# MEMOIR

OF

# LEWIS MORRIS RUTHERFURD.

1816-1892.

BY

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# MEMOIR OF LEWIS MORRIS RUTHERFURD.

It is somewhat more than two years since I received notice of my designation for the duty of preparing the biographical notice of our late colleague, Lewis M. Rutherfurd. It is an honoring duty, which could not fail to be most welcome, provided only that it could be fitly performed. Unhappily the possibility of its performance has depended upon circumstances beyond my control. Having been a constant and deeply interested observer of the successive steps by which Mr. Rutherfurd had given impulse to the progress of more than one branch of astronomy, leaving upon it the impress of his thought and ingenuity, and having been at the same time privileged to call him friend, it would have been a source of pain to me had the duty been assigned to another; and under whatever contingency it would have been regarded as paramount to any within my option. That it has been so long deferred has been due simply to my inability to undertake it, and even now it has been necessary to elect between the alternatives of relinquishing the task or of fulfilling it in a manner unsatisfactory to myself.

The most marked mental characteristics of this gifted and beloved man were clearness of comprehension, independence of judgment, and unselfishness of purpose. With these were combined rare mechanical ingenuity and inventive power, and the character was rounded out by learning, by the culture of a refined gentleman, and by an exceptional absence of all self-assertion. For knowledge of his achievements one might search the newspapers and popular magazines in vain, for he did not covet the applause of the multitude or other approval than that awarded by fully competent judges.

Mr. RUTHERFURD was born at Morrisania, New York, now a portion of New York city, on the 25th of November, 1816, being the son of Robert Walter Rutherfurd and Sabina Elliott Morris. His paternal grandfather, John Rutherfurd, represented New Jersey in the United States Senate from 1791 to 1798, being a son of Walter Rutherfurd, who had previous to the Revolution resigned a commission in the British army, become a citizen of New York, and married a daughter of James Alexander and sister of Major General William Alexander, known in American history as the Earl of Sterling, who commanded the left wing of our army at Monmouth. On the maternal side his ancestor of the sixth generation was Lewis Morris, chief justice of New York and New Jersey and the first governor of New Jersey. The great-grandfather, for whom he was named, was the signer of the Declaration of Independence.

Our late colleague studied at Williams College, whence he graduated in 1834, at the age of 18 years. While an undergraduate his inborn tastes for physical research and mechanical contrivance manifested themselves in a conspicuous degree, and he acted as assistant to the professor of physics and astronomy, preparing the experiments and constructing apparatus. After pursuing the study of law for two years in the office of William H. Seward, at Auburn, and afterwards in that of George Wood, in New York city, he began the practice of his profession as partner of Mr. Peter A. Jay, and subsequently continued it as partner of the late Hamilton Fish.

But, from the first, astronomy had for him a higher charm than legal studies, and after fortunate circumstances relieved him from the necessity of seeking pecuniary gain, he devoted himself more and more to scientific study.

In July, 1841, he had married the accomplished Margaret Stuyvesant Chanler, niece and adopted daughter of Mr. Peter Stuyvesant, husband of Mr. Rutherfurd's aunt. This happy union, which continued for almost half a century, was an indirect source of many benefits to science, for it afforded him inestimable encouragement and sympathy within his household, while the same were cordially extended to the associates of his researches. His uncle and aunt were more than glad to aid him in his scientific undertakings, and the ancestral house and garden in the midst of what had grown to be a densely populated portion of the great city gradually became a nucleus of scientific research. An observatory, with an 11¼-inch telescope constructed by Fitz under Mr. Rutherfurd's immediate guidance and supervision, and a good transit-instrument afforded opportunity for sundry researches of a higher character than those of a mere amateur, and later a workshop was gradually equipped with apparatus which he employed for the construction of instruments the precision of which was hardly, if at all, surpassed by any in the land.

While keeping up his law practice these early scientific labors were pushed forward with astonishing energy, and his health was maintained by the practice of sundry athletic sports, for he was an enthusiastic yachtsman and a champion racquet-player, and was actually on board the "America" during her celebrated race in English waters.

But soon after his withdrawal from practice of the law it became manifest that his wife's health demanded a complete change of climate and surroundings, and he entered upon a period of extended travel on the European continent. For several years he resided in cities of France, Germany, and Italy, gathering copious stores of scientific experience and becoming more familiar with the languages of these countries; so that when he returned home with renewed strength and energy he was ready to resume the scientific life for which he yearned.

During his residence in Florence he maintained intimate relations with Amici, who was then carrying on his experiments upon the achromatism of objectives for microscopes. his mechanician having been originally an umbrella-maker, whom Amici had gradually transformed into an admirable optical artist. Possibly this episode may account for a series of experiments which was undertaken by Mr. Rutherfurd more than a quarter of a century later, when he endeavored to apply, to the improvement of microscopic objectives, methods of local correction such as he had so brilliantly employed for telescopes.

His observatory in New York city served as a primary station for the determination of longitudes, being occupied, at his invitation, for this purpose by the Coast Survey on many occasions. We find "Stuyvesant garden" among the first points occupied by Sears C. Walker in his measurements of longitude.

It was in the last half of 1856 that his observatory was built and arranged, and in 1858 he began his experiments in astronomical photography. During the summer of that year he obtained negatives of the full moon which would well bear an enlargement of fifty diameters, and stereographs which gave excellent effects. This was at about the date at which De La Rue also obtained stereoscopic* results. I have been unable to decide which of the two preceded in this matter. At any rate, neither of them could have

*M. N., xvii, 257.

been much in advance of the other, and certainly each of them did the work independently. The earliest of Mr. Rutherfurd's lunar photographs preserved at Columbia College bears date June, 1858.

In the course of the next following year, 1859, he made extended studies for devising combinations of lenses for insertion in the tube of the telescope in order to make the light received from the object glass available for photographic purposes. Yet this proved successful only for the central portion of the field unless lenses of inconvenient size were introduced. Still, he did succeed to the extent of preparing apparatus for photographic observation of the total solar eclipse of 1860 in Labrador. Using for this an object-glass of about 4¼ inches (108 millimeters) and separating the crown and flint lenses by such an interval as should afford the best focus for the visual and chemical rays jointly, he obtained solar images decidedly superior to those afforded by his large telescope of 11¼ inches aperture. This was undoubtedly the first employment of a telescope constructed especially for photographic purposes, and on this occasion the difference in character of the limbs of the sun and the moon was first made distinctly and unmistakably manifest; that of the sun being hazy and indefinite, while that of the moon, in the same field, was sharp and with well-defined details of the serrated edge.

In 1861 he constructed a Cassegrainian reflecting telescope, with silvered glass mirror, having 13 inches aperture and 8 feet focus. It was figured by Mr. Henry Fitz, under his supervision, and weighed less than 15 pounds; but the silvering was so easily attacked by the abundant gases of the city and the moisture of the coast that he found it absolutely necessary to resilver the speculum at least as often as every ten days, and the tremors inseparable from the location in the heart of the great city opposed a fatal objection to good work, being about thirty-six times as large as in the achromatic telescope. where they gave no trouble. His employment of a reflector was consequently abandoned after about three months of trial.

It was at this time, however, that Dr. Draper was trying the same experiments with his silvered specula which gave such beautiful results in the dry, pure air of his observatory in the country.

It may be here remarked that the American process of figuring, or locally correcting, lenses of telescopes had been invented and used by Mr. Fitz, of New York, twenty years previously, and from association with him Mr. Rutherfurd obtained a knowledge of all its details; these he in turn taught to Henry Fitz, son of the inventor, who for a couple of years was a nightly visitor of his workshop and observatory.

Notwithstanding the earnest zeal with which Rutherfurd prosecuted his astronomical and physical observations—keeping pace with the advances of celestial discovery—his modest disposition prevented him from publishing his results and thus taking the position properly belonging to him among investigators. It was not until the year 1862 that he published his first astronomical paper,* a letter dated 1862 July 28, confirming Clark's discovery, with his new 18½-inch object-glass, of the companion of Sirius and giving measures of its position on seven dates, from March 11 to April 10 of that year. In the evening of the day on which he received news of the discovery he found the object with his 11-inch telescope, and long afterwards he stated that he had never looked for it in vain. If I am not mistaken, it was not until at least two years later that it was seen with sufficient distinctness to be measured by any other astronomer, using an object-glass of less aperture than 15 inches. The difficult measurements of distance were accomplished by him with exceptional precision and contributed largely to our early knowledge on the subject. During the next season he secured seventy-nine measures of position-angle on six different nights, and thirty-eight of distance, and he reported that he had seen it in February, 1863,† with a telescope of 9 inches aperture, also made for him by Fitz. These observations, with those made with the 15-inch telescope at Cambridge and on two nights at Pulkowa, afforded the chief basis for our knowledge of the new-found body during the first two years after its discovery. Whether it shines by its own light or by reflection from the flood of intense light emitted by its brilliant neighbor is yet an open question, although the researches of Auwers‡ have shown that its mass is not much less than one-half [0.47] that of the primary, round which it revolves in an eccentric orbit and a period of about 49½ years (49.4).

But during the year 1862, in the interval between these series of measurements, Mr. Rutherfurd entered upon another investigation,

* A. J. Sc., 34: 294.
† A. J. Sc., 35: 407.
‡ A. N., 129: 185.

with results which proved to be of high importance, and may, indeed, be regarded as inaugurating the now widely cultivated study of astrophysics.

In 1814–'15 Fraunhofer had published the memoir containing his discovery of the remarkable lines in the solar spectrum, which offered a problem unsolved by physicists until nearly half a century later. A few of these seem, indeed, to have been seen by Wollaston in 1802, but were supposed by him to form boundaries between primary colors of the spectrum, and neither he nor any other physicist gave them special attention; but Fraunhofer, while studying the laws of refraction and dispersion by different kinds of glass with reference to the improvement of achromatic telescopes, instituted experiments for determining whether their action upon sunlight was the same as upon the lamplight that he had been using.

In the memoir* cited he describes the apparatus by which a small beam of solar light was thrown upon a flint-glass prism placed upon a theodolite. In the place of an especially brilliant beam between the red and the yellow, he was surprised to find a vast number of dark lines athwart the spectrum. The most marked of these he specifies, denoting them by letters—the same, indeed, by which they are still designated. Examining similarly the light of the planets Venus and Mars, but without limiting the beam by any aperture, he found in their spectra lines similar to those which had appeared in solar light, although they were less markedly defined.

It was but natural to extend the inquiry to the light of sundry bright fixed stars. For a minute investigation of these, he increased the width of the spectrum by placing in front of the objective a plate of glass having one surface plane and the other slightly cylindrical. Making the axis of this parallel to the base of the prism, the length of the spectrum remained unchanged, while its breadth was increased sufficiently to enable him to study the lines with care. In the spectrum given by Sirius he found three broad bands totally dissimilar to those found in the solar spectrum and measured their positions. Then, passing to other stars—Castor, Pollux, Capella, Procyon, and *α* Orionis—he was able to recognize dark lines in the spectra of these also, although apparently different for each star.

Thus the question of stellar spectra remained for forty-seven years.

* Denkschr. d. Münch. Akad., V, 193; Schum. Abh., II, 13.

Rutherfurd's second scientific paper was dated December 4, 1862, and published in the American Journal of Science* for January, 1863. It is entitled "Astronomical Observations with the Spectroscope" and begins as follows:

"In the course of a conversation last December [*i. e.*, 1861] with Doctor Gibbs upon the remarkable revelations of the spectroscope, he suggested the continuation of Fraunhofer's observations upon the spectra of the heavenly bodies. At that time I had not seen Fraunhofer's paper on this subject. I immediately began a series of experiments with the view of determining the best form of instrument for the purpose," etc.

He proceeds to describe his apparatus, which was attached to the eye-tube of his large Fitz telescope. At first he found it necessary to throw the star out of focus in order to obtain a sensible breadth of spectrum, and the observations were thus subjected to the disadvantage of losing a large portion of the light upon the jaws of the slit; but, after obtaining a copy of Fraunhofer's memoir, he naturally availed himself of the device of a cylindrical lens, interposing this between the prism and the objective of the telescope and moving the slit to the focus, where no light was lost.

That even then he had already planned the photographic method of observation, by which he subsequently attained such distinction, is manifest from an incidental remark† made by him in this connection:

"I would here incidentally remark that the spectroscope, so mounted, furnishes the best means of investigating the achromatic condition of the telescope; for it is evident that if the different-colored rays have foci at different distances from the objective, it will require a change of focus for each in order that it may comply with the condition of passing the slit (in case of a star) as a point. In my telescope I find that when the luminous rays from near the outer margin of the red to the indigo are brought to a focus at one point, the ultra red require a small but measurable adjustment, and the violet and indigo quite a large change of focus. I intend to make use of this method to find more accurately the photographic focus of the instrument, which at present is determined only by experiment."

In this paper he gives the results of his observations and measurements not only for the Sun, Moon, Jupiter, and Mars, but also for

* Vol. 35, p. 71.

† Amer. Jour. Sci., 35:72.

seventeen fixed stars, as well as accounts of the examination of six others. He concludes as follows:

"The star spectra present such varieties that it is difficult to point out any mode of classification. For the present I divide them into three groups: First, those having many lines and bands and most nearly resembling the sun, viz., Capella, β Geminorum, α Orionis, Aldebaran, γ Leonis, Arcturus, and β Pegasi. These are all reddish or golden stars. The second group, of which Sirius is the type, presents spectra wholly unlike that of the sun, and are white stars. The third group, comprising α Virginis, Rigel, etc., are also white stars, but show no lines; perhaps they contain no mineral substance or are incandescent without flame.

"It is not my intention to hazard any conjectures based upon the foregoing observations—this is more properly the province of the chemist—and a great accumulation of accurate data should be obtained before making the daring attempt to proclaim any of the constituent elements the stars.

"One thought I cannot forbear suggesting: We have long known that 'one star differeth from another star in glory;' we have now the strongest evidence that they also differ in constituent materials—some of them perhaps having no elements to be found in some other. What, then, becomes of that homogeneity of original diffuse matter which is almost a logical necessity of the nebular hypothesis?

"Taking advantage of past experience, I propose to remodel and improve my spectroscope and continue to observe the stars, noting particularly the relations which may exist between the spectral revelations and the color, magnitude, variability, and duplicity of the objects."

I cannot forbear calling attention to the classification, essentially the same, subsequently published by Secchi without reference to this or to any of the other labors of Rutherfurd, and which is still generally cited * under Secchi's name.

Yet while these researches of Rutherfurd were not only independent, but were actually brought to the notice of astronomers in general at an earlier date than those of any other investigator since Fraunhofer, it must be conceded that they were antedated by analogous ones of Professor Donati at Florence, published in the *Annali del Museo Fiorentino* in the same year, 1862, the earliest being dated, indeed, in August, 1860. The Italian astronomer, using a large burning glass, kept in the museum at Florence since 1690, had essentially employed the method of Fraunhofer, with a translation of whose memoir he was familiar. The great lens being paral-

* See Scheiner, p. 258, and Translation, pp. 235, 236.

lactically mounted on a movable stand, a screen with a narrow slit was placed just inside of its focus and a cylindrical lens then interpolated between the image of the star and the prism. The spectrum was then viewed with a telescope. In this way Donati examined the light of fifteen stars and roughly described the prominent lines of their spectra. He stated that all these showed a line differing but little from the solar F, but modified somewhat in its position by a difference in the refractive quality of the light from the particular star.

It may fairly be asserted that Rutherfurd's independent results far excelled the others in comprehensiveness, minuteness of detail, and accuracy of measurement.

About four months later, at the close of March, 1863,* when publishing his second series of observations of the companion of Sirius, he states that he had mounted his astronomical spectroscope more conveniently and had added a prism, by which the spectrum from a lamp was kept in the field of view during the observation of a star. He thus established the existence of the lines D, E, *b*, and G in the light of Arcturus, and found that each line in the spectrum of that star had its counterpart in the solar spectrum.

In June of the same year, under the title of "Observations on Stellar Spectra," Mr. Rutherfurd called attention† to the results which had then been obtained by European investigators of the subject. He described the several forms of apparatus which they had employed, calling attention to their respective advantages and disadvantages and suggesting how the latter might be remedied. It will surprise no one who knew Rutherfurd, when I mention that in the whole paper there is not the slightest mention of any claim to priority, or allusion to his own previous results, except in one instance, where he modifies a previous announcement that he had found nine lines in the solar D by stating that five of these had since proved to be telluric.

From this time on, the study of the spectra of celestial bodies has gone steadily forward. It has become a favorite pursuit with a large class of students, to such an extent, indeed, as to absorb much of the energies which might otherwise have been devoted to the more laborious and exacting investigations of astronomy proper;

* A. J. Sci., 35: 407.
† Am. Jour. Sci., 36: 154.

but we cannot wonder at the fascination exerted by the new class of previously unsuspected revelations which we owe to this wonderful method of inquiry and from which astronomy is justified in expecting highly important contributions.

During the winter of 1862–'3 he had likewise constructed a large spectroscope, with telescopes of 4 centimeters [1.6 inches] aperture and 50 centimeters [20 inches] focal length, having six hollow glass prisms filled with bisulphide of carbon. This presented great technical difficulties, both in the attainment of plane parallel surfaces and in the quality of the bisulphide.

Yet it was not until the close of 1864 that he described* this instrument in its perfected form. In this, the observing telescope had two motions, one about the central axis of the instrument and the other about a second vertical axis, the whole being so arranged that the entire spectrum could be commanded by a single motion. Various devices were tried to secure equal density in the carbon bisulphide independent of thermal variations, and the very serious difficulties encountered in this respect were successfully overcome by methods still employed when prisms of this sort are required.

Finally, by an ingenious contrivance, he succeeded in avoiding all necessity for the laborious adjustment of the angle of least deviation for the several prisms by the mechanical arrangement, now well known, in which the prisms are hinged together at their corners and so connected with a central axis that all of them are, under all circumstances, kept in such a position that their backs are tangent to the same circle. By a motion of a milled head at the central axis all the prisms are, as has been stated, made to approach or recede from this axis, their backs thus becoming tangent to a larger or a smaller circle, and the adjustment can thus be varied as required for examining different parts of the spectrum.

Perhaps few of the observers, who now employ apparatus made on this principle, are aware that it was devised more than thirty years ago.

Rutherfurd lost no time in making this apparatus serviceable for photographic purposes, and in thus obtaining at an early date a magnificent representation of the solar spectrum, especially of the portion between the lines H and F, although it extended further. This exhibited three times as many lines as were shown on the map

*A. J. Sci., 39: 129.

of Bunsen and Kirchhoff, and was described in a communication which he presented to this Academy in January, 1864, when he exhibited impressions measuring 78.7 centimeters between the lines mentioned and 15 centimeters in width.

This brilliant achievement, which the older members of the Academy will remember, he neglected to put on printed record in due form. The National Academy was then in its infancy, and issued no series either of proceedings or of memoirs, and Mr. Rutherfurd himself was too much absorbed in the further prosecution of his researches to devote much of his time to narrating his own successes. The photograph spoke for itself and remained in existence, although it seems not to have been fully described in print until nearly two years later, when Müller published an account of it in Poggendorff's Annalen,* November, 1865. This disregard of public applause was characteristic of the man.

In this connection I may mention another very marked illustration of the same quality, afforded by his neglect to write out and publish his remarkable communication to the Academy at Northampton in August, 1866, in which he gave an oral account, in full detail, of the processes by which he had obtained the then wonderful photographs of stellar clusters, of the micrometer which he had constructed for measuring them, and of the measurements already obtained. The memoir by the present writer, containing the computation of the results, and read before the Academy on the same day, was naturally withheld from publication until Mr. Rutherfurd should have published his own paper describing the means and methods by which the data had been obtained. Rutherfurd's communication, was, however, never put in shape for the printer, and the other one remained unpublished for twenty-two years, after which interval it was printed from the original manuscript. Meanwhile the art of photography had been wonderfully developed and advanced and its application to stellar astronomy become a more common thing; although, to be sure, no other accurate measurements of relative positions thus determined had even then been made public. Indeed, but for a letter sent September 3, 1866, to the editor of the *Astronomische Nachrichten*, containing the resultant positions, relative to Alcyone, of the ten other brightest stars of the Pleiades and the incidental mention therein of Rutherfurd's

* 126, p. 435.

labors, no printed evidence would have existed of what he had then accomplished. Perhaps this may have been carrying his modesty somewhat too far.

The methods and their results attracted little notice from astronomers, and that little was chiefly in the way of general objections to numerical deductions from measurements of photographs. It was not until long afterward that it became generally conceded that, when employed with due precautions and under proper conditions, photography affords a mode of observation inestimably superior in convenience and certainly equal in accuracy to any measurements which could be made directly with the telescope. More detailed mention of the memoirs referred to and of the delay in their publication may be found in the Proceedings of the American Association for the Advancement of Science, at the Buffalo meeting, in 1886. It is not strange that these results should have been easily forgotten and ignored in foreign countries; yet it is sad, if not mortifying, that they should be overlooked by American writers on the subject at the present day.

To return, however, to the narrative of his photography of the spectrum, it was soon after the attainment of his results with the bisulphide prisms in 1863 that Rutherfurd became convinced of the possibility of obtaining yet better ones by the employment of a diffraction grating.

The best fine-ruled plates existing at that time were those made by Nobert at Greifswald, and largely employed for studying the phenomena of interference and determinations of wave-lengths. Rutherfurd determined to prepare some glass plates of this sort and adapt them to a spectrometer. Nobert had succeeded in ruling a few small groups of lines on glass as tests for microscopes* with about 296 lines to the millimeter—*i. e.*, at intervals of less than 3.4 microns—while for less severe test-objects intervals of eighteen microns sufficed; but his method of ruling these and the diffraction gratings was jealously guarded as a "trade secret;" so that Rutherfurd was compelled to devise and test his own methods, having, however, satisfied himself that Nobert's plates were not made by the aid of a screw, since their errors were not periodic, but quite irregular.

After numerous preliminary experiments he constructed a small

*Pogg. Ann., 1852, lxxxv, 80.

motor, with a little turbine impelled by the water from the city pipes, and fitted this up in his study in such way that its action should go on continuously, day and night, under sufficiently constant pressure. A diamond point traced parallel lines upon a glass plate pushed regularly forward by a system of levers acting on an acute glass wedge, this in its turn pushing the plate sideways. The gratings thus obtained were admirable, except that from time to time, after two or three hundred lines had been traced, some change would occur, producing a new series of lines with a slightly different interval. This he attributed at first to imperfect action of the pushing levers; but his friend, Professor Rood, who was deeply interested in the undertaking, prepared an optical-interference apparatus, by means of which it was discovered that the trouble was due to variations in the friction of the apparatus employed. This obstacle it was found impossible to remove; and in 1867 he constructed an elaborate ruling machine in which the plate was moved by a screw. Upon the construction of this he expended a very large amount of labor, and with it he made several beautiful gratings, although even these were not entirely to his satisfaction. The diamond points were made by a machine which he constructed for the purpose, and were conical; but they proved not to be durable, and he therefore substituted wedge-shaped edges, a form which he always used afterwards. By the study of the plates themselves he deduced the nature and amount of the periodic error of the screw and devised means for its correction. Thus, after the lapse of another year, all his difficulties with the machine, including those due to variations of temperature, had been overcome by patient and long-continued study of its products; and many gratings upon glass were ruled which gave no room for criticism, and left those of Nobert far behind. The toothed wheels for this machine he made himself, upon a dividing circle more than two feet in diameter, which he purchased but personally refitted. In Professor Rood's laboratory is an excellent grating on glass, with 255 lines to the millimeter, bearing the date 1870. In 1875, or earlier, he silvered the gratings with a view to their more convenient spectroscopic use, and Professor Rood has exquisite specimens of these, measuring about 16.4 millimeters by 24.5 millimeters and with 11161 lines at intervals of 680.4 to the millimeter.

Later still, similar gratings were made upon speculum metal, in order to avoid the great wear upon the diamond, and Mr. Chapman, his assistant, produced a large number of these.

The ruling machine was enlarged in 1877, so as to trace lines 43 millimeters long, and with this Mr. Chapman ruled several gratings of a quality which seems yet unsurpassed, although the best ones of Professor Rowland and Mr. Brashear contain a much larger number of lines. But they are now superseded for certain purposes by Professor Rowland's admirable device of five or six years later, according to which the gratings are ruled upon a concave surface.

With these gratings adjusted for spectroscopic use Rutherfurd obtained, from 1867 on, visual and photographic results for the study of both solar and stellar light, which commanded universal admiration and were not equaled until those of Draper * many years later.

But, important as were Rutherfurd's contributions to spectral analysis, these are entirely overshadowed by his epoch-making services in connection with celestial photography.

In his paper † of December, 1862, he had called attention to the peculiar adaptability of the spectroscope for investigating the achromatism of an object-glass and spoken of his intention to employ this device for determining the photographic focus of his telescope. The form of the spectrum from a star or any point of white light shows at once what colors are, and what are not, brought to a sharp focus; since in the one case it is simply a line, but in the other its width is expanded to that of the cone of rays where intercepted by the prism. Experimenting with the aid of this fact, he found that a good practical focus for the chief rays needed in celestial photography was attainable by separating the crown and flint lenses by such an interval that the focal length of the combination should be about one-twentieth shorter than that required for visual achromatism, and that, while such a separation of the lenses would be entirely unsuitable for vision, it would afford photographic impressions of a sharpness and nice definition which he had not succeeded in attaining otherwise. Still, since this naturally implied a mere compromise for convenience, by using lenses of such figure that part of the rays employed for either visual or photographic purposes must be sacrificed, he finally resolved to construct an object-glass

* A. J. Sci., xviii, 419.
† A. J. Sci., xxxv, 72.

adapted to photographic use only. This presented a very embarrassing problem, since the needful corrections for figure could not be determined by the judgment of the eye alone unless the more brilliant but less refrangible rays should be excluded. To attain this end his first essays were made by interposing colored solutions to absorb most of the undesirable rays. These, however, were found to obstruct too many of those rays which were required, and it thus became necessary to employ long and tedious photographic processes for determining the local corrections of the object glass for figure; yet these were considerably facilitated by using the spectroscopic method of examination for focus.

At last, toward the close of the year 1864, his patient labors were rewarded by the completion of a well-figured object-glass, constructed solely for photographic use. It had an aperture of 11¼ English inches, just equal to that of his existing achromatic, and was so mounted that either of the two could readily be substituted for the other in the same tube.

With this telescope, made by himself, with the younger Fitz as assistant, stars nearly, if not quite, as faint as the ninth magnitude were easily photographed by an exposure of three minutes, and beautiful impressions of the Pleiades and the Præsepe were obtained, showing in the former thirty-two stars and in the latter thirty-one; also another of the cluster in Perseus. On the evening of March 6, 1865, he made with it the exquisite photograph of the moon which is so well known and which long remained far superior in distinctness of definition to any others existing. Not until Draper had constructed and employed his 28-inch reflector was it equaled. The sharpness of the images is shown by his account published in the American Journal of Science* of May, 1865:

"Since the completion of the photographic objective but one night has occurred (March 6) with a fine atmosphere, and on that occasion the instrument was occupied with the moon, so that as yet I have not tested its powers upon the close double stars, 2″ being the nearest pair it has been tried upon. This distance is quite manageable provided the stars are of nearly equal magnitude. The power to obtain images of the ninth-magnitude stars with so moderate an aperture promises to develop and increase the application of photography to the mapping of the sidereal heavens and in some measure to realize the hopes which have so long been deferred and disappointed.

* xxxix, 308.

"It would not be difficult to arrange a camera-box capable of exposing a surface sufficient to obtain a map of two degrees square, and with instruments of large aperture we may hope to reach much smaller stars than I have yet taken. There is also every probability that the chemistry of photography will be very much improved and more sensitive methods devised."

In this connection it will, of course, be remembered that the dry plate and bromogelatine processes were not introduced until fourteen or fifteen years later; so that, not to speak of the far greater sensitiveness of these later plates, the removal of the limitation to the period of exposure, imposed by the condition that their moisture should not evaporate, makes comparisons between present results and those earlier ones almost absurd. At the time of Rutherfurd's experiments the duration of an exposure was restricted to three or four minutes in such states of the atmosphere as usually prevailed when the sky permitted good photographic work, especially in our relatively dry climate. The present custom of celestial photographers, who continue the exposures for a single impression through a series of nights, and these not necessarily consecutive, would have seemed as incredible as the telephone or the kinetoscope.

Beside a very large number of photographs of the sun and moon, many of them during eclipse, Rutherfurd took during the years 1865 and 1866 twenty-five impressions of the Pleiades, five of the Præsepe, six of the great cluster in Orion, and several of double and multiple stars, all with trails for determining the zero of position-angle.

But the mere attainment of these admirable impressions really accomplished no more for astronomical science than the preservation in permanent form of the configurations which a small telescope would exhibit to the eye. No one was more fully aware of this than the gifted and ingenious physicist whose devices and mechanical skill had secured the photographic records. To give them their scientific value they must be measured upon the plates with a careful accuracy analogous to that employed in delicate micrometric measurements in the telescope. This was his next task.

The special obstacles to be encountered in effecting these measurements were, of course, to be discovered by experiment, and for this purpose Rutherfurd planned and constructed, chiefly in his own workshop, a micrometric apparatus so arranged as to permit the measurements to be made in various ways. It was designed on the principle of the slide-rest of a lathe, a vertical microscope being carried over the photographic plate by either of two micrometer screws at right angles to each other, while the plate rested near the center of a graduated horizontal circle, which could be rotated within a concentric and fixed one, provided with verniers. Of course, no pains were spared in the micrometer-screws, which were made by himself, being about 12.5 millimeters in diameter and 159 millimeters long. Thus the apparatus permitted determinations of the relative positions of stellar images, using either rectangular or polar coordinates.

In all his photographs of stars special precautions were taken to secure round images, and, so soon as the micrometer had been finished, Rutherfurd proceeded at once to train assistants in the use of the apparatus, and with their aid to begin the measurement of the plates in his own house.

Early in February, 1866, Doctor Gibbs had written to me of the completion of this micrometer and of the numerical results which Mr. Rutherfurd was deducing from the measures. On the fifth of that month I wrote to the latter, expressing my congratulations and assuring him of the high pleasure it would afford me to do what I could in computing his measured values and comparing them with determinations made by the ordinary methods. In reply he cordially invited me to undertake the work. Various plans for reducing the measured quantities to ordinary astronomical units and standards of reference were promptly arranged by correspondence; and at the beginning of March I visited him in New York and had the gratification of studying the various processes by which he had attained such brilliant success. It is needless to say how much I was impressed and instructed, and to what extent they kindled my enthusiasm. Mr. Rutherfurd placed in my hands a considerable number of measured angles and distances, and on returning to Cambridge I began the various trial computations without delay. The data were, if I am not mistaken, measurements of impressions of the Pleiades, taken February 21 and 26; but immediately after the methods of computation had been decided upon Mr. Rutherfurd sent additional series of measures of the same group from three plates of March 10, taken with exposures of four minutes, one minute, and twenty seconds and containing respectively thirty-seven, twenty-two, and fifteen stars, as well as excellent trails. These plates he believed to be somewhat better than the previous ones, and not only were the images better, but more especially had longer practice given increased skill to the young women to whom most of the measuring was intrusted. The computations were continued and their results studied during the spring and early summer, and were essentially finished in July.

At the Northampton session of the Academy in 1866 Mr. Rutherfurd gave, on August 11, a detailed oral description of the methods and processes, telescopic and photographic, by which his impressions of stellar clusters had been obtained and of the micrometer with which he had measured them. On the same day it was my privilege to present a memoir containing the resultant determinations of the positions of the stars of the Pleiades, relative to *Alcyone*, which had been taken as center of reference.

Some allusion to these memoirs and to the history of their delayed publication has already been made, as also mention of the fact that the results for ten of the brightest stars of the group, besides Alcyone, were sent three weeks later to the *Astronomische Nachrichten* and there published in December, although without the details of computation.

The work thus begun was actively prosecuted by Mr. Rutherfurd, who continued to secure celestial photographs and measurements of the impressions; but his improvements in the methods were also unremitting. Within the next two years he had devised and constructed the photographic corrector. He replaced his 11¼-inch achromatic by an object glass of 13 inches aperture, and adapted to this an exterior lens which could be readily applied so that the combination should serve for the chemically active rays. This obviated all necessity for removing the achromatic objective when the instrument was to be used for photography; while the facility with which it was attached permitted the telescope and mounting to be employed for visual or for photographic purposes at will. Only a change of the counterpoises was requisite when the corrector was put on and the camera substituted for the draw-tube. This new instrument he completed in 1868, the whole work having been done in his own house; and soon afterward important modifications were introduced in the construction of the micrometer.* The measuring screw was transferred to the microscope, and a fixed glass scale was added, having divisions corresponding to ten revolutions,

* A. J. Sci., xii, 112.

so that the mechanical wear of the long micrometer screw became indifferent. This was first employed in March, 1871.

Thus the work of photographing and measuring was prosecuted until the year 1877, when failing health compelled him to desist. His physical constitution had for some time been delicate, and his scientific work, both intellectual and mechanical, was carried on in the face of serious obstacles. Moreover, frequent journeys on both sides of the Atlantic had been found necessary. Yet when he made to the observatory of Columbia College the princely gift of his apparatus, telescope, and collection of photograph plates, there were, among these last, 638 of stellar clusters, double and multiple stars, of which 190 had been elaborately measured; also a yet larger number of the sun, moon, and planets, and 174 of the solar spectrum.

It has been stated that the new method of observation was by no means enthusiastically received by astronomers. Most of them paid it no attention; others feared distortion of the relative positions of the stars as photographed, while others still distrusted the adequacy of the corrections to be applied; but the most serious criticism was based upon the supposed liability of the film to contract or expand, thus introducing new sources of error. Mr. Rutherfurd had carefully guarded against this danger by thoroughly albuminizing all his plates before applying the sensitive collodion, and had convinced himself by numerous and varied experiments that this danger was assuredly not a serious one; but, in the spring of 1872, a German astronomer, discussing the proposition to employ photography for observation of the transit of Venus—for noting which phenomenon preparations were then making in all astronomical countries—gave expression to strong distrust of the accuracy attainable by measurement of photographic plates. He gave, as results* of *his own experiments, shrinkages of the films to a great extent* by varying and irregular amounts and in different directions.

In an elaborate and very courteous article, published in the American Journal of Science on the 1st of December of the same year, Mr. Rutherfurd thoroughly disposed of these strictures. In addition to pointing our the probable explanation of the critic's results, he gave the results of his own experiments and measures with albuminized plates. He compared measures made when the

*A. N., No. 1884, lxxix, 188.

plates were taken from the camera, while they were still wet, with others made after they had become dry. He used negative impressions of dark lines on a white ground and of bright lines on a dark ground, some from which most of the collodion outside the lines had been removed while yet wet to facilitate shrinkage inward, and some from which most of that between the lines had been similarly removed to facilitate shrinkage outward, care being taken to insure that the same parts of the screw should be used in the measurements to be compared. The results fully justified Rutherfurd's confidence and corroborated his previous experience. He recognized a probable slight contraction of the glass plates, due to a cooling by evaporation as they dried; but he also showed how completely this could be allowed for by means of hygrometric observations.

In this connection I may be permitted to add a word as to my own personal experience. Having devoted much time during very many years to the study of a large number of stellar photographs and to the numerical values deduced from them, I cannot recall a single instance in which there has been reason to believe in any distortion of the film upon carefully albuminized plates. The employment of the much easier and more effective dry-plate processes of today makes the albuminization of the glass beneath the sensitive film more inconvenient than when the earlier wet plates were used, and as to the certainty of an unchanging record upon the bromogelatine film I feel less warranted in expressing a definite opinion. Two-thirds of my stellar photographs have been upon albuminized plates and by the wet process, and I have never found ground for doubt of the correctness of Mr. Rutherfurd's opinion concerning these.

Rutherfurd's latest scientific paper seems to have been a short one, dated June, 1876, and entitled, "A Glass Circle for the Measurement of Angles." After alluding to a communication which he had made to the Academy in April, 1870, describing the changes which he intended to make in the micrometer, and which have just been mentioned, and after reporting the great satisfaction which these modifications had afforded him, he stated that the success of the divided glass scale had confirmed him in a resolve of long standing, to try the experiment of substituting a glass circle for a metallic one in measuring angles with precision. He had owned a small spectrometer by Brunner furnished with a circle divided upon silver and permitting readings to ten seconds by means of verniers. Of this he says:

"The diameter of the circle is small, not quite seven inches, and the inability to read smaller angles [than ten seconds] has always been its weak point. I have substituted for this metallic circle one of glass about ten inches in diameter, divided by Mr. Stackpole to ten minutes of arc and read by two micrometer-microscopes, magnifying seventy-five times, each revolution of the screw being equivalent to one minute, the drums being divided into sixty parts, read to seconds with easy estimate of fractions. Each degree line is numbered so as to be visible in the field of the microscope. I was able to furnish to Mr. Stackpole a well-tried diamond, which has made lines of the greatest delicacy, being much finer, as seen in the microscopes, than the spider lines by means of which the bisections were made. The advantages of this system are obvious, viz., perfection of surface, permitting a line of any desired fineness; facility of illumination, permitting an extension of the power of the reading microscopes to several hundred times; smallness of dimensions and consequent cheapness and avoidance of almost all the questions of flexure and local effects of temperature.

"I am convinced from the ease with which one second is read on my instrument, with microscopes only 4¾ inches long, including objectives and eye-pieces, that upon a circle of fifteen inches, provided with powerful microscopes, greater precision could be attained in the reading of angles than with the largest metallic circles now in use."

He appends four series of measurements of lines upon this circle, two made by himself and two by a lady assistant. They show the mean error of a single reading to have been so large as 0″.332 for only one of the series of ten observations, those for the other three series having been respectively 0″.154, 0″.270, and 0″.286.

This important and striking suggestion does not seem to have ever been followed up by other observers, but I entertain small doubt that the time for this will yet come.

During the later years of Mr. Rutherfurd's life the maladies which had undermined his strength and precluded the activity requisite for experiments or continuous effort became more oppressive. Soon after passing the age of three score years he found himself compelled to discontinue his scientific activity and devote himself to the care of his health and that of his family. It became imperative that his winters should be passed in warmer climates than that of New York, so that his residence during much of the year was in Florida, and he made protracted visits to southern Europe.

Yet he did not entirely abandon his celestial photography. In the list of plates given by him to Columbia College, as published by Professor Rees, there are twenty-three photographs of star-groups and six of the moon, taken in the early months of 1877, and twenty-five of Mars and neighboring stars, taken on five nights in August and September of that year. The latest of all were twelve impressions of the transit of Mercury, 1878 May 6. The bromogelatine process did not then exist.

Soon afterwards his observatory was dismantled, and the places where his study, workshop, and laboratory had been, and whence so many contributions to science and refined mechanical art had been given to the world, were surrendered to the demands of the huge and increasing city. As early as 1866 he had told me that the site of his uncle's orchard and grounds, where as a boy he used to play and roam at will, was already occupied by a population of at least 200,000 inhabitants. Even at the date when he mentioned this, his residence remained there, although the field of view for his telescope had become sadly limited. The tremors of the great city interfered with delicate experiments, and the atmosphere was seldom pure and transparent. Before the year 1880 the place had ceased to be a home of science and the abode of happy domestic life.

After this date a large portion of the limited time in which it was not imperative for him to reside in milder climates was passed by him at the rural estate, in northwestern New Jersey, to which his ancestors had given the appropriate name of Tranquillity, and to which he was strongly attached; but his physical strength waned steadily, and he became resigned to the sad consciousness that his scientific life was ended. In 1884 he presented to the observatory of Columbia College the 13¼-inch telescope, with its accompanying corrector, which he had employed since 1868, and the improved micrometer used since the beginning of 1872. A few years later he completed the gift by adding the full collection of his photographic plates and the records of the measures made, all in perfect order and with the data needful for their proper computation. The total number of plates was 1456, of which 638 were stellar impressions, as has been already mentioned. A detailed catalogue of these was published in March, 1891, by Professor Rees, director of the observatory, who has stated that the measured values accompanying them fill some twenty folio volumes of two hundred pages each.

With the plates and apparatus Mr. Rutherfurd furthermore made a liberal provision for continuing the work of measurement.

It would be needless to say that a brave and gentle spirit, like his, supported with patient calmness the manifest progress of disease and constant decay of strength, accompanied too by the domestic afflictions which few who reach old age can hope to escape. Of all these he had his full share, but they did not impair the serenity of his disposition or his never-failing kindliness. The end of his sufferings came on the 30th of May, 1892, at Tranquillity, and just in the middle of his seventy-sixth year.

Such a man could not but exert a strong influence in the community, apart from that due to lineage and social position; and such influence was assuredly his, notwithstanding that he avoided public station and whatever savored of display. In 1863 he was appointed by Congress to be one of the fifty original members of this Academy. For 26 years he held the place of trustee of Columbia College, which institution conferred on him the honorary degree of Doctor of Laws. As a member of this board he was eminent for laborious and self-forgetful activity, and I am assured by competent authority that he was second to none in influence upon the guidance of the institution.

I will not attempt any minute analysis of the mental characteristics of our late colleague; for the simple narrative of what he accomplished makes such endeavor superfluous. An exceptional inventive power and boldness of device were combined in him with rare mechanical skill and the accuracy of an accomplished physicist, none the less well trained that the training was his own. His name will stand recorded as that of not only the pioneer, but the leader in more than one branch of what has become the department of astrophysics. He must be recognized as the father of celestial photography, and in spite of the cold indifference with which his first achievements were regarded by most astronomers, he kept steadily to his mission with an unostentatious disregard of obstacles until he saw it crowned with full success. Meanwhile his modesty withheld him from claiming the honors which the historian of astronomy must assign to him, and not until after his scientific career was accomplished did a new generation, for whose labors he had furnished much of the means, carry on the researches. Many for whom greatly increased facilities have been afforded by later progress, but whose acquaintance with the history of their science during the third quarter of our century is not commensurate with their attainments, seem to have forgotten that they were not themselves the pioneers but only followers. It will be remembered that Rutherfurd's last photograph of a star-cluster was made in the early part of 1877; that his proposition of a photographic map of the heavens was in May, 1865, and coupled with a prediction of great advances in photographic chemistry. It was not until 1879 and 1880 that the processes were introduced which are employed at present and which so inordinately facilitate the practice of celestial photography.

Of our colleague's moral qualities I hesitate to speak as I am impelled to do, lest the words should have an aspect of exaggeration. Soundness and soberness of judgment in the various relations of daily life, no less than in scientific matters, freedom from the bias of prejudice, conscientious discretion, generous recognition of merit in others, and a rare unselfishness, were prominent traits in his character. While doubtless appreciating the importance of the results which he had attained by long struggles against unforeseen impediments and through persistent toil, he never seemed either to overvalue them or to see them in their wrong relations. He never lost sight of the fact that much of his work was dedicated to securing means for research, and that means are but the steps toward ends. The micrometers, by which accurate numerical data should be deduced from the impressions on the plates, were quite as earnestly the subject of his study and experiment as was the attainment of trustworthy impressions themselves; nor were the device and construction of the micrometers allowed to distract his attention from their purpose of obtaining accurate data for astronomical research. Even after he had been compelled to desist from other scientific work he caused the measurements to be assiduously prosecuted under his own supervision, and to the last day of his life he provided for the continuance of these measures.

His nature was tender, sympathetic, and generous in the extreme. To assist others who labored in the fields he loved, always seemed to afford him especial delight. In his few scientific controversies he never forgot the courtesy of a gentleman, nor failed either freely to concede what he could not maintain with full conviction or to maintain his ground with courageous frankness. Although modesty and dignified caution always prevented him from hastening the public announcement of his results before they had been carefully tested and were evidently mature for publication, there was no jealous secretiveness in his nature, nor any reluctance to mention with perfect freedom the conclusions to which his researches seemed to be leading.

Such a man not only conferred honor upon our country and upon this Academy, but has left them a heritage—better even than honor—in the wide paths of usefulness he opened, in the incentive of his example, and in the memory of the dignified, unpretending modesty which manifested the unselfishness and sincerity of his scientific aims. His name will live in the annals of his science; but this will be solely by reason of his deserts and not through the heralds of the market-place.