MEMOIR

OF

WILLIAM AUGUSTUS ROGERS.

1832-1898.

BY

EDWARD W. MORLEY.

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BIOGRAPHICAL MEMOIR OF WILLIAM AUGUSTUS ROGERS.

William Augustus Rogers was born in 1832, at Waterford, a small village near New London, Connecticut. His father was David Potter Rogers (1808–1882), who in 1830 married Mary Ann Rogers (1808–1892). He was master of a fishing vessel and afterward a farmer. It is said of him that he was the first in his district to use a chain cable for the anchor of his vessel, in spite of predictions of disaster. David Rogers traced his descent from James Rogers, born in England in 1615, who came to this country in 1635 and died here in 1688. He made his home in Stratford, Connecticut, and married Elizabeth, daughter of Samuel Rowland; he lived afterward in Milford, and in 1656 or 1657 he removed to New London, in the same State. James Rogers was a descendant of the John Rogers who was one of the compilers of the first authorized English Bible, and who was burned at Smithfield, under Queen Mary, in 1555. He brought to this country a Bible, which is still preserved in the library of Alfred University, which, it is claimed, is the Bible used by John Rogers, the ancestor just named.

Professor Rogers had two sisters, both younger than himself. Julia Maria survived him a short time; Cynthia died in 1843. In 1857 he married Rebecca Jane Titsworth, third child of Isaac D. Titsworth. She was the only daughter in a family of eight children. The family lived at Shiloh, New Jersey, and afterward at Dunellen, in the same State. The marriage was a fortunate one, Mrs. Rogers being the possessor of a fine appearance, great strength of character, a pleasant temperament, and sound, good sense. She has been somewhat concerned in the management of the weekly newspaper which is the organ of the religious denomination to which they belonged. Under the supervision of Dr. Rogers, she has done much of the computation required in reducing his astronomical observations and in preparing them for the press. They have had three sons, of whom two are living.

Frederick Tuthill Rogers was born in 1859, received the degree of bachelor of arts from Union College in 1880, that of doctor of medicine from the University of the City of New York in 1882, and is now established in practice in Providence, Rhode Island. Allerton Titsworth Rogers was born in 1863 and died in 1864. During his whole life his father was absent. Arthur Kenyon Rogers was born in 1868, received his baccalaureate degree from Colby University in 1890, and that of doctor of philosophy from the University of Chicago in 1899. It may be worth noting that a book on the higher criticism of the New Testament, which he wrote partly while an undergraduate and partly in the first year after his graduation from Colby University, was so well conceived and written as to have been issued from the press of a leading publisher in New York.

William Augustus Rogers began his studies in 1846 in De Ruyter Institute, at De Ruyter, New York, and prepared for college at Alfred Academy, in the same State. After teaching in a school in New Market, New Jersey, he entered the freshman class of Brown University in February, 1854. He taught in Union Academy at Shiloh, New Jersey, during the academic year 1854–1855, and was graduated with the degree of master of arts with his class in 1857. After this date Brown University conformed to the practice of other American colleges by giving not the degree of master of arts, but that of bachelor of arts after four years of undergraduate study. That he was a good scholar was certified by his election to membership in the Phi Beta Kappa society.

Immediately after taking his degree he was appointed instructor in mathematics at Alfred Academy; in 1859 he became professor of mathematics in Alfred University. He was absent for a year as a special student of astronomy in the Observatory of Harvard College, and afterward was a student and assistant in the same observatory for six months. He entered the navy in 1864, serving for fourteen months, or to the close of the war. In 1865 he built Alfred Observatory and equipped it with a clock, a chronograph, a nine-inch equatorial, and some other instruments. In 1866 he was made professor of industrial mechanics, as well as of mathematics, and, soon after, he spent nearly a year in the study of theoretical and applied mechanics at Sheffield Scientific School.

In 1870 he resigned the professorship at Alfred and was appointed assistant in the Observatory of Harvard College; in 1877 he was made assistant professor of astronomy in the observatory. In 1886 he resigned this position and became professor of physics and astronomy in Colby University, at Waterville, Maine. In 1889 he built the Shannon Physical Laboratory on the campus of Colby University. This building had special features making it better adapted to the comparison of standards of length than any other laboratory in the country. The equal-temperature room on its first floor was especially noteworthy.

The professorship of physics and astronomy at Colby University was held by Dr. Rogers at the time of his death; his resignation would have taken effect if he had lived another month, and he would then have become professor of physics at Alfred University. A physical laboratory had been built there under his supervision, and Dr. Rogers had donated for its equipment most of the apparatus which he had accumulated during his career, to the estimated value of ten thousand dollars.

Dr. Rogers' earlier papers treated of astronomical matters; mention of his astronomical work does not fall within the scope of this memorial. Before 1870 his opportunities for research were slender, but after that time his publications were frequent. When seven or eight astronomical papers had appeared he read his first paper on a physical subject, and, after this, his thoughts were drawn more and more to the consideration of physical problems. It is interesting to note that these problems were nearly all developments from this first physical paper.

It tells how he sought unsuccessfully for spider lines suitable for the meridian circle of the Observatory of Harvard College. He then attempted the production of lines of the desired quality and size by ruling them on glass. After some trouble and study of conditions, this was accomplished by etching the glass with hydrofluoric acid. He attained such skill in producing lines of suitable quality that he was employed to furnish expeditions, sent out from this country to observe the transit of Venus in 1882, with the ruled plates needed for certain photographic observations.

In supplying this practical want, Rogers became interested in a mechanical problem to which he gave all the spare time of three years, and which drew in its train nearly all the labors of the rest of his life. Nobert's well-known test-plates exhibit lines of great delicacy, uniformity, and distinctness. Rogers desired to learn the nature of the manipulation employed, and to attain some degree of skill in it. The solution of the problem consists of two parts: First, of the operation of moving the plate over given equal spaces; and, secondly, of the production on it of lines of various degrees of fineness. He constructed a machine in which a screw of eight inches in length could move a plate-carrier on parallel ways. Rogers did not provide the head of this screw with the teeth of a ratchet in order to turn the screw by small equal fractions of a revolution, since the spaces moved over would, in case a ratchet wheel were employed, be limited to the possible combinations of the number of teeth originally cut, and would also be affected with the errors of the gear-cutter used. He accordingly invented his magnetic clamp, in which the head of the screw is cylindrical, and is carried forward by a pivoted arm, to which it held fast during motion in one direction, while it is released during the motion of the arm in the reverse direction. When this screw and its mounting were completed, he studied the periodic errors of the screw. By a great expenditure of time and patience, these errors were made very small. Then came a long study of the form and position to be given the ruling diamond. He made a machine for grinding diamond points, and succeeded in making good cutting edges, both of Brazilian diamonds and of the so-called black diamonds, the latter giving the better results. Grinding a black diamond to a cutting edge took from five to ten days. With this ruling machine Rogers ruled plates showing fine lines like those of Nobert's test-plates. Up to eighty thousand lines to the inch, the lines could be well and accurately counted. The lines from eighty thousand to one hundred and twenty thousand to the inch were nearly as distinct as those of Nobert, but scarcely so smooth and uniform.

The skill in ruling which Rogers attained in this study he did not utilize in making fine rulings to be used as test-objects for the microscope. He thought it better to confine his attention to another most important problem. This problem consisted of three parts: First, to obtain authoritative copies of the imperial yard and of the meter *des Archives* at the temperatures at which they are standard, and to subdivide them into aliquot parts and obtain accurate micrometric standards; secondly, to compare the yard and the meter so as to obtain their ratio with increased precision; and, thirdly, to produce accurately spaced diffraction gratings the distance of whose lines should be accurately determined.

For the construction of diffraction gratings and of micrometric standards, Rogers constructed a second ruling machine, on a design much like that of the first machine, but with certain improvements. This was made at the works of the American Watch Company, at Waltham, Massachusetts. At first, a screw of four inches in working length was made; this screw did not effect any improvement in the performances of gratings ruled with it. This failure was thought to be due to the vibrations to which the machine was subjected, during its construction, by its position in a large factory, and a longer screw was attempted. A screw of half a meter in length was finally made by the artifice of cutting threads an inch and three-quarters long upon ferrules, using always the same part of the master screw, and then placing these on a cylindrical shaft so as to form a continuous screw of the desired length. Whitworth abandoned this method, but Ballou, who made the screw for this machine, seems to have overcome some of the difficulties which Whitworth met, and the screw was found to be practically perfect for a working length of twenty inches. With this apparatus Rogers ruled micrometric standards and test-plates with great accuracy. For such uses, where the lines needed were short, the machine was practically perfect. When it was used to rule the long lines needed on diffraction gratings, a difficulty was encountered, due to the fact that the motions of the ruling diamond in cutting the line and of the screw in making the forward motion overlapped each other. Some little reconstruction of details would perhaps have removed the difficulty; but, before any attempt was made to do this, Rowland's success with his apparatus for ruling diffraction gratings led Rogers to limit his aims to the other parts of his original problem.

The magnetic clamp which Rogers invented for use in his ruling engine was afterward utilized for other purposes, especially in constructing dividing engines for straight lines and for circles. He exhibited a dividing engine for circles at Chicago in 1894, and furnished others to various physical laboratories. He described one for straight lines in an article which he wrote for Johnson's Cyclopedia on ruling machines.

At some time before 1878 Rogers had begun an investigation which was important, both in its character and results, and also in the amount and kind of labor required for its successful completion. The relation between the yard and the meter had been determined by Kater, Baily, Clarke, Chisholm, and Hassler; but in all their observations copies of the yard had been compared with copies of the meter, and the errors of the copies were not sufficiently well known. The uncertainty in the determination of the relation could scarcely be deemed less than the one-thousandth part of an inch, and Rogers desired to make a comparison which should be much more accurate. The experience gained in his studies of micrometric standards had well fitted him for the work. Such a labor called for the possession of authoritative copies of the imperial yard and of the prototype meter. The Rumford committee of the American Academy of Arts and Sciences was interested in a plan for "obtaining authoritative copies of the revised original standards of the French meter and kilogramme." Partly in the interests of this committee, Rogers visited London and Paris. He took with him, for comparison with the imperial yard, a steel yard, and for comparison with the meter, a meter traced upon a bar of pure silver inlaid with laminæ of gold and of platinum. Through the kindness of Mr. Chaney, the warden of the English national standards, Rogers secured comparisons of his steel yard with the imperial yard at temperatures ranging from 50° to 68° F. At Paris Professor Tresca was engaged in the operation of constructing prototype meters, and Rogers was therefore unable to obtain comparisons of his silver bar with the meter *des Archives;* but Tresca did him good service by presenting him with a meter traced on platinum surfaces inlaid in a bar of pure copper of the same form as the platinum prototypes. On the 4th of February, 1880, this bar was placed on the comparer, with the working standard of the Conservatoire. At two o'clock in the morning of February 6 the transfer was made by Tresca, and the comparison of this with the working line meter of the Conservatoire was at once commenced by Tresca and Rogers, and continued through the following day and night.

Rogers now hoped that he was prepared to compare the yard and the meter, but it was soon found that the copper meter and the steel yard were not to be easily compared, and he therefore constructed a brass yard of the same shape, size, and weight as the imperial standard. This was compared with his own steel standard, and also with the standard of the United States Coast and Geodetic Survey. It may be said that, while the comparisons just mentioned were the basis of Rogers' earlier work in metrology, he afterward took occasion to fortify his values by many other comparisons and cross-comparisons, which need not be further described.

In the work thus begun an immense number of comparisons of length were required. For such comparisons two methods are available: In one, two micrometers are placed at a fixed distance; in the other, one micrometer is moved over a fixed distance. In the first method, two micrometers being fixed at a proper distance, one of the lengths to be compared is placed under them, and then the other; but this method cannot be applied to lengths less than the diameter of the micrometer and its mounting. For such lengths a micrometer moving between two stops may be employed. The stops are so adjusted that the space described by the micrometer between its two limits is equal to the length to be compared. One bar is then placed so that the two positions of the micrometer coincide with the two ends of the bar; the other is treated in the same way, and the comparison has been accomplished. By this method one apparatus and one homogeneous system of measurement serve for a length of a yard or meter, and also for all its subdivisions. Rogers preferred the second method, and constructed a comparer for lengths up to one meter. For ease of working it is necessary that the motion of the micrometer shall be very nearly in a straight line. In the first instrument made the ways on which the micrometer moved were not very different from those of a lathe bed. After some experience with this, a second was made, in which great pains were taken to meet the requirement just stated. Ways like those of a lathe, if carefully planed on a good and well adjusted planer, carefully examined and corrected locally, and so designed as not to suffer subsequent distortion, may be made to do excellent service; but a cylinder can be made straight, even with imperfect tools, and Rogers next constructed a comparer in which the carriage of the micrometer moved on two cylinders made with the greatest care and supported so as to eliminate their flexure. This comparer was called the Rogers-Bond comparer, Mr. Bond being the mechanical engineer who carried out the design of Mr. Rogers, while Pratt and Whitney constructed the machine. It was an instrument designed to do the best possible work, without regard to expense. Rogers afterward designed a much cheaper apparatus, intended to be used not only in refined investigations like his own, but also in ordinary and commercial operations in a machine shop, and much of his later work in metrology was accomplished on such modified forms of apparatus. The modifications involved that the apparatus should be finally adjusted by accurate local corrections for errors of its ways.

A room for the first comparer was inclosed in the basement of the Observatory of Harvard College and for the second in Harvard Hall. Soon after he removed to Colby University a new comparing-room was constructed in the physical laboratory erected for him, and this room was the most complete and convenient which had at that time been designed.

In these comparing-rooms and on these comparers Rogers made repeated comparisons of the yard and the meter. The method employed was elegant. A yard with convenient subdivisions and also a meter with convenient subdivisions were ruled on the same bar of metal. The error of this yard and the error of this meter were then determined by comparisons with his authoritative standards. Next, the errors of the subdivisions were determined by proper measurements. This is no small labor. When it had been accomplished it was possible to read off the length of the meter in inches and their fractions and also to read off the length of the yard in fractions of the meter. In this last operation the disturbing effects of changes of temperature were reduced to a minimum; the yard and the meter were both on the same bar at the same temperature, with the same temperature coefficient.

In the determination of a length nominally equal to a yard or a meter the effect of changes of temperature is of the greatest importance, and the means of eliminating it are difficult and tedious. Rogers was therefore compelled to make a most careful and laborious study of certain problems of thermometry. Having given a thermometer whose readings will determine the temperature of its own bulb to a hundredth of a degree, he had to learn in what conditions and with what degree of approximation this instrument will determine the temperature of another mass, such as a standard measure of length. If the thermometer and the measure of length could both be contained in a sufficient mass of liquid protected from evaporation, the temperature of the thermometer would determine the temperature of the measure of length. If the upper surface of the liquid is exposed to evaporation the upper layers of the liquid are not at the same temperature as lower layers, and Rogers determined the amount of this difference in certain conditions. Standards of length can seldom be employed while immersed in liquids, and Rogers abandoned attempts to immerse them for the sake of knowing more precisely their temperature, preferring to use his bars in his comparisons much as they would be used in ordinary measurements, the bar being surrounded only with air and the thermometers being placed in contact with it. How to observe so that the temperature of the bar could be determined from the temperature of the thermometer, Rogers learned thoroughly by an immense number of well-ordered series of observations. Commonly such observations involved the comparison of two bars, equal in length, but different in coefficient of expansion or in mass, or in form of cross-section, and at temperatures as widely different as could be secured. He made a long series of such comparisons in the open air during the coldest weather of a winter in Maine. Sometimes he read a great number of thermometers to determine a given temperature. He made some twenty-two thousand readings of thirty thermometers for such a purpose. These experiments gave him a manipulative command of the matter which few other men have attained, even if some of his minor conclusions on some points needed revision.

Rogers announced values obtained for the relation of the yard and the meter as early as the summer of 1880, and described further experiments at many times during the next fifteen years. It is not too much to say that his results reduced the uncertainty in the relation of the two standards to less than the fourth part of what it had been before, and that any important advance beyond the accuracy which he obtained has required the organization, the instrumental appliances, and the access to original standards which belong not to a single individual, but to a great institution, a government office, or an international bureau.

During the progress of the work just mentioned Rogers rendered many services to institutions, to societies, and to individuals. He was, for instance, a member of a national committee appointed by the coöperation of some fifteen societies, to prepare an authoritative centimeter with subdivisions, to serve as a standard for the preparation and the verification of micrometric scales. For this committee he made an elaborate report, founded on a multitude of observations, establishing the total length, and the values of the subdivisions, of the centimeter procured by the committee. He made standard bars, meters, or yards for Harvard, and Yale, and Columbia, and Princeton, and the Lick Observatory, and the United States Signal Service, and for various other institutions. These were more authoritative than could easily be secured elsewhere at the time when these were furnished. He prepared a combined yard and meter on the same bar for the Department of Standards of the British Board of Trade, to be used in an official investigation of the relation of the yard and the meter. He published an investigation of the standards of length furnished by the Société Génevoise. He made an elaborate determination of the length of eight of Rowland's gratings. He made an exhaustive report upon the standards of length used by Pratt and Whitney in their system of gauges. He superintended the construction of copies of many of the forms of apparatus used in his own investigations, which instruments are now in use in physical laboratories in this country and in Canada. He designed comparers capable of high precision, but cheap enough to be used as tools in the machine shop. Some of these could compare lengths even as great as one hundred inches, and some were small enough to be used on the workman's bench. He had a veritable passion for the utmost precision in measurement, a keen eye for opportunities for its advantageous use, the most unwearied and indomitable patience and perseverance, and clear insight into sources of error and means of avoiding it.

In all metrological studies the determinations of coefficients of expansions occupies a large place. Rogers' mind was full of this part of the subject, and when a new method of determining such coefficients was once explained in his presence he was eager to carry the suggestion into practice. The method involved the comparison by interferential methods of the length of a bar whose temperature varied from that of ice to that of steam with that of another bar which was kept in ice. He first constructed an apparatus for a preliminary trial in which the bars were not inclosed in the apparatus designed to keep them at a constant temperature, and in which only the optical principles of the method were to be tested. The result being satisfactory, he began the more difficult task of constructing an apparatus in which the same optical apparatus should be inclosed in an air-tight case, capable of being surrounded with ice, water, or steam. The requirement that the apparatus should be air-tight taxed severely the resources at hand and caused much delay. But such enthusiasm and energy as Rogers possessed finally triumphed; and one of the last important papers on any physical subject which he published contained a determination of the coefficient of expansion of a bar of Jessop's steel which he had carried out on the new apparatus. He had expected to do a great amount of work with this apparatus, and had spared no expense to adapt it to the intended labors.

When Roentgen's discovery was made public Rogers was one of those who interested themselves in the new field. He devised improvements in influence machines adapted to produce the so-called X-rays.

His experience in the construction of several ruling or dividing machines led him to take much interest in the problem of making a perfect screw. Before the American Society of Mechanical Engineers he read more than one paper on this subject. At the Waterville machine shop he constructed a large lathe screw which was practically perfect—that is, the screw acting with its correction plate would cut threads of the same pitch with very minute errors. On this lathe he constructed many precision screws, such as, for instance, those on the apparatus which he made for the measurement of photographs of stars at the Observatory of Harvard University.

Rogers was a hard-working man, a man of untiring activity. Nothing daunted his courage; difficulties which might well have made many a man down-hearted did not make him pause an instant. His chief pleasure was found in his work, but he enjoyed a game of tennis, which he played well. He greatly enjoyed a village game of base-ball, such as a game of stout men against thin men. Such a game he would play with enthusiasm, enjoying it thoroughly and contributing in a manly way to the enjoyment of others. He was unassuming, kindly, considerate in his intercourse with others; and also perfectly frank and outspoken. He was very conscientious, faithful to his convictions; and also genial. He would sometimes adhere to a point in the face of everybody, and then quietly submit when he was overruled. He was lion-hearted; he feared nothing and nobody. In Waterville he belonged to a civic league, of which he was an officer, and he went through the city presenting for signature a petition in favor of the enforcement of the so-called Maine liquor law by the local authorities. He enjoyed meeting with men who did not agree with him; enjoyed the humor of the situation; and he possessed so much good nature and good humor that, although he went, impartially, to those who were least likely to sign the petition, he rarely met with any discourteous rebuff. The feelings of his students toward him were very kindly.

He was an earnestly religious man in the evangelical sense. He belonged to that branch of the Baptist church which makes the seventh day of the week its day of rest. To the end of his life he scrupulously abstained from labor from sunset of Friday till sunset of Saturday. He was valued in the councils of his church, and contributed papers or articles to its conferences or its publications. He read papers or lectures on religious matters before his students, to which they listened with interest, as the expression of thorough conviction, supported by scholarship.

He worked to the last. For perhaps five years his friends could detect the progress of disease. In the summer of 1896 he attended the meeting of the American Association for the Advancement of Science for the last time, making an exhibit of an excellent straight-line dividing engine. The next summer he spent in an ocean voyage and a residence in an island climate; but *tabies dorsalis* cannot be checked. In the first month of 1898 its progress had been considerable. He continued to work against all advice. When he became unable to walk, his classes came to his house, and such labors were continued till fourteen days before death came. Its immediate cause was hypostatic pneumonia. He died on March 1, 1898.

He was elected a fellow of the American Academy of Arts and

Sciences at Boston in 1873. In 1880 Yale University conferred on him the honorary degree of Master of Arts, in recognition of his labors in preparing a volume of the Annals of the Observatory of Harvard College, containing his observations with the meridian circle. In 1881 he was elected an honorary fellow of the Royal Microscopical Society. In 1886 Alfred University, on the occasion of its semi-centennial, conferred on him the degree of Doctor of Philosophy. In 1892, thirty-five years after his graduation, Brown University conferred on him the degree of Doctor of Laws. He was vice-president of the American Microscopical Society in 1884, and its president in 1887. He was elected vice-president of the Section of Mathematics and Astronomy of the American Association for the Advancement of Science in 1882 to fill a vacancy, and regularly elected to the same office in 1883. He was elected vice-president of the Section of Physics in 1894. He was elected to membership in this Academy in 1885.

BIOGRAPHICAL MEMOIR

OF

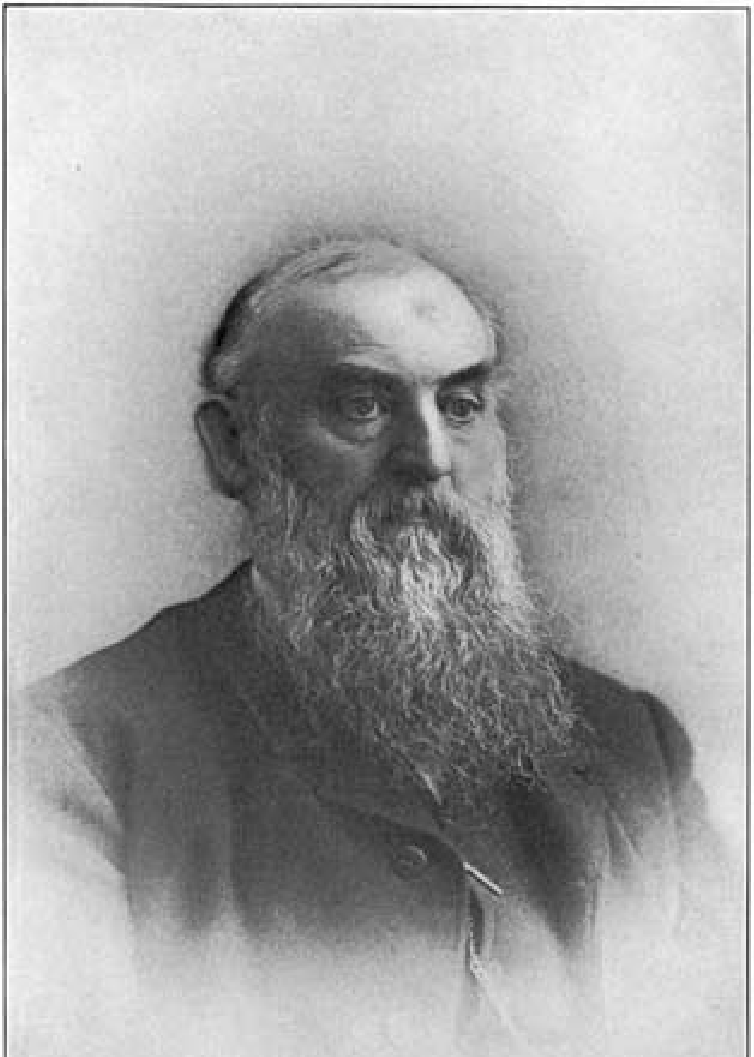
WILLIAM A. ROGERS.

PART II.

ASTRONOMICAL WORK.

BY

ARTHUR SEARLE.



As ever yours

W. A. Royer

BIOGRAPHICAL MEMOIR OF WILLIAM A. ROGERS.*

During the years in which Professor Rogers was connected with Alfred University his duties as a teacher and the limitations of his instrumental resources prevented him from making extensive astronomical investigations. So far as circumstances permitted, however, he made himself an active astronomer. He frequently computed the orbits of asteroids and made an interesting series of observations, necessarily attended by much personal discomfort, on the possible variations of personal equation resulting from fatigue or hunger. During the time which he passed at Harvard College Observatory on leave of absence from Alfred University he made a determination of the latitude of the observatory with a transit instrument in the prime vertical.

On returning to Harvard College Observatory as an assistant, in 1870, he was assigned to duty with the new meridian circle as soon as that instrument was mounted, and shortly afterwards he took exclusive charge of it, which continued until his removal to Colby University, in 1886. His work with this instrument included, first, the observation of 8,627 stars between the parallels of declination (for 1855) at 49° 50′ and 55° 10′; secondly, numerous observations of other, and generally brighter, stars, undertaken in connection with the zone observations just mentioned; and, thirdly, the observation, during the years 1879 to 1883, inclusive, of a special list of stars the right ascensions and declinations of which were to be determined independently of all previous observations. This required the very frequent observation of transits of the Sun and of Polaris.

The first of these three kinds of work was undertaken as a part of a comprehensive scheme formed by the Astronomische Gesellschaft for the accurate observation of the places of all stars not fainter than the ninth magnitude. Its results are published in the Annals of the Observatory of Harvard College, the fifteenth

* Part I Biographical Memoir of William A. Rogers, by Edward W. Morley, may be found in volume IV, pages 185–199.

volume of which comprises a catalogue of 1,213 stars, including those used as fundamental in the zone observations, while the second part of the same volume is occupied with the catalogue of the 8,627 stars of the zone itself. Volume XVI of the same series contains the separate observations of the stars used as fundamental and others observed in connection with them, partial publication of which had previously been made in volumes X and XII. Volume XXV contains the comparison of the separate observations of the zone stars with each other, and of their mean results with those previously obtained elsewhere. Finally, volumes XXXV and XXXVI contain the journals of the zone observations.

Professor Rogers lived to see the completion of all these volumes, the preparation of which remained under his charge after his removal to Colby University. They comprise the results of the first two classes of work which he carried on with the meridian circle. The work of the third class, that relating to the independent determinations of right ascension and declination, was only partially prepared for publication at the time of his death. Its reduction is still in progress. The work itself demanded extraordinary exertion on his part, as it required observations to be made at irregular and constantly varying times, which might occur at any hour of the day or night.

Besides the larger publications above mentioned, Professor Rogers frequently furnished the results attained from time to time in the progress of his work for publication in the astronomical periodicals and the proceedings of learned societies. As minor investigations of an astronomical nature which he undertook may be mentioned determinations of differences of longitude between Harvard College Observatory and other places, and observations for personal equation in the use of the meridian circle and of Mr. Chandler's instrument called the almucantar and described in volume XVII of the Annals of the Observatory.

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Vol. x. Observations made with the Meridian Circle, 1871–1872. (239 pp.)

Vol. xv. Catalogue of 1,213 Stars observed at the Astronomical Observatory of Harvard College, with the Meridian Circle, during the Years 1870 to 1879. (174 pp.)

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Vol. xxxv. Journal of Zone Observations during the Years 1870–1875. (272 pp.)

Vol. xxxvi. Journal of Zone Observations during the Years 1875–1883. (299 pp.)