave length 4,350 ten millionths of a millimeter to 3,440. Above that is placed a scale which is a copy of Angström's from just below G to H_2, with the same sized divisions carried out from H_2 to O. The lower part of the plate shows a magnified portion of the same negative having H_1 and H_2 about its middle, and extending from wave length 4,205 to 3,736. The great superiority of the photograph over a drawing, even in the visible regions of the spectrum, is shown by comparing the portion of the more refrangible region taken from Angström's chart and printed on the plate with the photograph beneath it. Between wave lengths 3,925 and 4,205 the drawing shows only 118 lines, while the original negative shows 293 at least.

In order to fit a scale to the photograph, advantage was taken of the fact that the second spectrum overlaps the third, the ray D of the second being near H of the third and *b* of the second near O of the third. Two fine steel points were placed, one in the position of D_2 of the second order and the other in that of b_4 of the second order. On developing the picture two sharply defined images of the steel points appeared on the spectrum; that of the point coincident with D_2 of the second order was found to have cast its shadow on H_2 of the third order, and that of the point at b_4 upon the spectrum of the third order near O. Hence a given ray in the composite H_2 has a wave length 3,930 ten-millionths of a millimeter, and one near O of 3,444.6. Since the ray G of the third order, the wave length of which is known, was photographed directly, three fixed points of reference in the photograph, of known wave length, have thus been secured. In order to produce and apply a scale to the photograph reading to ten-millionths of a millimeter, correct for these fixed points, the scale was ruled with a linear dividing engine and photographically reduced to fit the spectrum.

In speaking of this adjustment Dr. Draper says: "It is proper in this place to make a criticism on my scale and to point out a small error which may be due, however, to an incorrect determination of the wave lengths that I have used as fixed points." Taking the distance from G (wave length 4,307) to H_2 (3,930) and dividing it into 317 parts, and then prolonging these divisions toward O, he found that the third fixed point was not attained, the error being about two divisions. It is interesting, in proof of the scrupulous accuracy of Dr. Draper as an investigator, to note certain results published by Professor Pickering in 1886, obtained by comparing the wave lengths of the ultra-violet lines, as deduced from Dr. Draper's photograph, with those obtained from Professor Rowland's superb spectrum, taken thirteen years later with greatly improved apparatus and on a much larger scale. The positions of seventy-six lines on Dr. Draper's spectrum were read, estimating to tenths of a division by the aid of a lens; the same lines were then read from Dr. Rowland's map, their positions being also estimated to tenths. In this way a table of corrections was obtained, giving the value to be added to or subtracted from the wave lengths as given by Dr. Draper's map, to produce the true wave length. These systematic corrections being made, Professor Pickering shows that the mean difference for the seventy-six lines compared is 0.012, and corresponds to about one-eight-hundredth of an inch on Dr. Draper's map. "We may therefore assume," he concludes, "that the probable error of a wave length derived from the map of Dr. Draper will not exceed one-hundredth of a unit if the correction above given is first applied. The minuteness of this quantity is a good illustration of the accuracy obtainable from a record obtained automatically by photography." Since the divisions on Dr. Draper's scale represent ten-millionths of a millimeter, this corresponds to a probable error of only one-tenth of a single scale division.

This memoir of Dr. Draper's was received very cordially in Europe. Secchi reproduced the spectrum on steel and iutroduced it into his monograph upon the sun. In 1880 a lithographed copy of the plate was published in the proceedings of the British Association as the most suitable reproduction known for the purpose of determining the wave lengths of the fixed solar lines.

Stellar spectrum photography was a subject which, at least in this country, Dr. Draper had made entirely his own. In May, 1872, as soon as his great reflector was completed, he made a trial of it for this purpose, and succeeded in securing at this time his first spectrum of a fixed star. This star was Vega (α Lyræ), and the photograph of its spectrum was obtained with a quartz prism, placed just inside the focus of the small mirror, no slit or leus being used. On the 8th of August following, however, a much better photograph was secured of the spectrum of this star, showing four lines very distinctly, the least refrangible being near G. In order to secure width in the spectrum, the telescope was given a slight motion in declination during the exposure. On the 31st of August, 1873, he photographed the spectrum of α Aquilæ with the same apparatus, the photograph being half an inch long and one-thirty-secoud of an inch wide. Though the exposure was ten minutes, it does not appear that this spectrum showed any lines. Subsequently, the quartz prism was combined with a cylindrical lens, but the result was not satisfactory, since it gave the spectrum the form of an elongated image of the mirror instead of a narrow band. Afterwards the quartz prism was combined with a heavy flint-glass prism of 60°, thus forming a nearly direct-vision spectroscope, having very good dispersion. With this apparatus he obtained easily the spectrum of α Aquilæ as a narrow band in five minutes.

Such a research as the present one was beset with many and serious difficulties. In its earlier stages wet collodion plates were used, and the limitations imposed upon the time of exposure, in consequence, rendered it almost impossible to get strong impressions. Even then these impressions had no value for measurement, and were preserved generally by stripping the films from the plates and gumming them into the note book. With the use of the dry-plate process in 1879 these difficulties for the most part disappeared. The development of the dry plates was generally produced by ferrous oxalate, although the alkaline development and pyrogallic acid were also both used. Another difficulty encountered in such work is that of securing a sufficiently accurate movement of the driving clock, since any error here increases with the time of exposure. Dr. Draper was obliged to construct no less than *seven* driving clocks before he succeeded in getting one that was perfect. The regulator of the last one was a heavy conical pendulum, or rather pair of pendulums, weighing some fifteen pounds, and so hung that their revolutions were sensibly isochronous through quite a range of inclination. Whenever by increase of driving power or decrease of resistance one of the balls rose above a certain limit it acted, without affecting the radial motion of the ball, upon a friction spider which absorbed the superfluous energy. This regulator revolved once in a second. The gearing and driving screw were constructed, for the most part, by Dr. Draper himself, with the utmost care and accuracy; and, according to Professor Young, it may safely be said that in its ultimate perfected condition the driving clock was as good as any in existence, keeping a star upon the slit for an hour at a time when near the meridian and not disturbed by changes of refraction.

Other difficulties, which Dr. Draper was obliged more or less completely to overcome, related to the firm and rigid connection of the parts of the spectroscope with each other and with the sensitive plate; to the effect of temperature not only upon this connection, but also upon the dispersive power of the prisms employed; and, finally, to the mode of obtaining satisfactorily a reference spectrum for comparison with that of the star under examination. Then, too, the difficulties due to atmospheric conditions cannot be lost sight of. Photographic operations are much more sensitive to these conditions than are eye observations. A slight haze, which is sometimes even an advantage for ordinary telescopic work, cuts off the active rays so decidedly that the time of exposure must be greatly increased. On evenings apparently good an exposure of half an hour or an hour is needed to secure an impression which may be obtained on other evenings in five or ten minutes.

In this research quite a variety of forms of spectroscopic apparatus was employed. In the earlier photographs a quartz prism only was used, as above mentioned, this prism being placed in the path of the rays a few inches within the focus, and with this spectroscope the first stellar spectrum was taken which showed lines. Afterwards Dr. Draper used direct-vision prisms in the same way, and also spectroscopes made of such prisms, in some cases with a slit and in others without, the necessary width of the spectrum being secured frequently by the aid of a cylindrical lens. The apparatus finally decided upon, and with which all the later spectrum work was done, was a Browning star spectroscope having two 60° prisms of dense but white flint glass of the form suggested by Dr. Huggins for stellar observations. The telescope and collimator each had a focal length of six inches and an aperture of three-fourths of an inch, the parts being well braced to secure firmness. A diaphragm was placed over the slit, the opening in which was surrounded with a ring of phosphorescent paint to render it luminous in the dark. A movable finger enabled any part of the slit to be exposed at pleasure for the purpose of obtaining reference spectra upon the same plate. The eye-piece and micrometer were removed from the eye end of the observing telescope of this spectroscope and a piece of hard wood was fitted on at this end to carry the photographic plate. This was very small, only about an inch square, cut from a plate of ordinary commercial size. A small positive eye-piece was attached to the block in such a way that the operator could examine at pleasure the yellow and red portion of the spectrum which projected beyond the sensitive plate into the field of view, and so satisfy himself that the entire apparatus was working properly. The photographs which were obtained with this arrangement were about one-sixteenth of an inch in width and about half an inch long, extending from a point between the Fraunhofer lines F and G to a point near M.

The stellar-spectrum photographs taken in 1872 and 1873 have been already mentioned. In the summer of 1874 preparations for the expedition to observe the transit of Venus occupied all Dr. Draper's leisure time; so that it was not till the fall of 1875 that stellar-spectrum work was again resumed. In October of this year several photographs of the spectrum of Vega were taken, a Browning nine-prism direct-vision spectroscope being used without a slit, placed inside the focus of the 28-inch mirror, the sensitive plate being at the focus. In July, 1876, Dr. Draper contrived an apparatus which he called a "spectrograph," with which he took several photographs of the spectrum of Vega. This apparatus consisted of a box about three feet long, which screwed into the tail-piece of the reflector in place of the eye-piece, and was made up of the following parts: 1st, a slit; close behind this the brass tube of a Browning direct-vision spectroscope, containing either three, six, or nine prisms, at will; next to this, and fourteen inches from the slit, a 7-inch Voigtländer portrait lens and camera. The results were not materially different from those obtained by the earlier methods, and the apparatus was cumbrous and awkward to manage. About this time Dr. Draper introduced the plan of setting the slit in the direction of the right ascensional motion; so that any slight irregularities of the driving clock would only widen the spectrum a little instead of removing the star's image from the slit. He had already, during the preceding fall, experimented with a "Registering Transit Spectroscope," suggested by Dr. J. W. Draper, the idea of which was to drive the observing telescope of the spectroscope by clock-work and to register on the chronograph the transits of the Fraunhofer lines. The chief difficulty encountered was the fact that no two observations gave the same reading when the lines of the solar spectrum from *a* to F were observed—a result due to irregularities in the wheel-work of the clock and the shape of the teeth. In the hydrogen spectrum the readings from C to F were found to be liable to an error of four seconds of time in 110 seconds on the chronograph. By making the clock of the spectroscope break the circuit of the chronograph, instead of the chronometer, the error was reduced to 0.4 of a beat in 148.3 beats; corresponding to an error of one part in 370 in the distance between C and F. By lessening the speed of transit the error would be still further reduced.

In the early fall of 1876 the Browning direct-vision prism was placed, without slit or lens, inside the focus of the 12-inch refractor. The apparatus was so arranged that a cylindrical lens of 14-inches focus could be placed either between the prism and the object-glass or between the prism and the sensitive plate. By slightly tilting the plate the difficulty arising from the differences in the foci of the different rays produced by the object-glass was in great measure obviated. In October the Huggins star spectroscope was employed with one prism. It was attached to the refractor and used at first with the slit wide open. The collimator required to be accurately adjusted in line with the optical axis of the refractor. Another stellar spectroscope was arranged a few days later, consisting (1) of a slit with a wide open space between it and the end of the telescope, so that the centering of the star on the slit could be observed; (2) of the nine-prism Browning direct-vision combination; (3) of two opera-glass lenses; and (4) of the plate-holder. The several stellar spectra photographed with this apparatus turned out, however, to be rather faint. During the same month experiments were made upon the spectrum of Venus, using both the reflector and the refractor, the stronger pictures being given by the former. They show the lines well, especially those between G and H. On the 29th the aperture of the refractor was reduced to 1½ inches, the same stellar spectroscope was attached to it, the slit was closed so that in the solar spectrum *b* appeared distinctly triple, and a series of photographs was taken with exposures of four minutes, one minute, five seconds, and one second, the last being the most suitable for the purpose. Compared with the six photographs of the spectrum of Venus taken on the 25th, these results indicated the proper exposure for Venus to be 196 times that of the sun.

Pressure of scientific work in other directions caused an intermission in Dr. Draper's stellar-spectrum investigations. On his return from Europe in July, 1879, however, this work was again taken up and prosecuted with vigor. In a paper read in October before the National Academy of Sciences, Dr. Draper thus gives a description of his apparatus: "The especial spectroscope for stellar work that is now on the telescope is intended to satisfy the following conditions: 1st, to get the greatest practicable dispersion with the least width of spectrum that will permit the lines to be seen; 2d, to use the entire beam of light collected by the 28-inch reflector or 12-inch achromatic without loss by diaphragms; 3d, to permit the slit to be easily seen, so that the star may be adjusted on it; 4th, to avoid flexure or other causes that might change the position of the spectrum on the sensitive plate in pointing the telescope first on one and then on another object; 5th, to admit of observing the spectrum on the sensitive plate at any time during an exposure without risk of shifting or disarrangement. The dispersion is produced by two heavy flint prisms which are devoid of yellow color; the telescopes are about six inches in focal length and the slit has a movable plate in front of it, enabling the operator to uncover either the upper or the lower portion at will."

With reference to the telescopes Dr. Draper says: "There is an advantage possessed by the refractor for this work which does not appear at first sight. Naturally one supposes that a reflector which brings all the rays from the star, no matter what their refrangibility, to a focus in one plane would be best, because when the slit is put in that plane it is equally illuminated by rays of all refrangibilities, and the spectrum will be parallel-sided in its whole length. On the other hand, a refractor is not achromatic, for the violet end of the spectrum comes to a focus either inside or outside of the plane of the rays in the middle of the spectrum, and in observing the spectrum it is not parallel sided. It is easy, therefore, with a refractor so to adjust the position of the slit that you may have a spectrum tolerably wide at F and G, and which gradually diminishes in width toward H, and finally becomes almost linear at M. Now, as the effect of atmospheric absorptions on the spectrum increases as you pass from G towards H and above H, by diminishing the width of the spectrum you can in some measure neutralize the effect, and at one exposure obtain a photograph of nearly uniform intensity from end to end, though it is of variable width. If it were not for this, it would be necessary to have the spectrum overexposed at G in order to be visible above H, or else to resort to an elaborate diaphragming, which is difficult." However, he announces his intention of returning to the use of the 28-inch reflector because it collects nearly five times as much light as the 12-inch refractor, after making allowance for the secondary mirror.

Of the results obtained up to that time Dr. Draper thus speaks: 'A preliminary examination shows at once that these stellar spectra are divisible into two groups—first, those closely resembling the solar spectrum; and, second, those in which there are relatively but few lines and these of great breadth and intensity. The photographs of the spectra of Arcturus and Capella are so similar to the solar spectrum that I have not up to the present detected any material differences. But, on the other hand, the spectra of Vega and *α* Aquilæ are totally different, and it is not easy without prolonged study and the assistance of laboratory specimens to interpret the results, and even then it will be necessary to speak with diffidence."

"In the case of the spectrum of Vega when examined by the eye the lines C, F, near G and *h*, are readily visible, but lines such as D and *b* are relatively faint. It is clear, then, that hydrogen exists, to a large extent, in the atmosphere of that star; but, on examining the photograph of its spectrum, it is evident that other lines just as conspicuous as the hydrogen lines are present. One of these corresponds in position and character to H_1, and seems to coincide with a calcium line. It appears to me, however, that the evidence of this coincidence is not complete." "I have not as yet obtained any stellar-spectrum photographs belonging to the third and fourth groups of stellar spectra, as described by Secchi. These, if obtainable, will aid materially in discussing the whole subject; but, unless a star passes near the zenith, it is hard to make a fair study of its spectrum by photography, because atmospheric absorption in the ultra-violet region increases rapidly as the altitude decreases."

An excellent account of Dr. Draper's "Researches on Astronomical Spectrum Photography" by Professors C. A. Young and E. C. Pickering was presented to the American Academy of Arts and Sciences in April, 1883, and is published in its Proceedings. In this paper a list is given in tabular form of all the photographs of planetary and stellar spectra taken subsequent to August, 1879, which were thought by Dr. Draper worthy of preservation. These photographs are seventy-eight in number, all taken on dry plates with the two-prism Huggins star spectroscope, used in some cases with the reflector and in others with the refractor. The first column in these tables is one of reference numbers. The second gives the date of the photograph, the third the object giving the spectrum, the fourth the local mean time of beginning the exposure, so far as given in Dr. Draper's note books, the fifth the duration of the exposure, the sixth the width of the slit, the seventh the aperture of the telescope used, and the eighth gives remarks from the note books concerning the particular photograph in question. Twenty-one of these spectrum photographs were measured by Professor Pickering with the micrometer of the Harvard College Observatory, the work done upon them being divisible into three parts: First, the determination of the relative positions of the lines in the various spectra in terms of any convenient unit of length; secondly, from the known spectra of the moon and Jupiter, a determination of the relation of these measures to wave lengths; and, thirdly, a reduction of the measures of the stellar spectra to wave lengths and a discussion of the results.

The stars whose spectra were thus measured were α Lyræ, α Aquilæ, α Aurigæ, α Bootis, and α Scorpii; comparison spectra of the moon or Jupiter being photographed in some cases upon the same plate. In all, one hundred and twenty-seven lines were measured in the spectra of these five stars and their wave lengths determined by comparison with Dr. Draper's diffraction spectrum taken as a standard. The values for α Aquilæ and α Lyræ are shown to agree well together and with the results of Dr. Huggins' measurements. The distinctive feature of these spectra is a series of broad dark lines at regular intervals, the lines of greater wave length appearing to coincide with the hydrogen lines. The interval between the successive lines diminishes with the wave length. The spectra of α Aurigæ and α Bootis resemble that of the sun, their lines coinciding with the solar lines, not only in position, but also in intensity. "Of the twelve lines seen in at least seven of the nine spectra of the moon and Jupiter, every one is contained in the spectra of both α Aurigæ and α Bootis. Of the fifteen lines which are so faint as to be contained in but one or two of the spectra of the moon or Jupiter, only four are contained in the spectrum of α Bootis and but one in that of α Aurigæ. The evidence afforded by these photographs, therefore, points very strongly to the conclusion that the spectra of these stars, and consequently their constitution, are the same as that of our sun." In the spectrum of α Scorpii twenty-five lines were measured. A comparison of all the results showed that the plates used were sensitive to light of wave lengths 3,750 to 4,800—that is, from M nearly to F, although when the light was intense the spectra extended beyond these limits.

It would seem fitting to mention here the liberal plans which Mrs. Draper has made to carry on the work of her lamented husband in astronomical spectrum photography. Already, in 1885, appropriations from the Rumford fund of the American Academy and from the Bache fund of the National Academy had enabled Professor Pickering at the Harvard College Observatory to try a novel photographic method. The prism was placed in front of the object glass of the astronomical telescope, a plan suggested by Fraunhofer in 1823 for eye observations. By this arrangement not only was a great increase of light secured, but all the stars at the time in the field of the telescope impressed their spectra simultaneously upon the plate. Formerly only one star spectrum could be photographed at a time, and this only when the star was of the first or second magnitude. But by the new method more than three hundred spectra have been simultaneously obtained on a single plate, some of them of stars not brighter than the seventh or eighth magnitude. The first spectra thus photographed were taken with a prism of 30° placed in front of a photographic lens of two inches aperture and of seven inches focal length. The necessary width of the spectrum was secured by the trailing of the star, no clock-work being used; and yet with this imperfect apparatus the spectra of *α* Lyræ and *α* Aquilæ showed their characteristic lines, and in the spectrum of Polaris more than a dozen lines could be counted. Subsequently a prism of eight inches clear aperture, whose refracting angle was 15°, was placed in front of a photographic lens of the same aperture, having a focal length of forty-five inches. When the photographic lens was in the meridian the refracting edge of the prism was made to be horizontal, so that the spectrum extended north and south. By accelerating or retarding the clock-work, therefore, the trailing of the star could be made to give width to the spectrum, a gain or loss of twelve seconds an hour being the rate best suited to the faintest stars.

Early in 1886 Mrs. Draper, who, from the first had taken great interest in this work, so directly a continuation of that begun by Dr. Draper with so much promise, generously offered to place at Professor Pickering's disposal the excellent eleven-inch photographic telescope which Dr. Draper had himself used so successfully in his spectrum researches, together with a sufficient sum of money to enable the new method to be put to the test on a still larger scale. In consequence Professor Pickering decided to continue the investigation along three more or less independent lines: First, he purposed making a general survey of stellar spectra, each spectrum being photographed with an exposure of not less than five minutes; second, he desired to undertake a determination of the spectra of the faintest stars, each photograph of this set receiving an exposure of an hour; and, third, he decided to carry on a careful study of the spectra of the brighter stars. The entire research was to be designated as "The Henry Draper Memorial."

In his first annual report Professor Pickering has given the results obtained during the year 1886. In the first two of the directions above mentioned the work was done with the Bache photographic telescope, 15,729 stellar spectra having been photographed and measured. The photographs taken with an exposure of five minutes exhibit in general the spectra of all stars brighter than the sixth magnitude with sufficient distinctness for measurement. Those taken with an hour's exposure show upon a single plate the spectra of stars included in a region ten degrees square not fainter than the ninth magnitude. For the work of studying the spectra of the brighter stars the Draper eleven-inch corrected refractor was used, four prisms being placed in front of the object-glass, each of which had a refracting angle of 15°. The original negatives thus taken were enlarged by an ingenious process. A cylindrical lens was placed close to the enlarging lens, with its axis parallel to the length of the spectrum. In the apparatus actually employed the length of the spectrum was increased five times, while its breadth was increased nearly one hundred times, so that in the plate accompanying the report a spectrum of β Geminorum is shown twenty-two centimeters long and seven and a half wide. The photographs thus enlarged are remarkable. The spectrum of α Cygni shows the H line to be double, its two components having a difference of wave length of about one ten-millionth of a millimeter; that of o Ceti shows the lines G and *h* as bright lines, as also the four ultra-violet lines characteristic of spectra of the first type, to which Dr. Huggins gave the letters α, β, γ, and δ. But the lines H and K are dark, showing that they do not belong to the same series. The spectrum of α Tauri shows a multitude of lines and bands massed in the more refrangible region; that of Sirius shows a large number of faint lines in addition to the well-known and characteristic broad bands; that of α Canis Minoris, taken with four prisms, shows the solar lines G, *h*, H, and K.

So well satisfied was Mrs. Draper with these splendid results that she decided to extend greatly the original plan of the work and to include all departments of the subject, so that the final results shall form a complete discussion of the constitution and conditions of the stars as revealed by their spectra, so far as scientific methods at present permit. The investigations now in progress under Professor Pickering's direction comprise (1) a catalogue of the spectra of all stars north of —24° of the sixth magnitude or brighter; (2) a more extensive catalogue of spectra of stars brighter than the eighth magnitude, and (3) a detailed study of the spectra of the bright stars, including a classification of the spectra, a determination of the wave lengths of the lines, a comparison with terrestrial spectra, and an application of the results to the measurement of the approach and recession of the stars. For these purposes the two reflecting telescopes constructed by Dr. Draper will be used, in addition to the fifteen-inch refractor of the Harvard College Observatory and the instruments hitherto employed. "But," says Professor Pickering, "Mrs. Draper has provided not only the means for keeping these instruments actively employed, several of them during the whole of every clear night, but also the means of reducing the results by a considerable force of computers and of publishing them in a suitable form. A field of work of great extent and promise is open, and there seems to be an opportunity to erect to the name of Dr. Henry Draper a memorial such as heretofore no astronomer has received."

While using the gelatino-bromide dry process in stellar-spectrum photography, Dr. Draper conceived that the great sensitiveness of these plates might enable him to secure a photograph of a nebula, and in this way to obtain an accurate record of its present condition with a view to future comparisons. On September 30th, 1880, after an exposure of fifty-seven minutes, he obtained a photograph of the great nebula in Orion, which was sufficiently perfect to enlarge. In order to get the much fainter portions of the nebula, however, the plates had to be overexposed for the stars within it. Satisfied that the project was entirely feasible, he devoted a considerable time to securing the greatest possible perfection in the driving clock and to improving the details of the photographic manipulation. In March, 1881, a second and much better photograph of this nebula was taken, with an exposure of 104 minutes. Finally, a year later, on the 14th of March, 1882, he succeeded in making a successful exposure of 137 minutes, and in producing a superb photograph, which showed stars of the 14.7 magnitude of Pogson's scale invisible to the eye, and in which the faint outlying regions of the nebula itself were clearly and beautifully shown. This unrivaled photograph, by far the most brilliant success achieved by celestial photography up to that time, will ever have a high astronomical value, since by comparing with it photographs of this nebula taken many years subsequently, any changes which are taking place in its constitution may be traced and their history written. Ordinarily a photograph of the spectrum of an object is more difficult to obtain thau a photograph of the object itself; but in the case of a nebula this is not true. The spectrum in this case being of bright lines, its light is localized and readily impresses the plate. Moreover, any error in the rate of the clock or any tremor of the instrument, which in the case of the nebula itself would be fatal to the definition, counts for little in photographing its spectrum; since the image being simply shifted off the slit thereby produces no injurious results upon the definition. Many excellent photographs of the spectrum of the nebula in Orion were obtained by Dr. Draper in addition to those of the nebula itself. Two contrivances were made use of to obtain this spectrum: First, a direct-vision prism placed in the cone of rays from the objective before they had reached a focus; and, second, the two-prism spectroscope which had been employed to produce stellar spectra. To obtain good results with the direct-vision prism without a slit, it was necessary that the image should be kept stationary on the sensitive plate throughout the entire exposure of two hours. The most striking feature of these spectrum photographs, perhaps, is the continuous spectrum of the two portions of the nebula just preceding the trapezium, indicating that at these points there is condensed matter, either in the form of gas under great pressure or in the liquid or solid form. But neither in these portions nor in others which show the continuous spectrum more faintly was Dr. Draper able to detect any stars of a magnitude sufficient to produce this effect.

Of these spectra Dr. Draper writes as follows: "The hydrogen line near G, wave length 4,340, is strong and sharply defined; that at *h*, wave length 4,101, is more delicate, and there are faint traces of other lines in the violet. Among these lines there is one point of difference, especially well shown in a photograph where the slit was placed in a north-and-south direction across the trapezium; the H γ line, λ 4,340, is of the same length as the slit, and where it intersects the spectrum of the trapezium stars a duplication of effect is visible. If this is not due to flickering motion in the atmosphere it would indicate that hydrogen gas was present even between the eye and the trapezium. I think the same is true of the H δ line, λ 4,101. But in the case of two other faint lines in this vicinity I think the lines are not of the length of the slit, one being quite short and the other discontinuous. If this observation should be confirmed by future photographs of greater strength it might point to a non-homogeneous constitution of the nebula, though differences of intrinsic brightness would require to be eliminated."

"As illustrating the delicacy of working required in this research it may be mentioned that in one of these photographs the spectrum of a star of the tenth magnitude is easily discerned. It is only a short time since it was considered a feat to get the image of a ninth-magnitude star, and now the light of a star of one magnitude less may be photographed even when dispersed into a spectrum."

On the 14th of May, 1880, Dr. Draper communicated to the Royal Astronomical Society the results of some observations upon the spectrum of Jupiter, going to show that this planet emitted intrinsic light. Generally the close resemblance between the spectrum of Jupiter and that of the sun made it quite certain that most, if not all, of the light of the planet was simply reflected sunlight—a fact which enabled Dr. Draper to use its spectrum for reference in stellar work. But on the 27th of September, 1879, a spectrum photograph was obtained showing a modified condition of things. The image of the planet was thrown upon the slit of the spectroscope by a telescope of 183 inches focal length, this slit being placed approximately in the direction of a line joining the poles, so that the spectrum was that of a band extending across the disk at right angles to the equator. The exposure required was fifty minutes. The peculiarities observed in the photograph are not due to any change in the number or the position of the Fraunhofer lines, but to a variation in the strength of the background. In the case of the moon-spectrum, photographed for comparison on the same plate with an exposure of ten minutes, the background in any region is uniform across the width of the spectrum; while in the spectrum of Jupiter the background is fainter in the middle of the width of the spectrum in the region above the line *h*, and stronger in the middle in the region below *h*, especially toward F. These modifications in the spectrum seemed to Dr. Draper to indicate, first, an absorption of solar light in the equatorial regions of the planet, and, second, a production of intrinsic light at the same place. To reconcile these apparently opposite indications, he suggested the hypothesis that the temperature of the incandescent substances producing light at the equatorial regions of Jupiter did not suffice for the emission of the more refrangible rays, and that there were present materials which absorbed those rays from the sunlight falling on the planet. While, therefore, the absorption phenomena are not of special interest, the strengthening of the spectrum between *h* and F in the portions answering to the vicinity of the equatorial regions of Jupiter seems to bear very directly on the problem of the physical condition of this planet as to incandescence, and to be consequently of very considerable significance.

The large comet of 1881 was made a subject of investigation by Dr. Draper. On the 24th of June a photograph of the nucleus and part of the envelopes was obtained in 17 minutes; and subsequently, by an exposure of 162 minutes, a photograph was secured showing the tail ten degrees in length. He next attempted, by placing a direct-vision prism between the sensitive plate and the object-glass, to obtain a photograph which would show the continuous spectrum of the nucleus and the banded spectrum of the coma. An exposure of 83 minutes gave a strong picture of the spectrum of the nucleus, coma, and part of the tail, but the banded spectrum was overpowered by the continuous spectrum. The two-prism stellar spectroscope was then used, in order to weaken the continuous spectrum by the increased dispersion, and with this arrangement three photographs of the cometary spectrum were taken, the exposures being 180, 196, and 228 minutes, respectively, a comparison spectrum being taken with each. The most striking feature of these photographs is a heavy band above H, which is divisible into lines, and two faint bands, one between G and *h* and another between *h* and H; thus strengthening the hypothesis of the presence of carbon in comets.

The work at the Hastings Observatory was carried on, for the most part, during the summer months, Dr. Draper then residing at his country place in Dobbs Ferry, two miles distant. His investigations during the winter were made at his house in New York city, those researches being selected for the purpose which did not require the use of the telescope. At first two rooms upon the third floor were devoted to these winter investigations, and here all his earlier work, such as the construction of the 28-inch mirror and the production of the diffraction spectrum photographs was done. Subsequently, however, needing additional room and additional facilities, he built a special physical laboratory as the third story of his stable, situated directly in the rear of his dwelling, this laboratory being connected with the house by a covered way. The equipment of this laboratory is superb. A siderostat, by Alvan Clark & Sons, placed upon the roof, furnishes abundant sunlight, directed to any part of the room by a secondary mirror. An Otto gas engine of four-horse power gives motion to three dynamo machines for the production of electric currents of different intensities. One of these is a Gramme machine, the armature of which is wound double, with a collector on each side. In consequence, not only may the two sides be used independently or connected together in series or in multiple, but by an ingenious modification constructed by Dr. Draper they may be made to give continuous or alternating currents at will. The second dynamo is an Edison shunt machine, used mainly to light the laboratory by means of incandescent lamps. The third is a Maxim dynamo, the current of which is used to maintain arc lights for illuminating or experimental purposes, and also to maintain the field of the Gramme when run as an alternating machine. For the production of the electric spark an induction coil of large size is employed, made by Ruhmkorff. When used with the direct current it gives 18-inch sparks readily, although in order to avoid perforation the safety points are usually set at 10 or 12 inches. By means of an ingenious interrupter, attached to the axis of the Gramme machine, this coil, used with the direct current, can be made to give 1,000 10-inch sparks per minute. With the alternating current, which requires, of course, no interrupter, the spark, although silent and only about one-quarter as long, is of much greater volume; so that, with a condenser of considerable capacity in the secondary circuit, the discharge is like the rattle of musketry. The optical and photographic appliances of this laboratory are of the finest. Not only are there complete spectroscopes and cameras of all sorts, but there are also lenses, prisms, and gratings of the best materials and the finest workmanship, ready to be used in extemporizing any apparatus needed in research. A lathe, a file bench, and a carpenter's bench, each with its full set of tools, and a conveniently arranged dark room for photographic work, complete the appointments of this beautifully finished room.

It was in his New York laboratory that Dr. Draper made his important research upon the presence of oxygen in the sun, his first paper upon this subject having been presented to the American Philosophical Society in April, 1877. Already, in the year 1869, he had begun an investigation upon the photographic spectra of the elements, particularly of the metalloids carbon, nitrogen, and hydrogen, as preliminary to a comparison of these spectra with those of the sun and stars, especially in the more refrangible regions. The first photographs of metallic spectra were taken with apparatus at hand in the laboratory, a couple of Bunsen batteries being used to work an induction coil giving a half-inch spark, and a Hoffman direct-vision spectroscope producing the spectrum, which was less than an inch in length from G to H. This apparatus was soon replaced by a larger battery, a two-inch induction coil, and a Browning direct-vision prism of an inch aperture. Then the size of the coil was still farther increased, first to one giving six-inch sparks and then to a large Ruhmkorff machine capable of giving a spark of 18 inches. The battery was ultimately replaced by a Gramme dynamo machine, purchased at the Centennial Exhibition in 1876, and which was capable of giving an arc light of 500 candles. When used with the large coil it gave readily a thousand ten-inch sparks per minute; but this spark, even when condensed with fourteen Leyden jars, each having half a square foot of coated surface, placed in the secondary circuit, although of intense brilliancy, gave by measurement a light of only about one candle. The connections of the dynamo machine were so arranged that one-half of the armature gave a continuous current through the field magnets, while the current from the other half was used in the external circuit.

At first a Foucault mercurial interrupter was arranged to make and break the current passing into the primary circuit of the induction coil. But when the current was necessarily increased up to that given by the machine when making a thousand revolutions a minute, the mercury was driven violently out of the cup whenever the interrupter was in action. Hence it became essential to arrange a mechanical break, using solid metal only, a requirement met by Dr. Draper by the use upon the axis of the armature of a wheel with an interrupted rim. The arrangement of the terminals so as to get the steadiest and brightest effect offered great difficulties. The condensed spark taken in the open air or in a gas under atmospheric pressure pursues, if unconfined, a zigzag course, which tends to widen the lines in the photographed spectrum. After many experiments, however, it turned out that the spark could be compressed between two plates of thick glass; or, better yet, between two plates of soapstone; so that, under these conditions, if the interval between the plates was directed towards the slit of the spectroscope, the lateral flickering of the spark was entirely prevented, while at the same time the spark itself was freely exposed to the slit, and this without the intervention of glass or any substance on which the volatilized metal from the terminals could form a deposit. Early in the research it became apparent that Plücker's tubes could not be employed with electrical currents of more than a certain intensity, partly on account of the deposit that took place in the capillary portion and partly because the terminals became so hot as to melt and crack the glass.

The optical part of the apparatus underwent many modifications in the course of the research. The Hoffman direct-vision prism, combined with a lens of six inches focus, at first used, was soon replaced by a Browning direct-vision prism and a lens of eighteen inches focus, the latter being arranged for conjugate foci, so that it was virtually as if collimating and observing lenses of thirty-six inches focus were employed. The final system consisted of a collimator of two inches aperture and twenty-six inches focus, succeeded by two bisulphide of carbon prisms of two inches aperture and an observing or photographing lens of six and a half feet focal length. This system gave a dispersion of about eight inches between G and H, so that original negatives could be obtained with it on a scale about half the size of Angström's charts.

In order to facilitate accurate comparison between elemental spectra and the spectrum of the sun or a star, Dr. Draper arranged his apparatus so that the two spectra to be compared could be photographed closely superposed upon the same plate. The slit of the spectroscope was about an inch long, and opposite its lower half was placed a right-angled prism, which reflected through this half the sunlight from a heliostat. The spark-compressor was placed opposite the upper half of the slit, which it illuminated directly. In this way the solar spectrum and the air spectrum were thrown upon the plate by the same optical train. The terminals used were of iron and of aluminum, the object being to show by the coincidence of the bright iron lines with the corresponding dark iron lines of the sun spectrum that no shifting had taken place in the interval of changing from one source of light to the other.

Up to 1876 the photographs taken were on so small a scale that they did not give rise even to a suspicion of the presence of oxygen in the sun. During this year, however, original negatives two inches long from G to H were secured, which bore an enlargement of three or four times quite well, and which seemed to prove the coincidence between the oxygen and the solar lines very satisfactorily. An Albertype print of such an enlargement accompanied Dr. Draper's original paper of 1877. Of this plate Dr. Draper says: "No close observation is needed to demonstrate to even the most casual observer that the oxygen lines are found in the sun as bright lines, while the iron lines have dark representatives. The bright iron line at G (4,307), on account of the intentional overlapping of the two spectra, can be seen passing up into the dark absorption line in the sun. At the same time the quadruple oxygen line between 4,345 and 4,350 coincides exactly with the bright group in the solar spectrum above. This oxygen group alone is almost sufficient to prove the presence of oxygen in the sun, for not only does each of the four components have a representative in the solar spectrum, but the relative strength and the general aspect of the lines in each case is similar. The fine double line at 4,319, 4,317 is plainly represented in the sun. Again, there is a remarkable coincidence in the double line at 4,190, 4,184. The line at 4,133 is very distinctly marked. The strongest oxygen line is the triple one at 4,076, 4,072, 4,069; and here, again, a fine coincidence is seen, though the air spectrum seems proportionately stronger than the solar."

In consequence of these coincidences Dr. Draper concludes that "oxygen discloses itself by bright lines or bands in the solar spectrum and does not give dark absorption lines like the metals. We must, therefore, change our theory of the solar spectrum and no longer regard it merely as a continuous spectrum with certain rays absorbed by a layer of ignited metallic vapors, but as having also bright lines and bands superposed on the background of continuous spectrum. Such a conception not only opens the way to the discovery of others of the non-metals, sulphur, phosphorus, selenium, chlorine, bromine, iodine, fluorine, carbon, etc., but may also account for some of the so-called dark lines by regarding them as intervals between bright lines. The bright lines of oxygen in the spectrum of the solar disk have not been hitherto perceived probably from the fact that in eye observations bright lines on a less bright background do not make the impression on the mind that dark lines do. When attention is called to their presence they are readily enough seen even without the aid of a reference spectrum. The photograph, however, brings them into greater prominence. From purely theoretical considerations derived from terrestrial chemistry and the nebula hypothesis the presence of oxygen in the sun might have been strongly suspected, for this element is currently stated to form eight-ninths of the water of the globe, one-third of the crust of the earth, and one-fifth of the air, and should, therefore, probably be a large constituent of every member of the solar system. At first sight it seems rather difficult to believe that an ignited gas in the solar envelope should not be indicated by dark lines in the solar spectrum and should appear not to act under the law 'a gas when ignited absorbs rays of the same refrangibility as those which it emits.' But in fact the substances hitherto investigated in the sun are really metallic vapors, hydrogen probably coming under that rule. The non-metals obviously may behave differently. It is easy to speculate on the causes of such behavior, and it may be suggested that the reason of the non-appearance of a dark line may be that the intensity of the light from a great thickness of ignited oxygen overpowers the effect of the photosphere just as if a person were to look at a candle flame through a yard thickness of ignited sodium vapor he would see bright sodium lines only and no dark absorption lines."

The second paper on the presence of oxygen in the sun was read by Dr. Draper before the Royal Astronomical Society on the 19th of June, 1879. In order to meet the criticism that perhaps the dispersion hitherto employed was not sufficient to disclose the lack of coincidence, if it really existed, this paper was accompanied by an Albertype print showing the juxtaposed spectra of air and the sun on a scale about twice the size of Angström's chart, the negative thus enlarged having been taken with a dispersion about four times that formerly used. In speaking of this plate Dr. Draper says: "Of course an enlargement never does justice to the original from which it was produced, and, in order to study the matter faithfully, the negative must be examined carefully with a magnifier. Besides this, owing partly to the fact that the solar spectrum has suffered from absorptive influences, both in the earth's atmosphere and in the solar atmosphere, the conditions under which the oxygen spectrum is seen when compared with the spark spectra are modified. In fact, a critical study of the two spectra demands that each line of oxygen should be separately photographed with the corresponding region of the sun's spectrum, so as to reproduce as nearly as possible the same conditions for each. As an instance of the modifications which may be caused by the solar atmosphere the superposition of absorption lines on the bright lines of oxygen may be mentioned. If, as seems to be the case, the stratum giving the oxygen spectrum in the sun lies deeper than the reversing layer in which iron exists, I see no reason why an iron absorption line, for instance, may not fall upon an oxygen bright band. If it be conceded that there are bright lines in the spectrum of the solar disk, which seems to be the opinion of several physicists, and especially Lockyer, Cornu, and Hennessy, the question of their origin naturally attracts attention.

It seems that there is great probability, from general chemical reasons, that a number of the non-metals may exist in the sun. The obvious continuation of this research is in that direction. But the subject is surrounded by exceedingly great obstacles arising principally from the difficulty of matching the conditions as to temperature, pressure, etc., found in the sun. Any one who has studied nitrogen, sulphur, or carbon, and has observed the manner in which the spectrum changes by variations of heat and pressure, will realize that it is well nigh impossible to hit upon the exact conditions under which such bodies exist at the level of the photosphere. The fact that oxygen within a certain range of variation suffers less change than others of the non-metals has been the secret of its detection in the sun. It appears to have a greater stability of constitution, though Schuster has shown that its spectrum may be made to vary. I have already begun an extended series of experiments on the non-metals, but the results exhibit such confusion that their bearing cannot at present be distinctly seen. In the case of nitrogen the broad bands between G and H exhibit under the most intense incandescence a tendency to condense into narrow bands or lines, and indeed there are some sharp lines of nitrogen in the photograph now presented. It does not follow, therefore, that the bright bands of oxygen are necessarily the brightest parts of the solar spectrum. Other substances may produce lines or bands of greater brilliancy.

"There is also another cause for a difference of appearance in a bright-line spectrum produced in a laboratory and bright lines in the sun. While the edges of a band in the spark spectrum may be nebulous or shaded off, the corresponding band in the solar spectrum may have its edges sharpened by the action of adjacent dark lines due to one or another of the metallic substances in the sun."

"On the whole, it does not seem improper for me to take the ground that, having shown by photographs that the bright lines of the oxygen spark spectrum all fall opposite bright portions of the solar spectrum, I have established the probability of the existence of oxygen in the sun. Causes that can modify in some measure the character of the bright bands of the solar spectrum obviously exist in the sun, and these, it may be inferred, exert influence enough to account for such minor differences as may be detected."

An interesting discussion followed the reading of this paper. Referring to the earlier and the later photographs, Mr. Ranyard said:

"If Dr. Draper has increased his dispersion four times he has not merely increased the probability of his case four times, but he has increased the value of every coincidence he shows four times. On looking at the original photographs (which show the coincidences more sharply than the paper prints) I counted eighteen oxygen lines, and therefore the increase of probability on the present occasion as compared with the former occasion is as four to the eighteenth power to one, a very enormous number. There are two or three ways of looking at the probability of the proposition which Dr. Draper has laid down, that the bright lines of oxygen coincide with the bright lines in the solar spectrum. In the first place there is the chance that the center of no single line of oxygen should fall opposite to a dark line or space in the solar spectrum. Let us suppose that the breadth occupied by dark lines in the solar spectrum is equal to the breadth occupied by bright lines (probably, as seen with high dispersion, this is well within the truth), then the chance of any oxygen line falling opposite to a bright line or interspace in the solar spectrum whould be one-half; and if the eighteen lines of oxygen had been thrown down at random beside the solar spectrum the chance that the center of all the lines should fall opposite to bright spaces would be one divided by two to the eighteenth power." Mr. Christie, while expressing his great admiration at the splendid results which Dr. Draper had achieved, was afraid that the question which he had undertaken was a very difficult one. "According to Dr. Draper's supposition," he said, "the solar spectrum is made up of a continuous spectrum with dark absorption lines and also bright lines superposed upon it. Now, the ordinary spectrum, which up to the present time we have supposed that we had to deal with, was a continuous spectrum with dark lines; but when you superpose on this bright lines so faint that you cannot distinguish their brightness from the general background of the spectrum, it is evident that the problem becomes more complicated." Mr. Proctor regarded as of great importance the fact that "all the oxygen lines fall entirely opposite to bright interspaces in the solar spectrum and that none of them even partially overlap dark lines." He asked whether it was "antecedently probable that there should be any continuous background in the solar spectrum. If the photosphere is purely gaseous we should have only bright bands interfered with and modified by absorption lines." Dr. Gladstone expressed the opinion that Dr. Draper's results had "largely increased the evidence of there being real coincidences between the oxygen lines and bright spaces in the solar spectrum." "There seems to be still a great question," he said, "as to whether the solar spectrum is made up only of bright and dark lines or whether there is a background of continuous spectrum. I am not disposed to give up the idea that we have a continuous spectrum underlying these dark lines, but think that it is certain that we have also bright lines mixed with the dark. We know that when we look at the edge of the sun there are bright lines corresponding to hydrogen and some other elements to be seen, but there are no oxygen lines. Now, I would suggest that this shows that the oxygen never rises to the level of the chromosphere, so as to be seen at the limb of the sun, and probably that is just the reason why we see its lines as bright lines and not as dark lines, for it never gets up to a level where it is sufficiently cool to form dark lines." Dr. Huggins was "overwhelmed with a sense of the large amount of conscientious labor and care which Dr. Draper had evidently bestowed upon the investigation." He thought that "Dr. Draper had made out a *primâ facie* case, which entitled him to demand a careful examination of the evidence he had brought forward; but for his own part he should like to suspend his judgment until he had had an opportunity to re-examine that part of the spectrum." Captain Noble considered that, looking at the photographs impartially, if we were "to deny the evidence supplied by some of these coincidences, and notably by this group of four lines, and accept Mr. Christie's dicta, we literally should have no tangible evidence as to the existence of any element in the sun at all."

The presentation of these photographic enlargements of the superposed solar and air spectra to the French Academy was made by M. Cornu on the 23d of June, 1879. Upon this occasion M. Faye, after alluding to the remarkable fact that up to the present time spectrum analysis had furnished no evidence whatever of the presence of oxygen in the sun, went on to say: "M. Draper, however, has succeeded in discovering the oxygen not in the chromosphere but in the photosphere, where it discloses itself by bright lines. It is obvious that if this gas is dissociated at a depth, it is immediately taken up by multiple combinations in the region of and at the temperature of the brilliant surface. I see in these facts the hope of a confirmation and, above all, of an extension of the views I have put forth on the constitution of the sun; but, whatever may be the fate that the progress of spectrum analysis reserves to them, I express here my admiration for the discovery of M. Draper, and I hope that his results, so well confirmed by the photographic proofs that our learned member, M. Cornu, has shown to the Academy, will meet with no delay in being universally accepted by competent judges."

During the past year a paper upon the presence of oxygen in the sun has been published by Professor Trowbridge and Mr. Hutchins. Referring to the difficulties encountered by Dr. Draper, these authors say: "The time that has elapsed since his work does not seem to have made those difficulties less, and in spite of all that our ingenuity has been able to devise, we have been practically confined to taking the spark in free air or oxygen at atmospheric pressure, notwithstanding the broad and hazy character of the lines under these conditions." The electrical portion of their apparatus was essentially similar to Dr. Draper's. An alternating dynamo, whose current was sharply interrupted, was used to excite three large quantity induction coils connected in series, from two to twelve jars being placed in the secondary circuit. The spark discharge, taken between two aluminum rods placed in front of the slit, although producing a deafening rattle, gave a light of only about two candles. For producing the spectrum these authors used a Rowland concave grating having a ruled surface six inches by two. A quartz lens of five feet focus produced upon the slit an image of the sun reflected from a heliostat. The two spectra upon the negative lie closely edge to edge, so that accurate comparison is readily made between them. The wave lengths of the air lines were obtained by comparison with Rowland's map of the sun spectrum and a list is given of the wave lengths of nearly three hundred lines thus photographed in the air spectrum between wave lengths 3,749 and 5,034.

It is interesting to notice the close agreement of Dr. Draper's wave lengths as given by him for the oxygen lines with those obtained by means of this greatly improved apparatus. Dr. Draper speaks of a triple oxygen line between 4,345 and 4,350. The above list mentions four strong lines in the air spectrum at 4,347.94, 4,349.30, 4,351.40, and 4,353.70, and of a fifth at 4,345.52. To the Draper double line at 4,319, 4,317 correspond in the list two strong lines 4,319.50 and 4,317.20. The double line 4,190, 4,184 is given in the list as 4,190, 4,185.32, both very strong. Draper's line at 4,133 is given as 4,132.82, faint. The triple line, 4,076, 4,072, and 4,069, which Draper gives as the strongest line of oxygen, is given as 4,076.19, 4,072.34, 4,070.24, all strong. Besides these eleven oxygen lines, Draper's large photograph shows five others of wave lengths approximately 4,155, 4,147, 4,119, 4,105, and 4,093, making the sixteen lines identified as oxygen lines, given in this photograph. As this plate, which is about twenty inches long, extends only from wave length 4,025 to 4,375, the total number of lines in the Trowbridge and Hutchins list corresponding to this range is ninety. Of these, eighteen only are marked strong in the list; and of these eighteen, thirteen apparently are shown on Dr. Draper's photograph; the remaining three of Dr. Draper's lines—*i. e.*, 4,155, 4,147, and 4,133—being faint. Of the five list lines remaining, that at 4,109 may be a member of the 4,105 group, 4,349 may belong with 4,347, and 4,353 with 4,351; 4,280 does not seem to have been noticed by Dr. Draper, and 4,367 is near the edge of his plate. Possibly, too, some of them are nitrogen lines.

Of the eighteen lines prominent in that portion of the spectrum photographed by Dr. Draper, only three are mentioned in the list as agreeing; and of these, the words "may agree" indicate only a possible agreement. It is not stated in the paper itself what agreement means exactly. Presumably it means that the line opposite to the word "agrees" coincides with a dark line in the solar spectrum. If this be so, then it would appear that, since none of the sixteen lines observed by Dr. Draper and given in the list agree with dark solar lines, they must agree with the interspaces, as Dr. Draper himself believed. Applying the same rule to the entire spectrum photographed by Professor Trowbridge and Mr. Hutchins, it appears that out of the 288 air lines whose wave lengths are given only eighteen are stated to agree with lines in the solar spectrum, while eighteen others may possibly agree. These agreements may perhaps be due to metallic vapors, since the spark taken between aluminum terminals is stated to have been composite. If any fact is clearly established by this research, therefore, it would seem to be the fact that the lines in the spectrum of air, taken under the conditions stated, do not agree with the dark lines of the sun spectrum; and hence that oxygen—and, perhaps, nitrogen also—is not contained, under the conditions used in these experiments, in the chromosphere or reversing solar layer. But since, with the length of spectrum used, it would not seem probable that the air lines would extend over the dark lines and the interspaces also, the conclusion seems natural that if the oxygen lines do not coincide with dark lines they must coincide with bright ones, or at least must agree with the interspaces between the dark lines.

Moreover, in the above paper the authors remark: "The bright bands of Dr. H. Draper's spectrum are found to be occupied by numerous dark lines of various degrees of intensity." But this, as Dr. Draper himself has shown, does not in the least invalidate his theory. In the discussion before the Royal Astronomical Society Mr. Ranyard also pointed out this possibility. He said: "The observations of the bright lines seen at the limb of the sun renders it probable that the layer of the solar atmosphere which gives rise to the dark lines lies above the layer from which we receive the light of the bright oxygen spectrum, for no bright oxygen lines are seen in the chromosphere. So that it is possible to conceive that the oxygen lines of the solar spectrum may be modified as we observe them by the superposition of dark lines, and this appears in one or two instances to have been the case; but the character of the bright interspaces is very little changed." * * * "With regard to the bright lines falling opposite interspaces which are broader than the bright lines of oxygen, the probability is very great against there being two adjacent bright lines of exactly equal brightness; but it must be remembered that we are not examining the bright lines themselves, but only photographs of the lines, and that the bright parts of these photographs are what would be called by photographers over-exposed; consequently the gradations of brightness are very much obliterated." Indeed the authors themselves say that "it happens quite frequently that an oxygen line falls centrally upon the space between two dark lines of the solar spectrum." But they add that this takes place "not more frequently than we might expect as a matter of chance."

It would appear, therefore, that the question of the existence of oxygen in the sun resolves itself finally into the existence in the solar spectrum of bright bands. Reasoning *a priori*, there is not only no reason for their non-existence there, but there is good reason for their presence; since it depends solely upon the temperature and the radiating power of the oxygen under the conditions in which it exists on the sun's surface whether the lines it gives are brighter or darker than the general surface, as Meldola has shown. Moreover, as a matter of fact, bright lines are common in the spectra of many stars, and many astronomers maintain their existence even in the solar spectrum. Obviously they must be much better seen with low than with high dispersion; and some of the interspaces in Dr. Draper's large photograph produce strongly upon the mind the impression of bright bands. Moreover, upon what absolute proof does the background of continuous spectrum rest? Is not Mr. Proctor's suggestion that the photosphere is purely gaseous quite as probable as any other? And if so, then the solar spectrum may consist only of bright bands interfered with and modified by absorption bands.

The final solution of this question must await further light upon the constitution of the spectrum of the sun. The careful research made at the Jefferson Laboratory seems to have proven conclusively that the lines of oxygen obtained under the given conditions do not coincide with the dark lines of the solar spectrum, and therefore to have proved that these lines do coincide with the interspaces. If these interspaces are simply gaps between the dark lines through which the background of photospheric continuous spectrum appears, then the coincidence of the oxygen lines with these interspaces must be accepted as evidence, by the same reasoning that is applied to metallic lines, that oxygen is not present in the sun—at least in the same condition as that in which we know it. But if the solar spectrum does contain actual bright lines or bands superposed like the dark lines, upon a continuous spectrum; or much more, if this spectrum is made up only of bright and dark bands or lines, certainly a possible supposition, then it would seem clear that the coincidence of the bright oxygen lines with these bright solar lines is proof of the existence of oxygen in the sun of the same character as the proof of the existence of iron there, the increased radiation producing this reversal in intensity. But this is exactly Dr. Draper's theory, and so far, at least, it does not seem to have been disproved.

The new physical laboratory was completed in January, 1880. Dr. Draper's chief object in building it, as we have seen, was to secure increased facilities for his investigations upon the spectra of the elements, particularly those of the non-metals. The photographic work for the oxygen research had been done in a back room of the third story of his New York residence. The prisms which produced the spectra were hollow prisms filled with carbon disulphide. They were loaned for this purpose by Mr. Rutherfurd and had been used by him originally in obtaining his celebrated photograph of the solar prismatic spectrum. The temperature of this back room proved to be remarkably uniform, so that the quality of the photographs taken was excellent and their sharpness all that could be desired. When, however, the preliminary experiments required for the continuation and extension of this research were undertaken in the new physical laboratory, it was found practically impossible to use carbon disulphide prisms in this room, owing to the rapid variations of temperature which took place there. No definition whatever could be obtained with the same prisms which had performed so well in the main house. In consequence, the use of these prisms was abandoned, and a series of experiments was undertaken to obtain the spectrum by other means. First a Rutherfurd silvered glass grating of 8,640 lines to the inch was employed, and then a train of six Steinheil flint-glass prisms. With reference to these experiments, Dr. Draper says: "The exposures required when using the silvered grating were so long that experimentation was very tedious; but when in addition the definition did not equal that of the two bisulphide prisms formerly used a change became necessary. If we could overcome the effect of temperature on bisulphide it would doubtless serve our purpose best, because it is more transparent, less colored, and loses less light by reflection than glass prisms, since there are only two prisms needed to do the work of four flints. But the instability of a bisulphide train is so marked in the new laboratory, on account of the fluctuations of temperature, that we have not been able to depend upon it. Possibly if the prisms were enclosed in cotton batting or immersed in water these difficulties might be overcome." These experiments extended through nearly two years, beginning in March, 1880 and continuing until the early winter of 1881–'2.

Among the experiments undertaken in the new laboratory was a series made to test the performance of a disulphide prism of Thollon's construction, made by Hilger, of London, and obtained by Dr. Draper when in Europe, in the spring of 1879. This prism consists of a glass bottle ground away so as to have two plane sides, including between them an angle of 90°. Upon these sides are cemented two prisms of flint glass four inches by two upon the face, each having a refracting angle of 18°, the refracting edges of these flint prisms being opposed to that of the disulphide prism within. The compound prism thus made has a refracting angle of 54°. In using it the same difficulties were encountered which had been experienced with the Rutherfurd disulphide prism. Owing to the temperature variations, the spectrum lines were "wooly" and no definition was possible. Dr. Draper says: "The bisulphide prism touched with the finger or breathed on loses all definition at once." The result, however, was sufficient to show that the dispersive power of the Thollon prism was equal to that of about four of the Steinheil flint prisms, and this fact made it so extremely desirable to use this Thollon prism that Dr. Draper was led to investigate the cause of the unsteadiness of the disulphide, with a view of remedying it, if possible.

The difficulty now referred to has been encountered by all experimenters who have attempted to use carbon disulphide in prisms. Mr. Rutherfurd himself found it a serious one in his experience, and M. Thollon says that disulphide prisms must be protected carefully from temperature variations. While using his disulphide train Mr. Rutherfurd made an observation of great importance. He noticed that "if a good prism which with a high power refuses to define the soda line (a more stringent test than solar lines) is violently shaken and then placed in position it will for a few minutes define beautifully, but gradually settle into its former condition." It occurred to Dr. Draper, therefore, that possibly the striæ caused by convection currents, which were produced by inequalities of temperature and which occasioned the bad definition, might be destroyed by an active agitation of the liquid. Accordingly, on the 19th of November, 1881, he placed a small sheet-metal propeller in the disulphide within the Thollon prism, the driving shaft coming out through an opening in the stopper. By means of a small electric motor, this propeller could be rotated at any convenient speed. The result was marvelous; this simple device, by keeping the liquid in constant agitation, destroyed all inequalities of density, and the definition became excellent. On the 21st of November, with the stirrer revolving five times a second, the definition was so perfect that even with a faint flame the sodium lines could be seen distinctly reversed. A series of comparisons between the Thollon prism thus arranged and the train of Steinheil prisms showed that, while the relative dispersion was very nearly equal for the two, the amount of light transmitted by the Thollon was, on the average, four times, and in the region about G eight times as great as that obtained with the Steinheil train.

But now a new source of error was developed. Although by means of the revolving propeller the definition given by the disulphide prism was rendered independent of temperature changes, yet now it was found that these temperature changes, by altering the refractive indices of the liquid for the various spectrum lines, caused a gradual shifting of position in these lines, either in one direction or the other, as the temperature rose or fell. Obviously, during an exposure of any considerable duration, such as is often necessary with faint spectra, the change of position of the spectrum lines, produced by change of temperature, might be sufficient to destroy absolutely the definition of the image on the photographic plate. The amount of this displacement was quite considerable. During the night of December 8th the thermometer in the laboratory fell nine degrees Fahrenheit, and this temperature change caused a shifting of the sodium lines through a distance of 0.75 inch towards the more refrangible end of the spectrum. A direct experiment, made by placing a thermometer in the disulphide, showed that for a temperature change of 3.75° F. a displacement of 0.375 inch took place in the position of the sodium lines. In the hope of correcting this new difficulty an even-temperature box was constructed, surrounding the prism and filled with cotton. This box was 30 inches on a side, a plate of iron six inches square being let into the bottom and so arranged that it could be heated by a gas flame. An iron tube nine inches long and closed at the upper end passed through this plate and projected seven inches into the box. The temperature within was regulated by means of two compound expansion bars made of strips of vulcanite and brass riveted together, these strips being included in the circuit of an electro-magnet and a battery and so adjusted that when the ends of the bars came in contact as the temperature rose the circuit was closed and the electro-magnet acted to turn down the gas. As the temperature fell the circuit was automatically opened and the gas turned on. Subsequently a funnel was placed upon the lower end of the heating tube, and this tube was continued upward through the top of the box, an opening being made on one side of it within the box. A relay was so connected with a damper that it closed the top of this tube whenever the circuit was broken by the separation of the differential bars within the box, and opened it when the circuit was again closed. This relay acted in conjunction with the electro-magnet above mentioned, closing the tube at the top when the gas was turned on and opening it when it was turned off. When the gas-jet beneath the funnel was lighted the heated air rose into the tube and entered the box through the lateral opening in this tube. As soon as the temperature was reached for which the bars were set these bars came into contact and closed the electric circuits both of the electro-magnet and the relay, thus cutting off the gas supply and at the same time opening the damper. The heated air in the box now passed out through the lateral opening in the tube until the temperature had fallen to the point for which the expansion bars had been set; then the contact was broken, the electric circuit was opened, and the cycle was complete.

Some experiments made with this apparatus in 1884 showed that it was remarkably effective. After careful adjustment, the temperature within the box was found to be maintained constant within one-tenth of a degree Centigrade for seven hours, during which time the sodium lines did not change their position by an amount equal to the distance between them. These experiments confirm the opinion of Dr. Draper that the irregular action of the carbon disulphide, which is the cause of its bad definition, is due to an inequality between the temperature of the disulphide and that of its enclosing vessel, producing convection currents in the liquid. So long as the temperature of the liquid rises and falls with that of the prism and of surrounding objects, so long the definition remains perfect, notwithstanding the temperature change. It is only when considerable changes of temperature take place suddenly that these convection currects appear and produce the striæ which destroy the definition. Since this is the condition of things in most working laboratories, the method of curing the evil completely by agitation, as in Dr. Draper's apparatus, makes the experimenter practically independent of these temperature changes. But now these temperature changes, though they cannot produce bad definition, do cause a shifting of the spectrum lines. This trouble is readily obviated by the use of the even-temperature box. Indeed, when this box has been at a constant temperature for a sufficient time, the definition is good even without the stirrer.

In 1878 Professor Draper organized an expedition to observe the total solar eclipse of July 29. The party consisted of himself as director, Mrs. Draper, Mr. T. A. Edison, President Henry Morton, and the writer. Dr. Draper's familiarity with the locality through which the track of the eclipse was to pass led him to select Rawlins, Wyoming, an important station on the Union Pacific railway, as the point of observation. The chief object of the expedition was to gain as precise an idea as possible of the nature of the corona, and particularly to ascertain whether it was an incandescent gas shinning by its own light or whether it shone by reflected sunlight.

The site chosen for the temporary observatory was in latitude 41° 48′ 50″ N., and longitude 2h. 0m. 44s. W. of Washington, its height above the sea being 6,732 feet. While near the central line of totality, this station had the advantages of pure water, supplied from the granite of Cherokee Mountain, and of proximity to the railroad repair shops. The equipment consisted, 1st, of a Clark telescope of 5¼ inches aperture and 78 inches focal length, photographically corrected and equatorially mounted, with a spring-governor driving clock, the mounting being loaned by Professor Pickering; 2d, of a quadruple achromatic objective of 6 inches aperture and 21 inches focal length, provided with a Rutherfurd diffraction grating ruled on speculum metal, the ruled surface being 2 inches square; 3d, of a 4-inch achromatic telescope with a Merz direct-vision spectroscope; and, 4th, of a 4-inch Dollond achromatic, to which the Edison tasimeter was attached.

The photo-telespectroscope was arranged to obtain a photograph of the diffraction spectrum of the corona—a difficult and, in the opinion of many persons at the time, an impossible task. To attain success the lens must evidently be of large aperture and very short focal length; and the grating must be of the largest size and adjusted so as to utilize the beam of light to the best advantage. The whole apparatus must be equatorially mounted and driven by clockwork, so that the exposure may last during the entire totality. Preliminary experiment gave the apparatus its final form. The quadruple lens of 6 inches aperture and 21 inches focal length, gave an image of the sun of extreme brilliancy, though less than a quarter of an inch in diameter. Before the light from the lens reached its focus it was intercepted by the Rutherfurd grating set at an angle of sixty degrees. This threw the beam on one side and produced there three images—a central one of the sun itself and on either side of it a spectrum. These images were received on three separate sensitive plates. One of the spectra was about twice as long as the other and gave a photograph about two inches in length. It is clear that if the coronal light is that of an incandescent gas, ring-shaped images would be obtained upon the plate, as many in number as corresponded to the bright lines in the photographic region; while if the light be emitted from a glowing solid or be reflected from the sun itself a continuous spectrum image without rings would be obtained. On developing the photographs after totality was over, Dr. Draper found that the spectrum photographs were continuous bands without the least trace of a ring.

The large equatorial was arranged to take a photograph of the corona itself, the exposure being the whole time of totality, or about 165 seconds. The resulting picture showed that the corona is not arranged centrally with regard to the sun, The great mass of the matter lies in the plane of the ecliptic, but is not equally distributed. To the eye it extended about a degree and a half from the sun towards the west, although it was scarcely a degree in length toward the east; while in the photograph it extended to a height of not over twenty minutes of arc, or something more than 500,000 miles. If, therefore, the corona has the structure of a meteoric mass, the mass is probably arranged in the form of an ellipsoid about the sun.

The analyzing slit spectroscope of Merz was mounted upon a telescope of four inches aperture. It was provided with two compound direct-vision prisms, of which one or both could be used at will, each consisting of five single prisms, two being of flint and three of crown glass; the former and one of the latter prisms having a refracting angle of 84°, the other an angle of 87°. This dispersive power of each of these compound prisms was about equal to that of two equilateral prisms of good flint glass. The instrument had a collimating and an observing telescope each furnished with an object-glass two-thirds of an inch in aperture and four inches in focal length. During totality, the slit being placed radially, the spectrum observed, which was that of the region near G, seemed entirely continuous; nor did any bright lines appear when the green region was examined. Upon closing the slit, however, the region from *b* to G appeared filled with dark lines on the brighter background, these lines being readily recognized as those of Fraunhofer. Of these lines *b* and F were especially distinct; D, E, and G, though easily recognized, were less prominent.

The tasimeter of Dr. Edison was attached to a four-inch Dollond telescope. In this instrument a strip of vulcanite, placed between a fixed point and a soft carbon disk or button, was arranged so that its expansion by heat produced pressure upon the carbon disk, thus decreasing its resistance and allowing more current to flow through it. The tasimeter, adjusted to three ohms, was placed in one of the arms of a Wheatstone bridge, the opposite arm having a resistance of three ohms, and the pair of arms ten ohms each. A Thomson reflecting galvanometer was placed in the bridge wire. On the night of July 27th, says Dr. Edison in his Report, the image of the star Arcturus was brought upon the vulcanite strip. The spot of light reflected from the galvanometer moved to the side of heat. After adjustment five uniform and successive deflections were obtained with the instrument, as the light of the star was allowed to fall upon the vulcanite or was screened off from it. During the totality the tasimeter was placed in a double tin case containing water at the temperature of the air. At the instant when the sunlight disappeared the spot of light was passing slowly towards the side of cold. When the screen was withdrawn so as to permit the edge of the corona to fall upon the vulcanite, the spot of light came to rest and then moved gradually toward the side of heat, and in four or five seconds passed entirely off the scale.

The general conclusions reached by Dr. Draper from the results obtained were that the corona of the sun shines by light reflected from the solar mass by a cloud of meteors surrounding that luminary, and that on former occasions it has been infiltrated with materials thrown up from the chromosphere, notably with the 1,474 matter and hydrogen.

In 1874, upon the organization of the United States Commission to observe the transit of Venus, Professor Draper's achievements in celestial photography pointed him out at once as the person best suited to organize the photographic section of the expedition, and he was accordingly appointed in February the Director of the Photographic Department. In the early part of April he went to Washington, entered into the work most heartily at once, and during three entire months devoted himself almost without intermission to the work of devising improved methods, of testing instruments and materials, and of instructing those who were to use these methods how to obtain the best results with them; declining subsequently to accept compensation for the time thus spent. Although his duties at home prevented him from joining any of the expeditions thus sent out, yet so conspicuously valuable had been his services and so largely instrumental had they been in making the transit observations a success that, upon the recommendation of the Commission, Congress ordered a special gold medal to be struck in his honor at the mint in Philadelphia. This medal is 46 millimeters in diameter. Upon the obverse it has the representation of a siderostat in relief, with the motto, "Famam extendere factis hoc virtutis opus." Upon the reverse is inscribed the words: "Veneris in sole spectandæ curatores R. P. F. S. Henrico Draper, M. D., Dec. VIII, MDCCCLXXIV," together with the motto, "Decori decus addit avito.".

Toward the close of 1868 Professor Draper became greatly interested in a project to establish an observatory in Central Park, and had numerous consultations upon the subject with Mr. Andrew Green, at that time the controller, and Mr. Vaux, the architect of the park. In December the park was visited and the site of the observatory selected. It was a knoll at about 105th street, 130 feet above tide water, and commanding an unobstructed view. Dr. Draper was appointed the director of this new observatory, and plans were arranged for securing the $250,000 which it was estimated would be required for carrying the project into operation.

Besides that which was spent in scientific work, Dr. Draper's time was largely occupied with his duties as an instructor. We have already seen that as early as 1858 he had been appointed on the medical staff of Bellevue Hospital and had served in that position for eighteen months. As Professor of Natural Science in the Academic Department of the University of the City of New York from 1860 until 1882 and as Professor of Physiology in the Medical Department of the University from 1866 until 1873, he was called upon to deliver numerous lectures, and as Dean of the Medical Faculty much time was necessarily given to the management of the business affairs of the college. It is to his signal ability in this position, aided by a liberal use of his own private means, that the college is largely indebted for the promptness with which a new building was provided and its lectures were resumed after the destruction by fire of its old building on Fourteenth street. After the death of his father the chief inducement for him to retain his connection with the University no longer existed; so that, although elected to the chair thus vacated, he discharged its duties only until the close of the current academic year.

Still a third sphere of labor made its demands upon Dr. Draper's time. In 1867 he had married Mary Anna, the accomplished daughter of Courtlandt Palmer, of New York. Upon Mr. Palmer's death, in 1874, Dr. Draper became the managing trustee of a large estate; and, with his characteristic energy and ability, entered at once upon the task of reducing it to a basis of maximum production with the minimum amount of attention. The responsibility which thus rested upon him, the harassing demands of tenants, the endless details of leases, contracts, and deeds, and the no less annoying complications of necessary lawsuits worried him incessantly. Had it not been for his unsurpassed business capacity he might have been overborne by this excessive strain. But he was equal to the demands made upon him, and within a few years order had come out of confusion, and a few hours spent daily at his office enabled him to maintain the affairs of the estate in a satisfactory condition.

Early in February, 1862, Dr. Draper was commissioned surgeon of the Twelfth Regiment New York State Militia, and on the 6th of June he left with the regiment for three months' service in Virginia. He was mustered out of the United States service on the 7th of October, and returned to New York sick with the Chickahominy fever, contracted in the swamps bordering the Monocacy river. In 1876 he served as one of the judges in the photographic section of the Centennial Exhibition. Already, in 1875, Dr. Draper had been elected a member of the Astronomische Gesellschaft. In 1877 he was made a member of the American Philosophical Society in Philadelphia, and the same year was elected a member of the National Academy of Sciences. In 1879 he was elected a Fellow of the American Association for the Advancement of Science. In 1881 the American Academy of Arts and Sciences in Boston enrolled his name among the list of its associate fellows. In 1882 he received the degree of doctor of laws almost simultaneously from the University of Wisconsin and from his *alma mater*, the University of the City of New York.

For several years it had been Dr. Draper's custom, in order to get rest from the severe labors of the year and to fortify his constitution for the winter strain, to join his friends, Generals Marcy and Whipple, of the United States Army, for a few weeks' hunting in the early fall in the Rocky Mountains. These expeditions he enjoyed greatly. He was an enthusiastic sportsman and a capital shot, and he entered upon the chase with as much relish as he took a stellar photograph. It was while out upon such an expedition in 1877 that he made the important observations on the suitableness of the air of that region for astronomical investigations. The party in 1882 left New York on the 31st of August, went by rail to Rock Creek, on the Union Pacific Railway, and from there went north in the saddle, reaching Fort Custer, on the Northern Pacific Railway, near the middle of October. During the two months of their absence the party rode fifteen hundred miles on horseback, as Dr. Draper estimated. When above timber line, early in October, they encountered a blinding snow-storm with intense cold, and were obliged to camp without shelter. On the 25th of October Dr. Draper reached New York. Ordinarily he returned refreshed and invigorated with the splendid exercise of the trip; but this year the distance traveled seemed to have been too great, and this, together with the hardships encountered, seemed to have wearied him. Pressure of delayed business awaited him and occupied his time at once. Moreover, the National Academy of Sciences was to hold its November meeting in New York, and Dr. Draper was to entertain them as he had always done. This year the entertainment was to take the form of a dinner. In order to offer a scientific novelty, he determined to light the table with the Edison incandescent light, the current being supplied from the dynamo machine in his laboratory; but the source of the power being a gas engine, and therefore intermittent in its action, a disagreeable pulsation was observable in the light. To obviate this he contrived an ingenious attachment to the engine whereby, at the instant at which the speed was increased by the explosion of the gas in the cylinder, a lateral or shunt circuit, the resistance of which could be varied at pleasure, should be automatically thrown in. With his admirable mechanical skill, Dr. Draper extemporized the device from materials at hand and found it to work perfectly. The dinner was given on the evening of November 15th, and was one of the most brilliant ever given in New York; about forty academicians, together with a few personal friends, sitting at the table. Dr. Draper's overwork, however, now told upon him; slightly indisposed as he had been before, he was unable to partake of food and a premonitory chill seized him while at the table. As soon as the dinner was over and the guests had departed he took a hot bath, thinking thus to throw off the attack. But while in the bath a second and more severe chill of a decidedly congestive type attacked him, and it was only with the greatest difficulty that he could be carried to his bed. His warm friend and former colleague, Dr. Metcalfe, who had been a guest at the dinner, was at once summoned and pronounced the attack double pleuritis. The best of treatment and the most careful nursing seemed for two or three days to be producing an effect for the better. But on the Sunday following pericarditis developed, and he died about four o'clock on the morning of Monday, the 20th of November, 1882.

Viewed from whatever standpoint, the life of Henry Draper appears as successful as it was earnest, honest, and pure. His devotion to science was supreme; to him no labor was too severe, no sacrifice too great, if by it he could approach nearer the exact truth. The researches he had already made and, much more, those he had projected involved the largest expenditure of his time and means. But such was his delight in his scientific work and such his enthusiasm in carrying it on that he was never happier than when hardest at work in his laboratory; never more cheerful than when most zealously laboring with his superb appliances. Dr. Draper's abilities, too, were many-sided. He was eminent in astronomy, in physics, in chemistry, and in physiology. He possessed exceptional skill as a mechanician, as the wonderfully accurate mountings of his telescopes abundantly prove. Moreover, he was quite as distinguished as a teacher as he was as a scientific investigator. His lectures were simple, clear, and forcible. They held the interest of the classes he instructed and awakened their enthusiasm, while they enriched the student's store of knowledge and strengthened his powers of observation and of reasoning. In the laboratory he was keen, thorough, and impartial, while at the same time considerate and helpful, ever striving to encourage honest endeavor and to assist the earnest worker. As a business man he is said to have had no superior in the city of New York. In social life he was brilliant, entertaining, companionable. He made life-long friends often at the first contact by the charm of his presence and the suavity of his manner.

Professor Draper had not published very extensively at the time of his death. This is the more remarkable as he was fond of writing, a trait no doubt inherited from his father. A list of his publications is appended to the present memoir. There can be little room to doubt that had he not been cut down so abruptly in the midst of a host of projected investigations, the world would have been enriched during the succeeding twenty years with a wealth of discovery almost unparalleled.

To indicate the esteem in which Dr. Draper was held by his confrères in science the following passage may be quoted from an excellent biographical notice of him written by Professor Young, of Princeton: "In person he was of medium height, compactly built, with a pleasing address and a keen black eye which missed nothing within its range. He was affectionate, noble, just, and generous; a thorough gentleman, with a quick and burning contempt for all shams and meanness; a friend most kind, sympathetic, helpful, and brotherly; genial, wise, and witty in conversation; clear-headed, prudent, and active in business; a man of the highest and most refined intellectual tastes and qualities; a lover of art and music, and also of manly sports, especially the hunt; of such manual skill that no mechanic in the city could do finer work than he; in the pursuit of science able, indefatigable, indomitable, sparing neither time, labor, nor expense."

"Excepting his early death, Dr. Draper was a man fortunate in all things: in his vigorous physique, his delicate senses, and skillful hand; in his birth and education; in his friendships, and especially in his marriage, which brought to him not only wealth and all the happiness which naturally comes with a lovely, true-hearted, and faithful wife, but also a most unusual companionship and intellectual sympathy in all his favorite pursuits. He was fortunate in the great resources which lay at his disposal and in the wisdom to manage and use them well; in the subjects he chose for his researches, and in the complete success he invariably attained."

In closing this biographical notice of Henry Draper, I beg my colleagues of the Academy to remember that his life and work have been viewed by me through the medium of a warm personal friendship. To me Professor Draper was indeed a man among men, a scientist of the highest type. Stricken down as he was, in the midst of his life-work, at the early age of forty-five, the bright promise of his noble life was left unfulfilled. What brilliant researches in his favorite science he might have made we can never know. But with a mind so richly endowed and so thoroughly trained, with an experimental ability as earnest as it was persistent, with facilities for investigation which were as perfect as they are rare; with abundance of time and means at his disposal, and, above all, with a devoted wife, who keenly appreciated the value of his scientific work, was ever at his side as his trusty assistant, and always shared in the glory and honor of his discoveries, we may be sure that had he been permitted to reach the age of his honored father results would have been reaped by his labors which would have added still brighter lustre to the science of America.

LIST OF HENRY DRAPER'S PUBLISHED PAPERS.

1. On the Changes of Blood Cells in the Spleen. *New York Journal of Medicine*, III, v, 182–189, Sept., 1858.

2. On a New Method of Darkening Collodion Negatives. *Am. J. Photog.*, II, i, 374–376, May, 1856.

3. On a Reflecting Telescope for Celestial Photography. *Rep. Brit. Assoc.*, 1860, II, 63–64.

4. Article "Photography." *New American Cyclopedia.* New York, 1863.

5. On an Improved Photographic Process. *Am. J. Photog.*, II, v, 47, Feb., 1862. (*London Phot. News.*)

6. On a Silvered Glass Telescope and on Celestial Photography in America. *Quar. J. Sci.*, i, 381–387, April, 1864.

7. On the Photographic Use of a Silvered Glass Telescope. *Phil. Mag.*, IV, xxviii, 249–255, 1864.

8. On the Construction of a Silvered Glass Telescope 15½ inches in Aperture, and its Use in Celestial Photography. *Smithsonian Contributions*, XIV, Part II. July, 1864.

9. Petroleum; its Importance, its History, boring, refining. *Quar. J. Sci.*, ii, 49–59, 1865. *Dingler's Polyt. J.*, clxxviii, 107–117.

10. American Contributions to Spectrum Analysis. *Quar. J. Sci.*, ii, 395–401, 1865.

11. A Text-book on Chemistry. New York, 1866.

12. Report on the Chemical and Physical Facts collected from the Deep Sea Researches made during the voyage of the School-ship Mercury. *Rep. Comm. Pub. Charities.* New York, 1871.

13. On Diffraction Spectrum Photography. *Am. J. Sci.*, III, vi, 401–409, Dec., 1873. *Phil. Mag.*, IV, xlvi, 417–425. *Ann. Phys. Chem.*, cli, 337–350, 1874.

14. Astronomical Observations on the Atmosphere of the Rocky Mountains, made at Elevations of from 4,500 to 11,000 feet, in Utah and Wyoming Territories and Colorado. *Am. J. Sci.*, III, xiii, 89–95, Feb., 1877.

15. Photographs of the Spectra of Venus and α Lyræ. *Am. J. Sci.*, III, xiii, 95, Feb., 1877. *Phil. Mag.*, V, iii, 238.

16. Discovery of Oxygen in the Sun by Photography, and a new Theory of the Solar Spectrum. *Proc. Am. Phil. Soc.*, July, 1877, 74–80. *Am. J. Sci.*, III, xiv, 89–96, 1877.

17. Article "Speculum." *New Universal Cyclopedia.* New York, 1878.

18. Observations on the Total Eclipse of the Sun of July 29th, 1878. *Am. J. Sci.*, III, xvi, 227–230, Sept., 1878. *Phil. Mag.*, V, vi, 318–320.

19. On the Coincidence of the Bright Lines of the Oxygen Spectrum with the Bright Lines of the Solar Spectrum. *Am. J. Sci.*, III, xviii, 262–277, Oct., 1879. *Month'y Not. Astr. Soc.*, xxxix, No. 8.

20. On Photographing the Spectra of the Stars and Planets. *Am. J. Sci.*, III, xviii, 419–425, Dec., 1879. *Nature,* Nov. 27, 1879.

21. On a Photograph of Jupiter's Spectrum showing Evidence of Intrinsic Light from that Planet. *Am. J. Sci.*, III, xx, 118–121, Aug., 1880. *Monthly Not. Astr. Soc.*, xl, 433–436, May, 1880.

22. On Photographs of the Nebula in Orion. *Am. J. Sci.*, III, xx, 433, 1880. *Phil. Mag.*, V, x, 388. *Comptes Rendus*, xci, 688; xcii, 173, 964.

23. On Photographs of the Spectrum of the Comet of June, 1881. *Am. J. Sci.*, III, xxii, 134, 1881.

24. On Photographs of the Spectrum of the Nebula in Orion. *Am. J. Sci.*, III, xxiii, 339–341, May, 1882.