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Henry Draper: A Scientific Biography

by

Howard Neil Plotkin

A dissertation submitted to The Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy.

Baltimore, Maryland

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ABSTRACT

Henry Draper was born in 1837, and educated at the University of the City of New York. But perhaps more important than his formal education was the one he received at home from his father, John William Draper. Henry was taken into his father's confidence in all scientific matters, and was intellectually stimulated by him. Although trained in medicine, it was in astronomy that he made his greatest achievements and earned his international reputation.

Draper introduced the silvered-glass reflecting telescope to Americans in 1864 through a highly successful Smithsonian Institution publication which became an important landmark in the history of telescope making. He was one of the earliest and most successful persons to exploit the photographic possibilities of large telescopes, obtaining excellent lunar photographs in 1863 and the first photograph of a nebula in 1880.

Besides direct celestial photography, Draper also pioneered in spectrum photography. In 1872 he obtained the first photograph of a stellar spectrum which showed Fraunhofer lines. The following year he took an unrivaled diffraction-spectrum photograph of the sun in order to prepare a trustworthy map of the solar lines. After serving for three months

as Director of the Photographic Department of the Transit of Venus Commission in 1874, he returned to his spectrum photography investigations.

The summer of 1877 was probably one of the most exciting ever for Draper--it was marked by his alleged discovery of a third satellite of Mars (along with Edward S. Holden), and his presentation of a paper before the American Philosophical Society describing his alleged discovery of oxygen in the sun and a new theory of the solar spectrum. According to this theory, oxygen discloses itself in the solar spectrum not by the familiar dark Fraunhofer lines, but by bright lines. Many spectroscopists, however, were hesitant to drastically alter their ground rules, and a controversy arose amongst the leading scientists of America and Europe which went unsettled for nearly two decades.

Most of the opposition came from some members of the Royal Astronomical Society. Draper went there in 1879 to present some high-dispersion photographs he had taken. But, probably due more to a division within the Society which centered around J. Norman Lockyer than to the merits of his new photographs, Draper failed to convince everyone present at the meeting, and his presentation only sharpened the debate.

Draper's plans at the time of his death in 1882 were twofold: 1) to continue to examine the solar spectrum to see if he could discover any other nonmetals in it besides oxygen, and 2) to catalogue and classify the stars according to their spectra by means of photography. Both of these lines of investigation were carried out by other astronomers -- the former resulted in the eventual discovery of oxygen absorption lines in the solar spectrum by Carl David Tolmé Runge and Friedrich Paschen in 1896, the latter resulted in the Henry Draper Memorial.

Although highly regarded in his day by leading scientific figures, he is now often condescendingly characterized as a mere amateur. In a sense, of course, he was, but it is clear he was something more. For whereas many of his contemporary professional astronomers did not leave the traditional boundaries of classical astronomy, Draper was in the forefront of research in the new astronomy--astrophysics. It is for this reason that his scientific work deserves greater attention than it has hitherto received.

PREFACE

The publication by the Berlin Scientific Academy in 1859 of the results of the close collaboration of the chemist Robert Bunsen and the physicist Gustav Kirchoff led directly to a period of rapid and spectacular growth in the science of astrophysics. The next two decades or so saw astronomers who possessed fairly large equatorial telescopes engaging in an exciting if laborious field of inquiry in solar and stellar spectroscopy. Lewis Morris Rutherfurd, Charles A. Young, and Samuel Pierpoint Langley in America; William Huggins, W. A. Miller, and J. Norman Lockyer in England; Lorenzo Respighi, Angelo Secchi, and Giovanni Battista Donati in Italy; A. J. Ångström in Sweden; Fritz Zollner and H. C. Vogel in Germany; and Charles Wolf and Georges Rayet in France -- all were early pioneers in astrophysics. Henry Draper was an early and important contributor to this science, but probably because of his amateur status, his scientific work has never received the attention due it.

It is a pleasure to record here my thanks to Prof. Harry Woolf, who suggested Henry Draper as a dissertation subject and offered helpful criticisms of a seminar paper on the oxygen in the sun controversy as well as the preliminary draft of this dissertation. I would also like to thank Prof.

Robert Kargon for his incisive comments on the seminar paper, and Prof. William Coleman, now of Northwestern University, for providing me with working facilities in the Milton S. Eisenhower Library. I am grateful for the opportunity my research afforded me of meeting Mrs. John William Draper of Hastings-on-Hudson, Henry's grandniece, with whom my wife and I spent a most pleasant and informative day. Mr. and Mrs. Gardner Osborn of Hastings-on-Hudson were kind enough to show my wife and I around Draper's old observatory (now a museum) on two separate occasions. I am also indebted to Draper's niece, Mrs. Dorothy Draper Nye, also of Hastings-on-Hudson, with whom I engaged in correspondence.

Finally, I would like to express my sincere gratitude to the manuscript curators of the libraries of the following institutions for all the help they have so freely given: the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the American Institute of Physics, the American Philosophical Society, the George Eastman House, Harvard University, the Historical Society of Pennsylvania, Johns Hopkins University, the Library of Congress, the National Academy of Sciences, the National Archives, the New York Historical Society, the New York Public Library, New York University--University Heights Center, New York University--Washington Square Center, Princeton University, the Royal Astronomical Society, the Smithsonian Institution, the U.S.

Department of Interior--Edison National Historic Site, the U.S. Naval Observatory, and Yale University.

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Henry Draper (1837-1882)

(From a photograph in the possession of Dr. John William Draper, Hastings-on-Hudson, New York)

CHAPTER ONE

HERITAGE AND FORMATIVE PERIOD

When Henry Draper died in 1882 at the relatively early age of 45, it was claimed that "no greater calamity could have befallen American science."[1] In the midst of an active and brilliant career, and in apparent good health, Draper had just given up his professorship at the University of the City of New York (later, New York University), had greatly reduced his business obligations, and was now for the first time prepared to devote himself full-time to his research. Although he had not published very extensively up to that time, much was still expected from him:

> There can be little room to doubt that had he not been cut down so abruptly in the midst of a host of projected investigations, the world would have been enriched during the succeeding twenty years with a wealth of discovery almost unparalleled.[2]

Excepting his early death, however, he was

> a man fortunate in all things: in his vigorous physique, his delicate senses, and skillful hand; in his birth and education;

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[1][E. L. Youmans], "Sketch of Professor Henry Draper," _Pop. Sci. Mo._ 22 (1882-83), 405.

[2]George F. Barker, "Memoir of Henry Draper," _Biog. Mem. Nation. Acad. Sci._ 3 (1895), 136.

> in his friendships, and especially in his marriage, which brought to him not only wealth and all the happiness which naturally comes with a lovely, true-hearted, and faithful wife, but also a most unusual companionship and intellectual sympathy in all his favorite pursuits. He was fortunate in the great resources which lay at his disposal and in the wisdom to manage and use them well; and in the complete success he invariably attained.[3]

Henry Draper was born on March 7, 1837 in Prince Edward County, Virginia, the second child of John William Draper and Antonia Gardner Draper, a Portuguese lady of noble birth.[4] In 1839, John William resigned from his chair of Chemistry and Natural Philosophy at Hampden-Sidney College, accepted a position as Professor of Chemistry in the Undergraduate Department of the University of the City of New York, and moved there with his family. Henry Draper was then only two years old.

There can be no doubt that Henry was intellectually stimulated by his father:

> He had for a companion, friend, and teacher, from childhood, one of the most thoroughly cultivated and original

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[3] Charles A. Young, "The Late Dr. Henry Draper," _Science_ 1 (1883), 34.

[4] Antonia Gardner Draper had been born in Brazil, the daughter of Dr. Daniel Gardner. Her identity is disputed; according to one account, she was the Infanta Dona Isabel Maria, daughter of King John VI of Portugal and Brazil. See further Donald Fleming, _John William Draper and the Religion of Science_ (Philadelphia, 1950), 7-8.

> scientific men of the present age, who attended carefully to his instruction, and impressed upon him deeply the bent of his own mind in the direction of science. The boy was, in fact, immersed in science from his youngest years, and not merely crammed with its results, but saturated with its true spirit at the most impressible period. He was taughtt to love science for the interest of its inquiries, and was early put upon the line of original investigation in which he has won his celebrity.[5]

To live in contact with this learned man was of itself an education of the greatest value.

Henry was taken early into his father's confidence in all scientific matters, and was often permitted to assist him, not only in his university lectures, but also in his investigations.[6] In 1850, John William taught Henry the art of taking photographs through a microscope, and had his thirteen-year-old son take photomicrographs to illustrate his _Human Physiology, Statical and Dynamical_, which was published six years later.[7] From this period dates Henry's interest in photography, a field in which he later attained great eminence.

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[5]E. L. Youmans, "Professor Henry Draper," _Harper's Weekly_ 26 (1882), 756.

[6]Barker, _op. cit._, p. 85.

[7]Henry Draper, "On the Construction of a Silvered-Glass Telescope 15½ inches in Aperture, and its Use in Celestial Photography," _Smith. Inst. Cont. Knowl._ 14 (1864), 47-48.

When Henry was fifteen he enrolled as an undergraduate in the Collegiate Department of the University of the City of New York, having already attended the primary and preparatory schools which were connected with the University. He did not graduate with his class, however, for he left the classical course of studies he was undertaking upon the completion of his sophomore year.

The classical course of studies was administered by the Faculty of Science and Letters, and was organized into five separate departments: Ancient Language and Literature; Modern Language and Literature; Mathematics, Natural Philosophy, and Astronomy; Chemistry, Botany, Geology, and Physiology; and Moral Sciences. The studies were viewed primarily as a discipline for training and strengthening the mental powers of the students: "The object ... is not to impart professional knowledge, nor merely to communicate special knowledge of any kind, but to form the well-educated man, without reference to any particular destination in life."[8]

An examination of the University _Circular_ of that time reveals what Henry's course of study must have been: readings of Livy, Herodotus, Homer, Epictetus, Lucian, Horace, Xenophon, Thucydides, Cicero, Terence, Juvenal, and

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[8] _Circular of the University of the City of New York_ (New York, 1854), 5.

Persius; exercises in Latin and Greek prose composition; exercises in English composition; studies in modern history and in the history of English literature; and studies of algebra, geometry, trigonometry, surveying, and the calculus.[9] Further perusal of the *Circular* reveals two important facts: in the first place, Henry could not have taken Elias Loomis' astronomy course, since it was offered in the third semester of the junior year, and secondly, he could not have taken the chemistry course taught by his father, for it was offered in the first term of the senior year.[10]

Although his undergraduate career was distinguished for excellent scholarship,[11] he decided to enter the Medical Department at the end of his sophomore year, largely on the advice of his father. When Draper entered in 1854, the Faculty of Medicine consisted of the Chancellor, Isaac

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[9] *Ibid.*, pp. 10-11.

[10] *Ibid.*, pp. 11-12. Elias Loomis taught mathematics and astronomy at the University of the City of New York from 1844-60, and at Yale University from 1860 to his death in 1889. He is remembered more for his meteorological studies than for his mathematical or astronomical work. See further H.A. Newton, "Memoir of Elias Loomis," *Biog. Mem. Nation. Acad. Sci.* 3 (1895), 213-52.

[11] Barker, *op. cit.*, p. 84. For an uninhibited account of the preoccupations of an undergraduate at the University of the City of New York a few years before Draper enrolled, see John E. Parsons, "A Student at N.Y.U. in 1847. Excerpts from the Diary of John E. Parsons," *N.Y. Hist. Soc. Q.* 38 (1954), 325-44.

Ferris;[12] Valentine Mott, Emeritus Professor of Surgery and Surgical Anatomy;[13] Martyn Paine, Professor of Materia Medica and Therapeutics;[14] Gunning Bedford, Professor of Obstetrics, the Diseases of Women and Children, and Clinical Midwifery;[15] Alfred C. Post, Professor of the Principles and Operations of Surgery, and Surgical and Pathological Anatomy;[16] William Van Buren, Professor of General and Descriptive Anatomy;[17] John

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[12] Isaac Ferris was Professor of Moral Philosophy and the Evidences of Revealed Religion, and was Chancellor of the University from 1852 to 1870.

[13] Valentine Mott was the outstanding figure of the Medical Faculty, and was its first president, serving from 1841 until Draper assumed office in 1850. He was the most famous surgeon of his day in America, and perhaps the first one to make a million dollars by his profession. Biographical information on Mott and the other members of the Faculty of Medicine can be found in Claude Edwin Heaton, _A Historical Sketch of New York University College of Medicine, 1841-1941_ (New York, 1941), 4-8.

[14] Martyn Paine was a widely-known practitioner of the old school of physicians, whose abuse of the lancet and calomel prompted his students to answer each examination question with the pat response, "The treatment is bloodletting, sir." He also played a large and successful role lobbying at Albany for legalized dissection.

[15] Gunning Bedford played an important role in establishing gynecological teaching on a solid basis in the United States.

[16] Alfred C. Post was a prominent New York surgeon who chastized busy doctors who assumed teaching responsibilities without being able to devote much personal attention to the instruction of their pupils. See further William Frederick Norwood, _Medical Education in the United States Before the Civil War_ (Philadelphia, 1944), 38-39.

[17] William Van Buren married Valentine Mott's eldest

Swett, Professor of the Institutes and Practice of Medicine;[18] and John William Draper, Professor of Chemistry and Physiology, and President of the Faculty.

The original intention of the founders of the medical school had been to imitate the University of Paris, which had a rigorous four-year program with excessively high standards.[19] A special committee appointed by the University Council to set up the new medical program, however, felt that "to require an attendence upon the instructions of the Medical Faculty for the full term of four years before conferring the degree of Doctor of Medicine would prove fatal to the hopes and prospects of the Faculty."[20] Accordingly, the committee decided to graduate students after three years' apprenticeship, two four-month lecture courses, and the writing of a thesis.[21] Notwithstanding the good intentions of the committee, the curriculum was equal to that of most medical schools of those early and lax days of professional instruction, and

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daughter, was appointed Vice-President of the New York Academy of Medicine in 1859, and was Professor of Surgery at Bellevue Hospital Medical College from 1866 to his death in 1883.

[18]John Swett was a New York physician who served on the Faculty of Medicine for one year, 1853-54.

[19]Norwood, op. cit., p. 134.

[20]Quoted in Heaton, op. cit., p. 2.

[21]Norwood, op. cit., p. 135.

the lectures were designed to be of a distinctly popular character.[22]

To encourage a large enrollment of students, the medical school's _Announcement_ called attention to the fact that the University's charter released the Medical Department from that portion of the state code which declared that degrees conferred by any college in the state did not constitute a license to practice physic or surgery. That is to say, the medical graduates of the University were authorized by charter to practice in the state without the formality of receiving a license from the state or county societies.[23] The _Announcement_ also strongly emphasized the availability of clinical material in New York City, which stood in sharp contrast to the limited facilities of country schools.[24]

The medical Faculty was quite successful in recruiting students. Enrollment increased from 268 in 1842-43 to 421 in 1847-48, and remained above 400 until the beginning of the

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[22]James A. Walsh, _A History of Medicine in New York. Three Centuries of Progress_, Vol. 2 (New York, 1919), 455. The efforts of Edward Dixon to bring about reform in the training and licensing of doctors at this time is discussed in Martin Kaufman, "Edward H. Dixon and Medical Education in New York," _N.Y. Hist._ 51 (1970), 394-409.

[23]Walsh, _op. cit._, p. 454.

[24]_University of New York. Medical Department. Annual Announcement of Lectures_ (New York, 1848), 4-5.

1850's. The dwindling to 290 by 1852-53 may be explained by the withdrawal of Valentine Mott, who had been a magnetic attraction for the school during the 1840's. Under John William Draper's guidance, however, the University regained much of its lost prestige, and reached an enrollment of 411 in 1859-60, only to slump tremendously with the opening of the Civil War.[25]

A signal advance in medical education was achieved to a large degree by the efforts of the Medical Faculty: to them belongs the honor of obtaining the legalization of dissection of the human body in the state of New York. As early as 1788, a serious riot had broken out in New York by the stealing of bodies for dissection, and medical schools had great difficulty in obtaining bodies for anatomical study. Witness Mott describing his adventures as a body snatcher:

> I well remember on one occasion driving, in disguise, a cart containing eleven subjects, from the old Potter's field burying ground, sitting of the subjects, and proud enough of my tropies; but we were not always so fortunate, being on many occasions discovered and pursued, and obliged to leave our spoils behind us, with only our hard labor for our pains.[26]

Although the fight to abolish the stringent laws against dissection was state-wide, much credit can be as-

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[25] Norwood, _op_. _cit_., p. 137.

[26] Quoted in Heaton, _op_. _cit_., p. 8.

cribed to two members of the Medical Faculty: John William Draper and Martyn Paine. Draper, then President of the Medical Faculty, issued "An Appeal to the People of the State of New York, to Legalize the Dissection of the Dead," arguing that the opening of the western territories meant that many surgeons and physicians would be needed there, and that these doctors should be well-trained. At the same time, Paine spent three months in Albany lobbying for the measure. As a result of their efforts, the "Bone Bill," as it was commonly called, was passed in 1854.[27]

The original building of the Medical Department was a large granite building on Broadway nearly opposite Bond Street, known as the Stuyvesant Institute. Here, in 1846, the American Medical Association was organized. Lectures and clinics were held in the Institute until September, 1851, when a larger building was completed on Fourteenth Street between Third Avenue and Irving Place. When Henry Draper enrolled in the medical school in 1854, the new grounds contained two museums and three lecture halls, each capable of seating six hundred persons. Competent authorities claimed it was "the most complete medical college building in the country."[28]

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[27] Ibid., p. 9.

[28] Walsh, op. cit., p. 456. The entire building, including its museums and laboratory equipment, was destroyed by fire in 1866.

For his graduating thesis, Draper undertook research on the changes of blood cells in the spleen, in an effort to settle the argument whether the spleen was the generator or destroyer of blood cells. He chose the frog as his experimental animal, partly because it was so readily accessible, but mostly because the large size of its blood cells made it easy to see the changes occurring in them.[29]

Draper illustrated his thesis with photomicrographs which he had taken, noting that

> the value of photographs turns on the fact that they are produced (it might be said) without the intervention of human art, and are copies of microscopic images executed by the sun, not having passed through the draughtsman's and the engraver's hands, each of whom introduces in his work necessarily some inaccuracies ...[30]

The operation of successfully photographing the microscopic image, which consisted of photographing the image on glass and of then transferring it to paper, was the most difficult aspect of his thesis, and took the better part of three summers. It was while taking these excellent photomicrographs that Draper discovered the remarkable power possessed by chloride of palladium in intensifying negatives, an observation which subsequently proved of much value in

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[29] Henry Draper, "On the Changes of Blood Cells in the Spleen," N.Y. J. Med. 3 (1858), 183.

[30] Ibid., p. 185.

photography. Not only was the opacity of pictures increased sixteenfold by its usage, but it also increased adhesion to the glass plate, thereby prolonging the life of the picture.[31] By comparing blood cells entering and leaving the spleen, Henry was able to correctly assert that "the spleen must be an organ for the disintegration of blood cells."[32]

By 1857 he had completed his thesis and had successfully passed all his examinations, but he was only twenty. Since the Medical Department had set a minimum age of twenty-one for graduation, he decided to go abroad with his older brother, John Christopher, for an extended period of study and recreation. Upon his return in 1858 he received his medical degree, graduating with distinction, and joined the staff of Bellevue Hospital.[33] Draper remained on the Bellevue staff for eighteen months, leaving in the fall of 1860 to accept a teaching position at his alma mater.

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[31]Henry Draper, "On a New Method of Darkening Collodion Negatives," Amer. J. Photog. 1 (1858-59), 374-76.

[32]"On the Changes of Blood Cells in the Spleen," p. 189.

[33]Barker, op. cit., p. 84. From 1847 forward, close cooperation had existed between the University's Medical Department and the College of Surgeons and Physicians on the visiting staff of Bellevue Hospital. Although Bellevue Hospital opened its own Medical College in 1861, its partial destruction by fire in 1897 and its close proximity to the University Medical College led to the complete merger later that year of these two medical schools under the title "The University and Bellevue Hospital Medical College." See further Walsh, op. cit., pp. 465-67.

The only other time that he actually practiced medicine was while on a tour of duty during the Civil War. Early in February, 1862, Henry and John Christopher (who had also received a medical degree from the University of the City of New York) were commissioned as surgeons with the Twelfth Regiment of the New York State Militia. After four months spent at Fort McHenry in Baltimore, Maryland, the two brothers accompanied their regiment to Harper's Ferry, Virginia. In October, however, Henry was mustered out with the "Chickahominy fever," which he had picked up in the swamps bordering the Monocacy River.[34]

To his first appointment in 1860 as Professor of Natural Science in the Undergraduate Department of the University of the City of New York, he later added (1862) the chair of Analytical Chemistry in the Academic Department, retaining both positions until 1882. In 1866 he was simultaneously appointed Professor of Physiology in the Medical Department and Dean of the Faculty, but resigned from these last two positions in 1873. Finally, upon the death of his father in January, 1882, he was chosen to succeed him as Professor of Chemistry, a position which he held, however, only until the close of the current academic year. At that

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[34]Barker, op. cit., p. 134.

time, he severed entirely his connection with the University.[35]

His lectures were said to have been "simple, clear, and forcible. They held the interest of the classes he instructed and awakened their enthusiasm, while they enriched the student's store of knowledge and strengthened his powers of observation and reasoning."[36] They were, furthermore,

> so interesting and absorbing to his hearers, that the question of order, which in some recitation rooms assumed large proportions, is hardly even thought of with him. After class, an eager group surrounds him; and every tap by inquiring students is followed by a rich stream of information from a mind whose varied treasures always lie at instant command.[37]

When he began teaching in 1860 he was twenty-three years old, a young man "of medium height, compactly built, with a pleasing address, and keen black eye which missed nothing within its range."[38] When he ended his career in 1882 he was world-famous.

Trained in medicine, enjoying a highly successful academic career, it turned out to be the field of astronomy in which Henry Draper made his greatest achievements and

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[35] _Biographical Catalogue of the Chancellors, Professors, and Graduates of the Department of Arts and Science of the University of the City of New York_ (New York, 1894), 239.

[36] Barker, _op. cit._, p. 136.

[37] Quoted in Young, _op. cit._, p. 31.

[38] _Ibid._, p.34.

earned his international reputation. During his sojourn in Europe, 1857-58, Draper had attended the annual meeting of the British Association for the Advancement of Science, which was held in August at Dublin. After the meeting, he was invited by the Earl of Rosse to join a party to visit the famous six-foot reflecting telescope at Birr Castle, Parsonstown. There he saw not only the great instrument itself, and the machinery and methods by which it had been produced, but also had the opportunity of observing several celestial objects through it. This not only inspired him to build a similar telescope, but was instrumental in turning his attention to astronomy and astronomical photography: "On returning home in 1858, I determined to construct a similar, though smaller instrument; which, however, should be larger than any in America, and be especially adapted for photography."[39]

Accordingly, in September, 1858, immediately after his return from Europe, he began the construction of a telescope and observatory on land belonging to his father's estate at Hastings-on-Hudson, a country village in Westchester County, about twenty miles north of New York City. The observatory was situated on a hill about 250 feet above the river and commanded a superb view across the Hudson to the

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[39] "On the Construction of a Silvered-Glass Telescope ...," p. 1.

Palisades at Indian Head, and through a gap at Piermont to the Ramapos beyond:

> An uninterrupted horizon is commanded in every direction, except where trees near the dwelling house cut off a few degrees toward the southwest. The advantages of the location are very great, and often when the valleys round are filled with foggy exhalations, there is a clear sky over the Observatory, the mist flowing down like a great stream, and losing itself in the chasm through which the Hudson here passes.[40]

It was a good place for Henry to take his astronomical photographs.[41]

The observatory proper was 17½ feet square, and was two stories high; the foundation and lower story of the building was excavated out of the solid granite forming the base of the hill, and the second story or superstructure was of wood. Inside, twenty-two feet separated the apex of the tin dome from the ground. Two windows, when opened, admitted sunshine into the decorated interior: "The interior of the

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[40] *Ibid.*, p. 42.

[41] See further "John William Draper Memorial Park," *Scenic and Historic America* 2 (1930), 59-62 and "The Draper Estate," *Annual Report, American Scenic and Historic Preservation* 29 (1924), 73-77. I wish to thank Mr. Gardner Osborn, who resides at and is curator of the house built around Draper's original observatory, for calling my attention to these two articles and sending me photostatic copies of them. The observatory residence was bequeathed to the American Scenic and Historic Preservation Society in 1923 by Mrs. Antonia Draper Dixon, John William Draper's daughter, and is presently maintained as a museum. Many objects of interest used and collected by Henry Draper are exhibited there.

building is painted and wainscoted, and the roof is ornamented partly in blue and oak, and partly with panels of tulip-tree wood."[42]

For the mirror of his reflecting telescope, Draper cast a 15½-inch metal speculum out of an alloy of copper and tin in the proportions given by Lord Rosse. The casting turned out to be "very fine, free from pores, and of silvery whiteness."[43] It was two inches thick, weighed 110 pounds, and was intended to be of twelve feet focal length. It was ground and polished with a Rosse-designed machine that Draper built, and mounted as a Newtonian telescope. In February, 1860, the speculum was one day found split into two nearly equal halves, due to the expansion in freezing of a few drops of water that had found their way into the mirror's supporting case.

That summer, John William visited Sir John Herschel while abroad, and on telling him this tale was advised to tell Henry to abandon speculum metal and to make his mirrors henceforth of silvered glass. Such mirrors, he related, possess greater capabilities for astronomical purposes since they reflect more than ninety percent of the light that

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[42]"On the Construction of a Silvered-Glass Telescope ...," p. 43.

[43]Ibid., p. 2.

falls upon them, and weigh only one-eighth as much as specula of metal of equal aperture.[44]

Henry then began experimenting with silvered-glass mirrors, grinding and polishing more than a hundred, ranging in size from ¼-inch to 19 inches in diameter. Satisfied that he had mastered the necessary technique, he began to simultaneously grind three 15½-inch glass discs. Draper had found that three mirrors of the same focal length and aperture were necessary because frequently two mirrors ground in succession were so similar that a third was required in order to make any advance beyond them.[45] All three mirrors were completed and tested together in October, 1861. The first was found to be nearly spherical, the second parabolic, and the third hyperbolic in form. After further work, they were all pronounced good and were consequently silvered and tried out.

The mirror was then mounted, resting upon a rubber air cushion. A rubber tube ran from the air cushion to the observer who, by pressing a bulb, adjusted the inflation to that just necessary to keep the mirror against its retaining rim. The air cushion was in turn supported by an oak disc attached by three flat iron bars to the lower end of the telescope tube. The mirror and mount were then entirely

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[44] Ibid., pp.2-3.

[45] Ibid., p. 1.

enclosed within a curtain of black velvet which served to keep out stray light. The tube was a sixteen-sided construction of black walnut, eighteen inches in diameter and twelve feet long. The wooden staves, each three-eighths of an inch thick, were hooped together and bound externally by four brass rings, and strengthened interiorly by two iron ones.

The telescope was mounted as an altazimuth instrument, rather than as an equatorial.[46] This type of mounting was chosen for two reasons: in the first place, Draper thought that it would be steadier than a clock-driven equatorial, and secondly, simple rotation about the polar axis of an equatorial would not suffice to counteract the moon's motion in declination, anyway.[47] The mounting, however, differed from the usual instrument of this kind in one important aspect: the eyepiece (or place of the sensitive plate when the telescope was used to take photographs) was set up in such a way that it was stationary at all altitudes --that is, the observer could always look straight forward, without ever having to stoop or assume an inconvenient

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[46]With an altazimuth mounting, two motions of the telescope (in altitude and azimuth, i.e., about a horizontal and a vertical axis) are needed to keep a star in view. An equatorial mounting, however, requires but a single motion because one axis of rotation, the polar axis, is parallel to the earth's axis of rotation.

[47]"On the Construction of a Silvered-Glass Telescope ...," pp. 27-28.

position (see Fig. 1).[48]

For photographic purposes, the eyepiece of the telescope was equipped with a sliding plate holder, which was automatically driven in the apparent direction of the moon's path.[49] The advantages of such a plate holder were twofold: in the first place, it could be set up so as to compensate for the moon's motion in declination, and secondly, it necessitated the motion of a weight of scarcely more than an ounce instead of that of the entire telescope, weighing more than a ton.[50] A sand clock was first employed to move the plate holder. This was subsequently replaced by a form of clepsydra, or water clock, which gave very satisfactory results for a period of up to four minutes--several times longer than the exposures usually required. For short exposure solar photographs, a spring shutter triggered by a stout rubber band was attached to the eyepiece.

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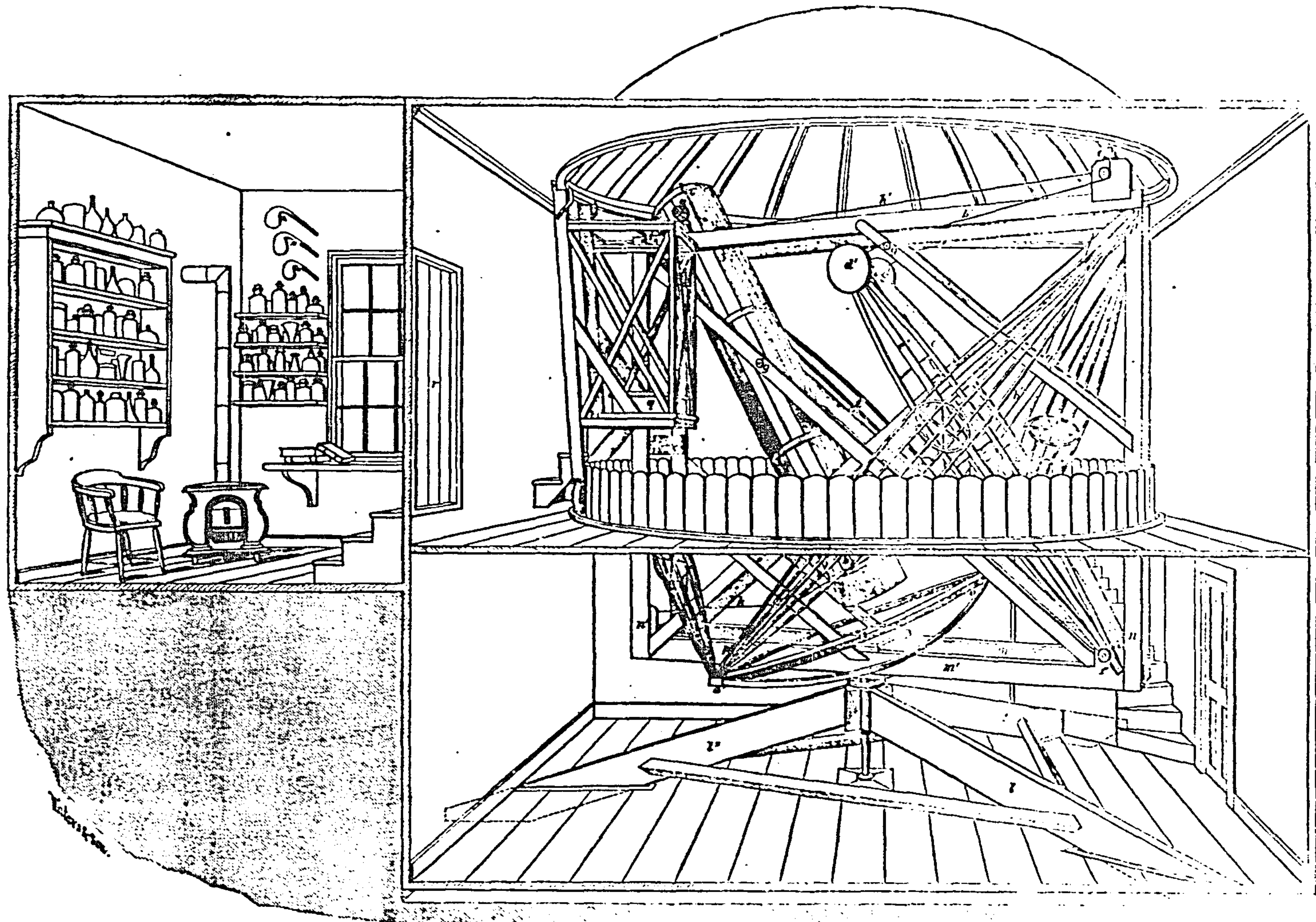
48 Ibid., p. 27. The stationary eyepiece mounting was first used by Caroline Herschel, who had a 27-inch Newtonian reflecting telescope arranged on that plan.

49 Ibid., p. 33. Warren de la Rue was an English astronomer who designed the first photoheliograph, an instrument used for photographing the sun daily, in 1858. He was awarded the Gold Medal of the Royal Astronomical Society for his sterioscopic pictures of the moon in 1862, and served as that society's president from 1864 to 1866. He was the first person to suggest photographing the moon on a sensitive plate carried by a frame moving in the apparent direction of its path, but never applied an automatic driving mechanism to it.

50 Ibid., p. 34.



Sectional View of Observatory.

Fig. 1 "Sectional view of observatory" (From Smith. Inst. Cont. Knowl. 14 (1864), Art. 4, 29)

The construction of Draper's telescope greatly interested Joseph Henry, the director of the Smithsonian Institution, who visited the observatory in the spring of 1863. Since silvered-glass reflecting telescopes were new to the American astronomical scene, and Draper had worked out the practical details of their construction so successfully, Henry persuaded Draper to write a monograph on that subject. The resulting work, entitled "On the Construction of a Silvered-Glass Telescope 15½ inches in Aperture, and its Use in Celestial Photography," was published in July, 1864 as No. 180 of the Smithsonian Institution Contributions to Knowledge, and immediately became a standard reference on telescope making.

For the first time, amateur astronomers were invited to make their own instruments, and to see celestial objects with definition and magnification equal to those of the larger refractors of the professionals. John A. Brashear in his autobiography claims that the book

> opened a new world, a new heaven to me... indeed, his book was of almost inestimable value to hundreds who were enabled to make their own instruments through a knowledge gained by studying it.[51]

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[51]John A. Brashear, The Autobiography of a Man Who Loved the Stars, ed. W. Lucien Scaife (New York, 1924), 55. Brashear, a Pittsburgh millwright, had been interested in astronomy since his boyhood. He became noted for his method of silvering mirrors, and the precision instruments he made. He was also associated with the founding of the Carnegie

American astronomers, however, were not the only ones to value the work; when John William Draper was in England in 1870, he wrote Henry: "I found that your Smithsonian publication is quite an authority here. But few copies of it are in circulation so they lend it to one another."[52]

Upon returning to New York in the fall of 1862, after having spent four months with his regiment in Virginia, Draper reground and repolished mirror no. 3, satisfying himself that "It is as good as we know how to make it." The greater part of 1863 was spent taking photographs of the moon and planets. Some 1500 negatives of the moon were taken that year with this telescope. About 1¼ inches in diameter, they bore enlargement to three feet, and in one case to fifty inches, with excellent results.[53] They were among the best photographs of the moon ever taken by anyone up to that time.

The year 1867 marked two significant events in Draper's career: his marriage to Mary Anna Palmer, and

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Institue of Technology.

[52]Letter from John William Draper to Henry Draper, December 10, 1870, Henry and Anna Palmer Draper Papers, Manuscript Division, New York Public Library. Hereafter, citations to this source will be abbreviated as, e.g., John William Draper to HD, December 10, 1870, Draper Papers, NYPL.

[53]"On the Construction of a Silvered-Glass Telescope ...," pp. 1-2.

the beginning of construction of a 28-inch silvered-glass telescope. Anna Palmer was the daughter of Courtlandt Palmer, a very prominent and wealthy New York businessman. She was beautiful,[54] learned, talented, and charming. The Draper home was spacious, and was well adapted to the elaborate entertaining for which it became well-known. Mrs. Draper frequently served as hostess to celebrated politicians and scientists, and regularly entertained the members of the National Academy of Sciences during their New York meetings after Henry's election in 1877. Even after her husband's death in 1882, she continued to entertain in this fashion:

> Mrs. Draper was a friend to many scientific men and frequently gave elaborate entertainments in her spacious home. The old laboratory in New York was fitted up as a lecture or exhibition room and could seat two hundred people. Here many famous men came to lecture to scientific societies and invited guests. Here various scientific exhibitions were placed when she entertained such societies as the National Academy [of Sciences] or the American Astronomical Society.[55]

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[54]An oil of Mrs. Draper, painted by John W. Alexander in 1888, hangs over the stairway connecting the ground and second floors of the New York Public Library. This portrait was part of a large collection of books, prints, and valuable objets d'art bequeathed by her to the New York Public Library. For a description of this collection, see "The Draper Bequests," Bull. N.Y. Public Lib. 19 (1915), 419-22.

[55]Annie J. Cannon, "Mrs. Henry Draper," Science 41 (1915), 382. Miss Cannon played an important role in the preparation of the Henry Draper Memorial.

The Draper house stood at 271 Madison Avenue, between 39th and 40th Streets. When originally built by Mr. Palmer, it was the last house in New York City, and his business friends cautioned him against investing in property so far from the business center. Mrs. Draper could remember "when the old omnibus running on Fifth Avenue went only as far as Thirty-ninth Street, so that when any one alighted and started to walk in their direction they were sure of a visitor.[56] During the summer months, however, the Drapers lived in Dobbs Ferry, two miles from the Hastings observatory. It was their custom to drive together to the observatory for the night's work, and so great was her interest in this that Henry never went there without her.

Anna also proved to be a talented assistant, both in Henry's laboratory and in the observatory. In the days of the wet plate, she herself always coated the glass with the collodion. During the total solar eclipse of July 29, 1878, she accompanied Henry on an observing expedition to Rawlins, Wyoming:

> Her special duty was to count the seconds during the eclipse and lest the vision might unnerve her, she was put within a tent and therefore saw nothing at all of the wonderful phenomenon. Here she sat

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[56] *Ibid.*, p. 381. 271 Madison Avenue is now the site of a Chase-Manhattan Bank skyscraper.

> patiently and accurately calling out the seconds while the glorious and awe-inspiring spectacle was unfolded.[57]

After Henry's death, she established the Henry Draper Memorial in connection with the Harvard College Observatory. Until deterred by failing health, she visited Cambridge regularly, personally inspecting the progress of the work, giving advice about matters of policy, and displaying great interest in the actual inspection of various stellar spectra. Thus she not only was her husband's associate in his investigations during the fifteen years of their lives together, but after his death provided the means for carrying on his work. Her name, like that of Lady Huggins, will always be honorably associated with the science of astrophysics.[58]

In the fall of 1867, the year of their marriage, Draper began the construction of a glass mirror of 28 inches aperture and 12½ feet focal length, which was to be mounted as a Cassegrain telescope. Most of his spare time for the next eighteen months was spent on grinding and polishing the mirror, which was finally completed in June, 1869. During that summer another dome was added to the Hastings observatory, and toward the end of August the new mirror was mounted

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[57] Ibid.

[58] Margaret Lindsay Huggins was an enthusiastic and talented co-worker during many years of incessant labor, and played an important part in the career of her husband.

in it. Although as yet unsilvered, the mirror easily showed the companion star to Polaris.

The following winter, while Henry was working on the driving clock of the telescope, John William visited England. He used the occasion of a dinner meeting of the Royal Atronomical Society to brag about the huge telescope Henry was then constructing:

> Three papers were read and then Mr. [William] Lassell [the President of the Society] publickly introduced me and asked if there was nothing doing in America that I should like to give an account of. Of course I knew that he referred to your new telescope and therefore in a little speech of 10 or 15 minutes I gave them a description of it--the mirrors and their support [,] the stand [,] the clock [,] the observatory [,] etc.[59]

He kept to himself, however, some things which he thought Henry could work up into a memoir later:

> I avoided saying anything about those points that you choose to keep secret, such as the method of polishing, for it is better that you should make a special communication of your own when you think fit.[60]

Henry never did write this up!

John William was, quite obviously, very proud of Henry. Although he had reason to be proud of all his sons (John Christopher, his eldest son, was teaching physiology

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[59]John William Draper to HD, December 10, 1870, Draper Papers, NYPL.

[60]Ibid.

at the College of the City of New York and chemistry in the Medical Department of the University of the City of New York; and Daniel, his youngest son, was a prominent meteorologist who had invented self-recording instruments), Henry was clearly his favorite:

> Happiest were the days when Henry could be home. Then he sat facing his father; and when they two carried on the conversation, the rest sat silent. For it was well known that everything they said was too important for any word of it to be lost. To his father, in whose face a serene repose mingled with sustained intensity of intellectual penetration, Henry was the perfect foil, his dark eyes flashing electrically over the latest discoveries in physics or astronomy, or when relating some humorous incident, they brimmed with laughter to the point of tears.[61]

John William also performed all kinds of errands for Henry while abroad, ordering books and scientific instruments for him.[62] He also kept his eyes open, with the intention of spying out the land in order to see what kind of research would make Henry famous in Europe in the least possible time:

> From what I see here your proper course is to use your telescope first in getting

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[61] Antonia C. Maury, "Recollections of my Grandfather, John William Draper," typewritten manuscript in her possession, Hastings-on-Hudson, New York. Quoted in Fleming, op. cit., p. 138.

[62] See, e.g., John William Draper to HD, December 10, 13, and 19, 1870 and February 9 and 16, 1871, Draper Papers, NYPL.

> some good lunar photographs. After what I have said depicting it they will look for something of the kind here... That done, try your hand at the invisible stellar spectra. You intended I know to begin with this first but I am satisfied that the above course is the best one and I have special reasons too long to be here detailed for saying this.[63]

As we shall see, Henry took his father's advice on this matter.

To make sure that Henry would not lose any valuable time in beginning this line of investigation, John William exhorted him to push work on completing the observatory:

> By a little pushing you might have it all in readiness by the time I get back early in April. You will have nothing to do at the University as I will take charge there and so might get to work without interruption or delay. Push the thing a little and you can do it.[64]

Here, too, Henry followed his father's advice.

Henry spent all winter working on the driving clock, which had to be sufficiently accurate to keep the telescope centered on an object throughout the duration of a photographic time exposure. Draper had to construct no less than

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[63]John William Draper to HD, December 19, 1870, Draper Papers, NYPL.

[64]John William Draper to HD, February 9, 1871, Draper Papers, NYPL.

seven complete driving clocks before he could succeed in getting one that worked to his satisfaction. The regulator of this last one consisted of a pair of heavy conical pendulums, so hung that their revolutions were sensibly isochronous through quite a range of inclination. The regulator, which revolved once a second, was constructed, for the most part, by Draper himself, with the utmost care and accuracy. In the opinion of Charles A. Young,

> it may safely be said that in its ultimate perfected condition the driving-clock was as good as any in existence, keeping a star on the slit [of the spectroscope] for an hour at a time when near the meridian and not disturbed by changes of refraction.[65]

The mirror was not silvered until July, 1871. Observations, however, convinced Draper that the defining power of the 28-inch mirror was not equal to that of the 15½-inch one, so he decided to repolish it. This was done the following winter, and in March it was regarded as virtually perfect. The accessories were then finished, and by the end of May, 1872, the large telescope was pronounced to be in complete

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[65] Charles A. Young and Edward C. Pickering, "Researches upon the Photography of Planetary and Stellar Spectra, by the late Henry Draper, M.D., LL.D. With an Introduction by Professor C.A. Young, a List of the Photographic Plates in Mrs. Draper's Possession, and the Results of the Measurements of these Plates by Professor E.C. Pickering," Proc. Amer. Acad. Arts Sci. 19 (1883), 235.

working order.[66]

As to the observatory proper, the only description we have is contained in a description of the residence that Mrs. Antonia Draper Dixon, Henry's sister, had built around the observatory after his death:

> The rotunda, about 20 feet in diameter, one story high, with low ceiling, forms the round room now used as a parlor. Adjoining the equatorial dome room on the west is a transit room, built of brick, about 9 by 14 feet in size...North of the rotunda and the hall which lies between it and the old observatory, is a long room with a lower floor level which was the work-shop, and which Mrs. Dixon converted into an attractive dining room. The front hall was the old photographic room, and there is a little aperture in its south wall at the west side of the doorway, which was used for photographic purposes. Adjacent to the dining room is a pantry, which was the old engine room, and a small kitchen.[67]

It is presently maintained as a museum.

Years later, in the summer of 1880, and again at the request of Joseph Henry, Draper began preparing a description of this telescope and the methods employed in its construction. Intended to be published by the Smithsonian Institution as a supplement to his 1864 memoir on his 15½-

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[66] Barker, op. cit., p. 93.

[67] "The Draper Estate," op. cit., pp. 75-76.

inch telescope, the paper was never completed.[68] As far as I am aware, no trace of it now exists.

When Draper began to use this telescope to photograph the spectra of the heavenly bodies, he began a series of investigations which were uniquely his own in this country, and which were to catapult him to international fame.

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[68] Barker, op. cit., p. 95.

CHAPTER TWO

SCIENTIFIC ACHIEVEMENTS

In May, 1872, as soon as Draper had added the final touches to his 28-inch telescope, he tested it to see if it could be used to photograph stellar spectra. His initial attempt was successful, and he was rewarded with a photograph of the spectrum of α Lyrae (Vega), ½-inch long and 1/32-inch wide. The photograph, however, did not show any spectrum lines:

> Two photographs of the spectrum of Vega were taken with collodion plates. The first was with an exposure of 3 minutes, the next of 30 seconds. No slit was used and no lenses. A quartz prism was placed inside of the focus of the telescope, and a sensitive plate at the focus. The photographs showed no lines.[1]

Apparently the low sensitivity of the wet collodion plates and the difficulty of keeping the image of the stellar spectrum motionless on the plate prevented him from obtaining

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[1]Excerpt from Henry Draper's notebook records, dated May 29, 1872. Quoted in Young and Pickering, op. cit., p. 237. Although I have made an extensive search for these notebooks, I have not been able to find them; most likely they were lost in a fire which destroyed a large portion of the original observatory in the early years of this century.

anything more than a faint continuum.

Repeated experiments during the next two months enabled Draper to improve his technique to the point where by August 1, 1872, he was able to obtain a photograph of the spectrum of Vega which showed four distinct lines.[2] J. Norman Lockyer in England immediately recognized the significance of this achievement: "I wish to congratulate you on your star [spectrum] photographs. However difficult this is the most important thing to be done in the present state of science."[3] The spectroscopic apparatus employed for this photograph was arranged as it had been earlier, with a quartz prism placed just inside the focus of the small diagonal mirror, no slit or collimating lenses being used.

William Huggins was also pursuing this line of investigation in England, but Draper did not then know it:

> At this time I did not happen to know that Dr. Huggins, who is so distinguished for his thorough and accurate researches on the visible portion of the spectra of the heavenly bodies, had already made some attempts in this direction.[4]

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[2]Henry Draper, "Photographs of the Spectra of Venus and α Lyrae," Phil. Mag. 3 (1877), 238.

[3]J. Norman Lockyer to HD, November 26, 1873, Draper Papers, NYPL.

[4]Henry Draper, "On Photographing the Spectra of the Stars and Planets," Amer. J. Sci. 18 (1879), 421.

Huggins did turn out to be Draper's closest competitor, but it was not until 1876, four years later, that he finally succeeded in obtaining a photograph of stellar spectrum lines.[5]

Further photographs of the spectrum of Vega and, most notably, α Aquilae (Altair), were taken that summer, and it became obvious that a photographic study of the spectra of various metals and nonmetals would be necessary to interpret the results.

> This of course opened out a large field for experiment, requiring many years for its study, and hence, as several physicists were engaging in the study of the spectra of the metals, I concluded to discontinue the experiments commenced in 1870 on the spectra of the metals and to confine the investigation mainly to the non-metals.[6]

It was this investigation of the spectra of the nonmetals that led to his alleged discovery in 1877 of oxygen in the sun.

Having thus embarked on a very ambitious program, Draper decided he could best utilize his time by dividing his experiments into two distinct parts: an astronomical portion carried on during the summer months at the Hastings

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[5] William Huggins, "Note on the Photographic Spectra of Stars," Proc. R. Soc. 25 (1876-77), 445-46.

[6] "On Photographing the Spectra of the Stars and Planets," p. 421.

observatory, and a laboratory portion carried on during the rest of the year at his New York laboratory. The former consisted of observations and photographs of the spectra of the stars, planets, and sun; the latter of photographic works of the spectra of various elements, particularly the non-metals.

Draper's laboratory at first consisted of two rooms on the third floor of his Madison Avenue residence. All of his earlier work, such as the construction of the 28-inch mirror, was done here. Subsequently, however, he realized the need for additional rooms and facilities, and to this end he built a special physical laboratory. The new laboratory comprised the third story of his stable, situated directly behind the residence, and connected to it by means of a covered passageway.

The equipment in Draper's laboratory was superb. A siderostat, built by Alvan Clark and Sons, was placed on the roof and furnished abundant sunlight which could be directed to any part of the room by a secondary mirror.[7] A four-horsepower gas engine drove three dynamos for the production of electric currents of different intensities. A large

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[7]A siderostat is a mirror arrangement with clock drive that reflects light from a celestial body to a fixed position for an extended period of time.

Ruhmkorff induction coil was used to produce the electric sparks necessary to volatize the elements under study.[8] When used in conjunction with one of the dynamos, this coil readily gave one thousand ten-inch sparks per minute.

The optical and photographic instruments employed were also of the very highest quality:

> Not only are there complete spectroscopes and cameras of all sorts, but there are also lenses, prisms, and gratings of the best materials and the finest workmanship, ready to be used in extemporizing any apparatus needed in research. A lathe, a file bench, and a carpenter's bench, each with its full set of tools, and a conveniently arranged dark room for photographic work, complete the appointments of this beautifully finished room.[9]

Within a short time, Draper's laboratory acquired the reputation of being the best-equipped in America.

As an introduction to his investigation of the spectra of the fixed stars, Draper felt it was necessary to prepare a trustworthy map of the solar spectrum lines, so that the wavelengths of these lines could be determined with precision. To do this accurately, he employed a diffraction grating rather than a prism, for whereas a prism spreads

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[8] Heinrich Daniel Ruhmkorff, a German precision instrument maker, opened a workshop in Paris in 1840. The Ruhmkorff induction coil, invented in 1851, produced a high-tension current through a sudden interruption of direct current in its primary armature winding.

[9] Barker, "Memoir of Henry Draper," op. cit., p. 114.

out the blue end of the spectrum more than that of the red, a diffraction grating yields a normal spectrum--i.e., one in which equal distances correspond to equal differences in wavelength. The grating which Draper used was a glass plate ruled with 6,481 lines to the inch made by Lewis Morris Rutherfurd.[10] The ruled part of the glass plate was 1 8/100-inch long and 64/100-inch wide.

A diffraction grating produces a series of spectra, with the various spectra referred to as different orders. For his photographs, Draper decided to use the spectrum of the third order because of two conspicuous advantages which it possesses. In the first place, while it is dilated to such an extent that it produces a long image, yet it is not too faint to be copied by a reasonable exposure of the sensitive plate. And secondly, the spectrum of the second order overlaps it in such a way that some of the more prominent Fraunhofer lines of the second order fall very nearly onto prominent lines of the third order. These coincidences can then be used in determining the true wavelengths of all the

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[10]Rutherfurd, like Draper, was an independently wealthy New York amateur astronomer, who gained international fame primarily from the high-quality diffraction gratings he ruled and sent gratis to leading astronomers in America and Europe. See further B.A. Gould, "Memoir of Lewis Morris Rutherfurd," _Biog. Mem. Nation. Acad. Sci._ 3 (1895), 415-41; John K. Rees, "Lewis Morris Rutherfurd," _Cont. Obs. Columbia Univ._ 1 (1906), 5-15; and a description of his work which was rewarded with the Rumford Medals in _Proc. Amer. Acad. Arts Sci._ 9 (1874), 303-08.

intermediary Fraunhofer lines.[11]

Draper's best photograph included on a single plate a very large portion of the solar spectrum, which clearly showed all the lines from G to O--i.e., from wavelength 4350 to wavelength 3440.[12] Comparing his photograph to previous maps, even to "the finest maps drawn by hand, such as those in the celebrated 'Spectre normal du soleil' of A. J. Ångström," Draper proudly claimed the superiority of his photograph: "Between wave-lengths 3925 and 4205 Ångström shows 118 lines, while my original negative has at least 293."[13]

The next step was to produce and apply a scale to the photograph reading to ten-millionths of a millimeter, so that the wavelengths of the Fraunhofer lines could be directly read out. At first, Draper tried to reduce Ångström's maps to the proper dimensions, but this undertaking proved to be unsuccessful. After many abortive attempts, he was compelled to rule his own scale with a linear dividing engine. He then photographically reduced this divided scale to the proper size to fit his spectrum photograph. "It follows, therefore,

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[11] Henry Draper, "On Diffraction-Spectrum Photography," _Phil. Mag._ 46 (1873), 419.

[12] The prominent dark lines between A and I were mapped by Fraunhofer in 1814, and extended into the ultraviolet region by Mascart in 1864. See Éleuthère Mascart, "Recherches sur le spectre solaire ultra-violet et sur la détermination des longuers d'onde," _Ann. sci. Éc. Norm._ 1 (1864), 219-62.

[13] "On Diffraction-Spectrum Photography," p. 418.

that the lines in the solar spectrum are correctly represented in their relative positions."[14]

Draper's diffraction-spectrum photograph was the finest of its kind ever made. John Browning, the London instrument maker, wrote Draper: "I am glad you have stated so clearly that the plate is a perfectly untouched photograph, for I have not been able to get my friends to believe this in many instances."[15] Charles A. Young at Dartmouth College also highly praised the photograph and memoir Draper published describing it and the methods he employed in obtaining it: "I regard the paper as one of the most important published for a long time."[16] A. J. Ångström, who was probably the greatest living authority on such matters, called the photograph "extraordinarily beautiful and the most perfect I have ever seen."[17] Father Angelo Secchi in Italy reproduced the spectrum on steel and published it in his famous monograph, _Le soleil_,[18] and in 1880 a lithographed copy of the plate

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[14]_Ibid_.

[15]John Browning to HD, January 7, 1874, Draper Papers, NYPL.

[16]Charles Young to HD, June 5, 1874, Draper Papers, NYPL.

[17]A.J. Ångström to HD, February 21, 1874, Draper Papers NYPL.

[18]Barker, _op. cit._, p. 100.

was published in the <u>Report of the British Association for the Advancement of Science</u> as the most suitable reproduction known for the purpose of determining the wavelengths of the solar lines.[19] As a result of this line of investigation, Draper came to be recognized as an authority on solar spectroscopy, a fact which played an important role when he presented his new theory of the solar spectrum four years later.

Draper's astronomical researches were interrupted the following year when he was appointed Director of the Photographic Department of the Transit of Venus Commission. In October, 1873, Simon Newcomb, the Secretary ofthe Commission, had written Draper to see if he would be inclined to accept a position with the Commission were one offered him:

> I write you privately to know whether the Transit of Venus Commission can secure your services in making its arrangements for photographing the phenomenon...As the matter is not yet formally decided upon by the Commission, I beg you to consider this letter a personal one from me.[20]

Draper responded that he would be willing to work for the Commission, but only if his position would be an honorable one:

> I acknowledge that in many respects the proposition is very agreeable to me but ...I, of course, should like to ascertain

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[19]The plate faces p. 300.

[20]Simon Newcomb to HD, October 9, 1873, Draper Papers, NYPL.

> exactly what position or connection I should have with your great scientific operation. I wish it to be understood that I do not allude to pecuniary compensation as that is a secondary matter ...But an honorable position would tempt me greatly.[21]

Draper, of course, was implying that the position would have to be above that of merely a photographer for him to accept it.

The Commission, however, was not at that time willing to offer him any higher position, and so Newcomb was obliged to retract his initial offer:

> I am sorry to say that after discussing the matter with some other members of the Commission we found difficulties in the way of making our photographic work suitable to a gentleman of your position.[22]

Newcomb understood perfectly well the implications of Draper's earlier response:

> I believe I once asked you whether you thought you could be induced to go out as photographer of one of the parties, but I never repeated the question for the reason that in view of the facts that nearly all our photographers would be mere manipulators, and that there would be little or no field for the exercise of scientific talent, the position was not one I could advise you to accept.[23]

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[21]HD to Simon Newcomb, October 14, 1873, Simon Newcomb Papers, Library of Congress.

[22]Simon Newcomb to HD, October 21, 1873, Draper Papers, NYPL.

[23]*Loc. cit.*

In February of the following year, however, the Commission changed its position, and Newcomb now made a firm offer to Draper:

> That Dr. Henry Draper of New York be invited to take charge, under direction of the Commission, without pay, of the work of putting into successful execution the various operations necessary for photographing the Transit of Venus by the methods already decided upon by the Commission, and of instructing the parties in these operations.[24]

Draper accepted this offer, and left New York early in April.

Draper spent the next three months in Washington, devising improved observational methods, testing instruments, and instructing those who were to use them on the expeditions. Although he did not join any of the expedition parties, the Commission deemed his services so valuable that after the transit it asked Congress to order a special gold medal to be struck in his honor at the U.S. Mint in Philadelphia. The medal bears the representation of a siderostat in relief, and the inscription, in Latin, "He adds luster to ancestral glory."[25] This was the first time that an American scientist had received such an honor.

Returning once again to his astronomical researches,

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[24] Simon Newcomb to HD, February 11, 1874, Draper Papers, NYPL.

[25] [E.L. Youmans], "Sketch of Professor Henry Draper," op. cit., p. 408.

Draper was desirous of comparing the performance of his 28-inch reflector against that of a large refractor. Accordingly, he ordered from Alvan Clark and Sons, in the winter of 1875, a refractor of 12 inches clear aperture. The lens, having a focal length of 183 inches, was completed in September, and was mounted on the same equatorial stand as the large reflector. Alvan Clark tnought this objective one of the best he had ever seen; while testing it, his son Alvan Graham Clark had discovered the companion star of 102 Herculis.[26] Photographs of the moon taken with the two telescopes were of about equal clarity; the terraces and multiple cones in the crater Copernicus were visible in both.

In the summer of 1876, the refractor was furnished with a Rutherfurd grating, and spectra of the sun, moon, planets, and stars were examined. In July, he devised an apparatus which he called a "spectrograph." It consisted of an entrance slit, employed to purify the resulting spectrum and to permit the impression of reference spectra; a Browning direct-vision spectroscope, containing either three, six, or nine prisms at will; a 7-inch Voigtländer portrait lens; and finally an ordinary pocket camera. The entire apparatus

[26] Deborah Jean Warner, Alvan Clark and Sons, Artists in Optics (Washington, 1968), 57-58. In 1880, Draper returned this telescope to the Clarks in partial exchange for a newer model; it was subsequently sold to the Lick Observatory, and was used by E.E. Barnard to take exquisite photographs of comets and nebulae.

fit into a box about three feet long, which screwed into the tailpiece of the reflector in place of the eyepiece. With it, Draper took several photographs of the spectrum of Vega, but the results were not materially different from those obtained by his earlier methods. Since the apparatus was awkward to manage, it was abandoned and other ideas were tried out.[27]

Another apparatus which Henry experimented with at this time was an instrument he called a "registering transit spectroscope," the idea of which had been suggested to him by John William Draper. The principle behind this was to drive the observing telescope of the spectroscope by clock work, and to register on a chronograph the transits of the Fraunhofer lines as they passed a spider line in the eyepiece of the spectroscope. John William considered this a capital invention: "If your fingers are not quick enough to touch off the different lines, Anna's piano-practiced ones will do it. *I consider this the most important improvement in the spectroscope that has yet been made.*"[28]

Unfortunately, however, in practice the registering transit spectroscope did not work very well. The main difficulty encountered was the fact that no two observations gave the same reading when the lines of the solar spectrum were

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[27]Barker, *op. cit.*, p. 103.

[28]John William Draper to HD, August 15, 1875, Draper Papers, NYPL.

observed. This was primarily due to minute irregularities in the wheelwork of the driving clock and in the shape of the teeth. Experiments with this instrument, like those with the spectrograph, had to be abandoned.

John William was well aware of the fact that his son's astronomical researches were not only unique, but also of fundamental importance. As was his custom, he pushed Henry hard, knowing that he was capable of great accomplishments:

> You can either make star spectra, or examine different regions of the sun's surface, and have a paper ready for the Astronomical Society before Christmas. To do this you ought to come out every day on the 4 o'clock train, have dinner on your table at 5, have the carriage at your door at 6, get to Hastings at 6½ and work till 9½, then go home. Permit nothing whatever to interfere with this program and you will accomplish a great deal.[29]

Henry did push himself hard that fall, doing extensive experiments with various forms of spectroscopic apparatus. During September he tried putting the Browning direct-vision prism, without slit or lenses, inside the focus of the 12-inch refractor. In October, a Huggins-designed star spectroscope employing a single prism was attached to the refractor, and at first used with a wide-open slit. During the same month experiments were made upon the spectrum of Venus, using both the reflector and the refractor, the former giving

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[29] _Loc. cit._

much the stronger pictures.[30] In February he published a note describing photographs he had taken of the spectra of Venus, Vega, and Altair (just missing John William's suggested Christmas deadline).[31]

The summer of 1877 was probably one of the most exciting ever for Draper--it was marked by his reading of a paper before the American Philosophical Society in July describing his alleged discovery of oxygen in the sun and a new theory of the solar spectrum (which will be discussed at length in the following chapters), and by his alleged discovery of a new satellite of Mars.

Considerable excitement was aroused when Asaph Hall announced his discovery of two Martian satellites during the particularly favorable opposition of August, 1877. Hall's discovery was not simply the good luck of a keen observer, for his search was deliberate and guided by gravitational theory.[32] During the days prior to his discovery, he was worried he might be anticipated by his assistant:

> In the case of the Mars satellites there was a practical difficulty of which I could not speak in an official Report.

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[30] Young and Pickering, _op. cit._, pp. 238-39.

[31] Henry Draper, "Photographs of the Spectra of Venus and α Lyrae," _op. cit._

[32] This point is emphasized in Owen Gingerich, "The Satellites of Mars: Prediction and Discovery," _J. Hist. Astr._ 1 (1970), 109-15.

> It was to get rid of my assistant...by the greatest good luck Dr. Henry Draper invited him to Dobb's Ferry at the very nick of time. He could not have gone much farther than Baltimore when I had the first satellite in hand.[33]

The assistant Hall wanted to get rid of was Edward Holden, a young protégé of Simon Newcomb at the Naval Observatory, and a personal friend of Draper's.

Hall's suspicions that Holden would try to get into the act were quickly confirmed. On August 28, Holden wrote Hall from Dobb's Ferry that he and Draper had detected a third satellite of Mars on August 26 and 27. Hall's response, addressed to Draper, was cordial:

> I am so human that I wanted to get all the Mars moons, but as this cannot well be I want you and Holden to come next...Considering the battery of telescopes now turned on Mars you are well entitled to praise.[34]

His praise turned to skepticism, however, after he repeatedly looked for the new satellite but could not find it:

> I have looked carefully but without success. It is very singular, and some things I cannot account for. Aug. 28 was the best night I have had, and I looked...in the place you give and could see nothing. Next day came

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[33]Asaph Hall to E.C. Pickering, February 14, 1888, Hall Papers, Harvard University Archives. Quoted in Gingerich, p. 112.

[34]Asaph Hall to HD, August 30, 1877, Draper Papers, NYPL.

> letters from Draper saying that on the same night, at the same time, he and his brother Daniel saw your moon in the place we were looking at.[35]

Even though Holden's and Draper's alleged discovery of a third Martian satellite had not yet been confirmed, excitement at the Hastings observatory ran very high. A good sense of this excitement is conveyed in a letter which Daniel wrote to Anna Draper relating the events of an evening's observations:

> Having wound up the clock, turned the dome, pointed the telescope at that world-renowned warrior, I very soon discovered that there was a star or satellite two diameters off, Antonia now mounted the ladder, and instantly exclaimed oh!!!I see it, ah!!!!!the satellite, she now descended and the Esquire Edward [Dixon, Antonia's husband] mounted the ladder as if he were judge of some terrible criminal case. He remarked, I see it, it is there two diameters to the right hand, a little above the center of the planet, I think, no, yes, no, humph, yes I do another a little above and nearer in, is that the Doctor's?...I now wound up the clock, adjusted the instrument, and left them to watch the planet and guard the premises, and the valuable canine Hector to guard them from the robbers that attacked Mr. Peterson, the Lager Bier man of Hastings, who had seven shots fired at him on Saturday night while he was shutting up his saloon...Having thus left the two children to watch and guard, and be guarded, I assayed to wake my Father

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[35]Asaph Hall to Edward S. Holden, September 7, 1877, Draper Papers, NYPL.

> from his gentle slumbers. After a short time he appeared at the Observatory door, armed with the key of the back door of the house, so that the burglars should not disturb the slumber of our good and worthy Aunt [Catherine]. Father took his position on the ladder soon saw the bright satellite, and after a few moments saw the other doubtfully. It was now approaching the hour of 1 A.M. he thought we children had better shut up and go to bed, but we thought otherwise, so I escorted him home, locked the back door, put the key in my pocket, and returned to the observatory. There I found the two children still Mars gazing...We watched till nearly two A.M. when we decided...that it was time to shut up and go home. Remarking as we sauntered in that direction that it was one of the most beautiful nights that we ever remembered to have seen, the stars did not twinkle, there was not a breath of air stirring, the temperature about 60°, the dew gently falling, and the night silently passing away.[36]

Two weeks later, Holden confused matters even further by claiming to have observed a fourth satellite of Mars since September 24th. He was eager to publish a joint article with Draper to publicly announce their discovery,[37] but was counseled against this by John William Draper: "We shall be hearing from the foreign observatories in a few days... for this reason I think it desirable to wait."[38] John William

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[36] Daniel Draper to Anna Draper, September 10, 1877, Draper Papers, NYPL.

[37] See, e.g. Edward S. Holden to Mrs. Draper, September 4, 1877, and Edward S. Holden to HD, September 22 and 26, 1877, Draper Papers, NYPL.

[38] [John William Draper] to Edward S. Holden, September 8, 1877, Draper Papers, NYPL.

was waiting especially to hear if the new satellite had been observed with the great 48-inch Melbourne reflector, especially since Mars was better placed for southern observers. But confirmation did not arrive from there or from any other observatory, and Holden finally conceded defeat:

> I have now satisifed myself that there is no satellite of Mars visible (under extremely good conditions) in the place where ours of Aug. 26-27-28 should be. There is a great number of small <u>stars</u> about this region--an astounding <u>number</u>, and I believe the observ[ation]s Aug. 26 and 27 were observations of this nature.[39]

John William's advice proved to be sound, and it was fortunate for both Holden's and Draper's reputations that they did not rush into print with their "discovery."

The remainder of 1877 was occupied mainly with work connected with Draper's research upon the alleged existence of oxygen in the sun. In 1878, the observing season was occupied with a transit of Mercury in May, and a solar eclipse in July; so that nothing was done with stellar spectra during these two years. In the spring of 1879, Draper went to England to address the Royal Astronomical Society with regard to his alleged discovery of oxygen in the sun. While there he visited Huggins, who informed him that dry photographic plates had become more sensitive than wet collodion ones.

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[39]Edward S. Holden to HD, September 26, 1877, Draper Papers, NYPL.

Huggins had found for himself the advantages of using dry plates:

> [At first] I used wet collodion, but I soon found how great would be the advantages of using dry plates. Dry plates are not only more convenient for astronomical work, being always ready for use, but they possess the great superiority of not being liable to stain from draining and partial drying of the plates during the long exposures which are necessary even with the most sensitive plates. I then tried various forms of collodion emulsion, but finally gave up in favour of gelatine plates, which can be made more sensitive.[40]

The definition that Huggins obtained with these plates was so good that the photographs could be examined with advantage even under a microscope.

Draper returned to New York with the best dry plates then available, those made by the firm of Wratten and Wainwright, and used them exclusively from that time on. The plates made by the collodion process prior to then had no value for measurement, and most of them were either lost or destroyed. Those that Draper wished to save were done so by stripping the films from the plates, and then gumming them into his notebook.

This spectroscopic apparatus that Draper used in conjunction with the new dry plates was a Browning star spectro-

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[40] William Huggins, "On the Photographic Spectra of Stars," Phil. Trans. 171 (1880), 673. See further "The Evolution of Dry Plates" in Helmut and Alison Gernsheim, The History of Photography (London, 1955), 243-54.

scope, with two 60° prisms of dense but white flint glass, of the form designed by Huggins for stellar observations. The telescope and collimator each had a focal length of six inches. The slit was covered with a diaphragm having a hole at the center, and painted with phosphorescent paint to make the aperture visible in the dark. A movable "finger" enabled any part of the slit to be exposed at will, so as to obtain spectra of different objects on the same plate side by side for reference. The eyepiece and micrometer were removed from the eye end of the observing telescope of this spectroscope, and a block of hard wood was fitted on to carry the photographic plate. A small eyepiece was mounted on the block so that the operator could examine at will the yellow and red portion of the spectrum which projected beyond the sensitive plate into the field of view, and thus assure himself that the clock work was driving properly, and that all adjustments remained correct. The whole apparatus weighed less than five pounds, and screwed on to the eye end of the telescope it was used with. The photographs obtained with this arrangement were ½-inch long and 1/16-inch wide.[41]

During the summer of 1879 Draper used the new dry plates and spectroscope in conjunction with his 12-inch refractor. With this arrangement he obtained high-quality

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[41] Young and Pickering, op. cit., p. 236.

spectrum photographs of the moon, planets, and stars. He confirmed Huggins' discovery of hydrogen in Vega, and noted that all the stars he had so far observed could be placed in Secchi's first two spectral classes.[42] In his report that year to the National Academy of Sciences, however, he cautioned, "It is not easy without prolonged study and the assistance of laboratory experiments to interpret the results, and even then it will be necessary to speak with diffidence."[43]

It was Draper's usual practice to photograph either the spectrum of the moon or Jupiter as a reference spectrum on his stellar spectrum photographs, since both shone entirely by reflected sunlight. But on one occassion, however, examination of a spectrum of Jupiter with a comparison spectrum of the moon seemed to indicate that Jupiter was giving off more light than it was reflecting from the sun. The main difference was not due to a change in the number or arrangement of the Fraunhofer lines, but rather to a variation in the strength of the background. In the case of the moon, the background was uniform across the width of the spectrum; but in the case of Jupiter, the background was noticeably stronger in the region around the Fraunhofer line F. From this, he concluded that "eruptions of heated gases and vapors of

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[42] Henry Draper, "On Photographing the Spectra of the Stars and Planets," op. cit., p. 424.

[43] Ibid.

various composition, color, and intensity of incandescence are taking place on the great planet."[44] This peculiarity in Jupiter's spectrum, first noticed by George Phillips Bond in 1860, still puzzles astronomers; recent studies conducted with photoelectric scanning monochromators show that Jupiter radiates about 1.2 times more heat than it receives from the sun.[45]

The following summer, Draper decided to return his 12-inch refractor to the Clarks in partial exchange for a newer model. The new telescope was an 11-inch refractor which the Clarks had made for the Lisbon Observatory in 1877, but which had never reached its Portuguese destination. This instrument was especially valuable because it was equipped with a special correcting lens fitted to be placed in front of the object glass to adapt it to photographic work. The focal length of the telescope without its photographic corrector was about 176 inches; with the corrector applied, it was

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[44] Henry Draper, "On A Photograph of Jupiter's Spectrum, showing Evidence of Intrinsic Light from that Planet," Amer. J. Sci. 20 (1880), 120.

[45] George Phillips Bond to R.C. Carrington, February 29, 1860. Quoted in Edward S. Holden, Memorials of William Cranch Bond and George Phillips Bond (San Francisco and New York, 1897), 185. Bond was then the Director of the Harvard College Observatory. For a recent analysis, see Donald J. Taylor, "Spectrophotometry of Jupiter's 3400-10000 Å Spectrum, and a Bolometric Albedo for Jupiter," Icarus 4 (1965), 362-73. Taylor believes that Jupiter's intrinsic heat is a remnant of the planet's original gravitational contraction energy.

shortened by 24 inches. Its equatorial stand and driving clock were made by Draper himself, and it was mounted in place of the 12-inch instrument on the same stand as the 28-inch reflector (see Fig. 2).[46]

One of the first objects the new telescope was used to examine was the Great Nebula of Orion. Draper devoted special attention to this nebula for eighteen months, with two objects in view:

> First, to ascertain whether any changes are taking place in that body by making a series of photographs to be compared in the future with a similar series; and second, to photograph the spectrum of the Nebula in various parts so as to see whether the composition is uniform throughout.[47]

His first successful photograph was taken on September 30, 1880, after an exposure of fifty minutes.[48] In order to get the much fainter portions of the nebula, the plates had to be overexposed for the stars within it.

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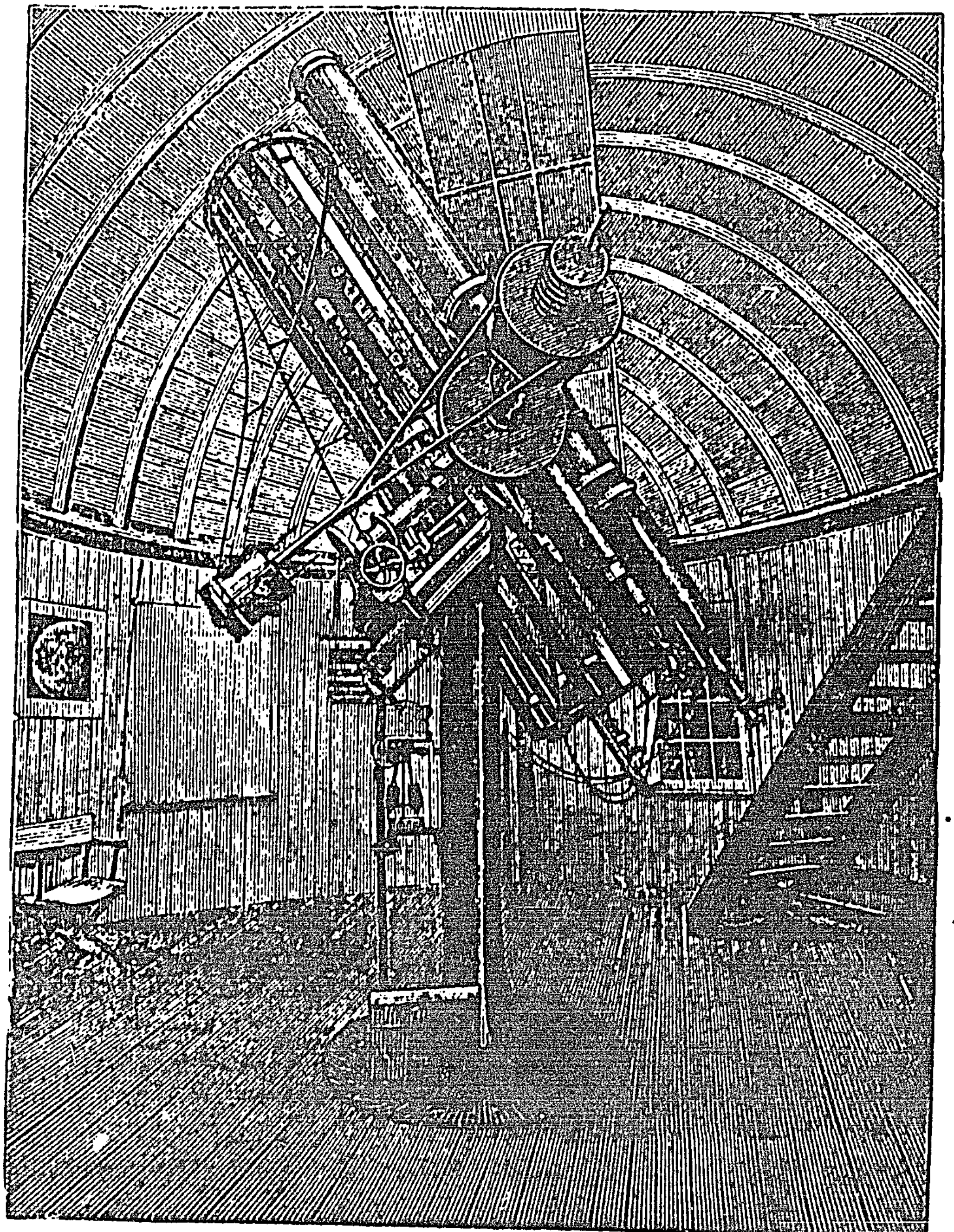
[46] After Draper's death his widow made the 11-inch available to astronomers at the Harvard College Observatory to aid them in their preparation of the Henry Draper Memorial. In 1947, Harvard sent it on a long-term loan to the Sun Yat-sen University Observatory in Canton, China. See Dorrit Hoffleit, "A Famous Old Telescope Goes to China," Sky and Telescope 7 (1947), 8-9.

[47] Henry Draper, "On Photographs of the Spectrum of the Nebula in Orion," Amer. J. Sci. 23 (1882), 339.

[48] Henry Draper, "Photographs of the Nebula in Orion," Amer. J. Sci. 10 (1880), 388.



THE TELESCOPES IN THE HASTINGS OBSERVATORY.

Fig. 2 "The telescopes in the Hastings observatory"

(From Science 1 (1883), 31)

Satisfied, however, that the project was entirely feasible, he devoted considerable time to perfecting his driving clock and to improving the details of the photographic manipulation. In March, 1881, a second and much better photograph of this nebula was taken, with an exposure of 104 minutes. Finally, a year later, on March 14, 1882, he succeeded in making a successful exposure of 137 minutes. This yielded a superb photograph, in which stars down to magnitude 14.7 were visible, and in which the faint outlying regions of the nebula were clearly and beautifully shown. This unrivaled photograph, by far the most brilliant success achieved by celestial photography up to that time, led him to speculate: "It is not unreasonable to hope that by still further prolonging the exposure and by still further study of photographic processes, stars and details entirely invisible to the ...[telescope] may be secured.[49]

Ordinarily, a photograph of the spectrum of an object is more difficult to obtain than a photograph of the object itself; but in the case of a nebula, this does not hold true. The spectrum in this case consisting of bright lines, its light easily makes an impression on the plate. Moreover, any error in the driving rate of the telescope or any tremor of

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[49] Henry Draper, "On Photographs of the Nebula in Orion, and of its Spectrum," Mon. Not. R. Astr. Soc. 42 (1882), 368.

the instrument, which in the case of the nebula itself would be fatal to the photographic definition, matters little in photographing its spectrum (since it would merely shift the image harmlessly off the slit). Draper obtained many excellent photographs of the spectrum of the Great Nebula. The best results were obtained with the two-prism spectroscope which had been employed to produce stellar spectra.[50]

Draper had succeeded in making spectrum photography the best means of studying the sky. He observed that

> It is only a short time since it was considered a feat to get the image of a ninth magnitude star, and now the light of a star of one magnitude less may he photographed even when dispersed into a spectrum.[51]

He was full of confidence, thinking he was by no means at the end of what he could do. He felt that prolonged exposures during the clear nights of the following winter would result in another step forward. But before another winter came, Draper died.

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[50] "On Photographs of the Spectrum of the Nebula in Orion," p. 340.

[51] *Ibid.*, p. 341.

CHAPTER THREE

OXYGEN IN THE SUN CONTROVERSEY, I: A NEW THEORY OF THE SOLAR SPECTRUM

Draper forsook the quiet solitude of his laboratory and entered the tumultuous world of theoretical science on only one occasion; unfortunately, this proved to be the biggest blunder of his scientific career. This took place on July 20, 1877 when he read a paper before the American Philosophical Society in which he described his alleged discovery of oxygen in the sun and a new theory of the solar spectrum. The high degree of excitement and anxiety which this aroused in him shows clearly in the covering letter he wrote to J. Peter Lesley, the Society's secretary, accompanying the manuscript of his paper:

> May I ask you to keep the contents of my paper as confidential till the meeting of the Society as I do not wish to run the risk of being anticipated in a matter of so much importance.[1]

Draper's discovery and new spectrum theory was indeed "a matter of so much importance"--it gave rise to a heated controversy amongst the leading astronomers of America and

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[1] HD to J. Peter Lesley, July 6, 1877, American Philosophical Society.

Europe which raged unsettled for nearly two decades.

In this paper, Draper explained that he had discovered oxygen in the sun not by the familiar dark Fraunhofer lines, but by bright lines in the solar spectrum. These bright lines had not been "hitherto perceived probably from the fact that in eye observations bright lines on a less bright background do not make the impression on the mind that dark lines do."[2]

Draper's new theory of the solar spectrum, therefore, meant that astronomers would have to alter their current interpretation of the solar spectrum as a bright, continuous background crossed only by dark lines, and realize that bright lines are also superposed on the background. To do so, however, would wreak havoc to the science of spectrum analysis, a science that was becoming increasingly sophisticated in the identification of solar and stellar elements. For if one admitted the existence of bright as well as dark lines, then any given dark line could either be a true Fraunhofer (absorption) line or merely a space between two bright (emission) lines. Similarly, a bright line could either be a true emission line or simply a gap between two

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[2]Henry Draper, "Discovery of Oxygen in the Sun by Photography, and New Theory of the Solar Spectrum," Proc. Amer. Phil. Soc. 17 (1877-78), 76.

Fraunhofer lines. In short, there would be no way of verifying a particular interpretation of any given spectrum line. Needless to say, spectroscopists were not about to drastically alter their ground rules without very good reasons.

But there were very good reasons. At the time of his discovery, Draper enjoyed a high reputation in the scientific communities of America and Europe. His achievements in astronomical photography and spectroscopy inclined one astronomer to regard him "as a kind of scientific Black Douglas, suitable to frighten presumptuous baby-scientists."[3] He had already been elected to membership in the American Philosophical Society and the prestigious National Academy of Sciences, and had received international recognition by election to the Astronomische Gesellschaft. Furthermore, the great success with which his 1873 diffraction-spectrum photograph of the sun and accompanying memoir was met established him as an authority on the solar spectrum. Clearly, his paper on the discovery of oxygen in the sun and a new theory of the solar spectrum had to receive very serious attention; it simply could not be ruled out of hand and ignored.

The photographs which Draper took in his research on the presence of oxygen in the sun were taken at his New York

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[3]Edward S. Holden to HD, February 7, 1874, Draper Papers, NYPL.

laboratory by using hollow prisms filled with carbon bisulphide.[4] Light from the entire solar disc was utilized in obtaining the solar spectrum by employing the beam reflected from the flat mirror of a heliostat[5] without any condenser.[6]

The laboratory spectrum was that of an open-air spark, the two terminals being of iron and aluminum, respectively. An open-air spark spectrum was deemed preferable to that of an exhausted (vacuumized) Plücker tube[7] for two reasons. In the first place, a stronger current could be used. This resulted in the production of a brighter light, which allowed the slit of the spectroscope to be narrower, giving a sharper picture. Secondly, it allowed the use of an iron terminal. This allowed Draper to line up the iron spectrum with known iron lines in the solar spectrum, thus avoiding any error arising from accidental displacement of the reference spectrum. In order to be certain that his laboratory lines did, in fact,

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[4]George F. Barker, "On the Use of Carbon Bisulphide in Prisms; being an account of Experiments made by the late Dr. Henry Draper of New York," Amer. J. Sci. 29 (1885), 269-70. The prisms were filled with carbon bisulphide in order to produce greater dispersion.

[5]A heliostat is a mirror which is so arranged that it can follow the motion of the sun, sending the solar image to the spectroscope.

[6]A condenser is an auxilliary lens which is sometimes placed in front of the slit to concentrate the light from the source.

[7]Similar in shape to an hourglass but with a relatively long capillary section in the middle, the Plücker tube produced a brilliant illumination in its narrow section.

correspond to oxygen lines, he compared, under various pressures, the spectra of air, oxygen, nitrogen, carbonic acid, carburetted hydrogen (methane), hydrogen, and cyanogen in Plücker tubes with their open-air spark spectra. As a further precaution, a double set of photographs was taken when these gases were in Plücker tubes--one set taken with, and the other without, Leyden jars.[8] This was necessary because certain gases give different spectra according to whether or not a Leyden jar is put in the circuit.

The wavelengths of the solar spectrum lines were taken partly from Ångström,[9] and partly from Draper's own 1873 solar diffraction spectrum.[10] By taking into account not only the correspondence in position of the laboratory and solar oxygen lines but also their relative strengths and general physical aspects, Draper noted the presence of eighteen bright oxygen lines in the solar spectrum. The most prominent of these were single lines at wavelengths 4069, 4072, 4076, and 4133; two sets of double lines at 4184 and 4190, and 4317 and 4319; and a set of quadruple lines between 4345 and 4350 (see Fig. 3).

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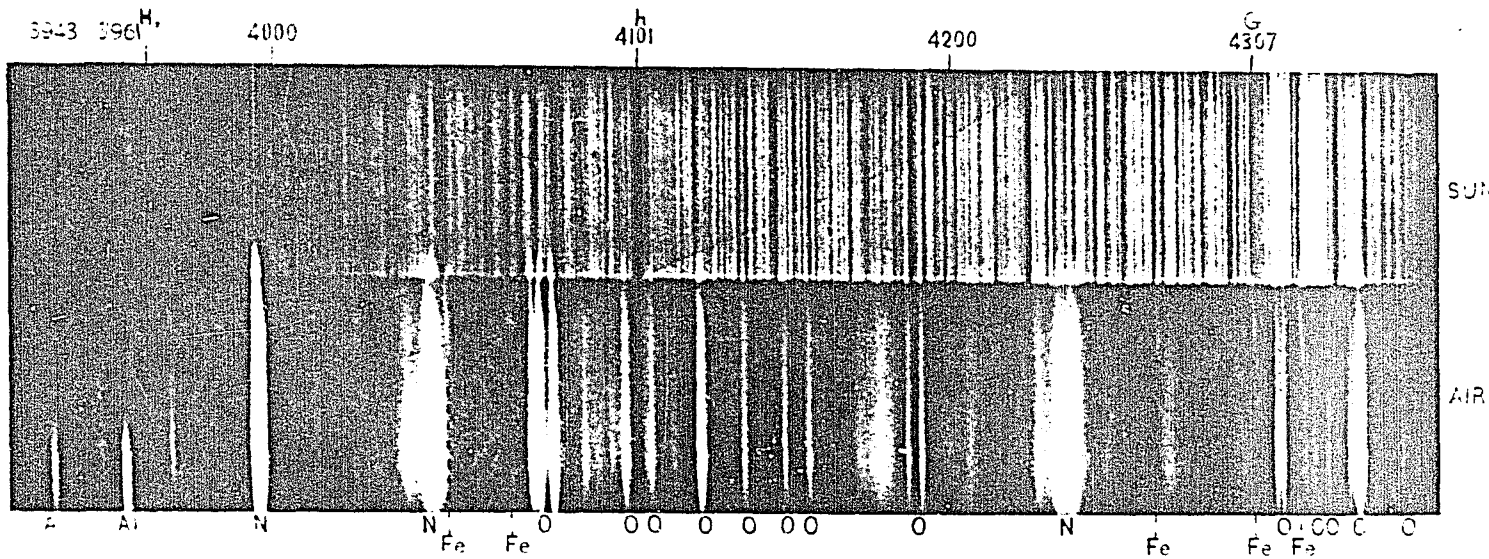
[8] "Discovery of Oxygen in the Sun...," pp. 74-76.

[9] A.J. Ångström, Recherches sur le spectra normal du Soleil (Upsala, 1868).

[10] Henry Draper, "On Diffraction Spectrum Photography," Phil. Mag. 46 (1873), 417-25.



DISCOVERY OF OXYGEN IN THE SUN BY PHOTOGRAPHY, BY PROFESSOR HENRY DRAPER. M. D, 1876.

The upper part of the photograph is the spectrum of the Sun, the lower part is the spectrum of the Oxygen and Nitrogen of Air. The letters and figures on the margin are printed with type on the negative; with this exception the photograph is absolutely free from hand work or retouching. O. indicates Oxygen, N. Nitrogen, Fe. Iron, Al. Aluminium. The figures above the Sun's spectrum are wave-lengths; G. h, H., are prominent Solar lines at the violet end of the spectrum. The principal point to examine is the coincidence of the bright Oxygen lines with bright lines in the Solar spectrum. The picture is printed from Draper's original negative by Bierstadt's Albertype process.

Fig. 3 "Discovery of oxygen in the sun by photography, by Professsor Henry Draper, M.D., 1876"

(From J. Frank. Inst. 74 (1877), facing p. 84)

The presence of oxygen in the sun offered no theoretical difficulties to Draper; in fact, he claimed that its presence was strongly suspected from purely theoretical considerations derived from terrestrial chemistry and the nebular hypothesis. From chemical considerations, he argued that since oxygen forms eight-ninths of the water of the globe, one-third of the crust of the earth, and one-fifth of the air, it should be a large constituent of every member of the solar system. Similarly, since the nebular hypothesis postulates an initial uniform composition to the entire solar system (i.e., a hot, gaseous mass extending beyond the orbit of the furthest planet), we should expect the chemical composition of all the ultimate members of the solar system to be similar.[11]

Just as Draper had reasons for believing that oxygen should be present in the sun, so had he explanations as to why the oxygen lines were bright instead of dark. On general grounds, he suggested that the nonmetals might "behave differently" than the metals. He argued that the case of the D_3 line (helium) strengthened the supposition of exemptions from the well-known spectrum laws of emission and absorption,

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[11]"Discovery of Oxygen in the Sun...," p. 76. See also Draper's "The Spectroscope and its Revelations," The Galaxy 1 (1866), 313-19 for a fuller statement regarding the application of spectroscopy to the establishment of the nebular hypothesis.

for while there could be no doubt of the existence of an ignited gas in the solar chromosphere giving this line, yet there was no corresponding dark line in the spectrum of the solar disc, as spectrum theory demanded.[12] Draper's main explanation, however, was that "the intensity of light from a great thickness of ignited oxygen overpowers the effect of the photosphere" below.[13]

Because Draper's explanation of the bright lines "revealed a failure to appreciate the significance of Kirchoff's law[s] of radiation,"[14] and because his new theory of the solar spectrum would have wreaked havoc to the science of spectrum analysis, a heated controversy arose between those who believed in and defended his results, and those who would not or could not accept them. While the controversy ostensibly centered around the existence of oxygen in the sun, the real point at issue was whether or not bright lines existed in the solar spectrum. If they did, how could they be differentiated from the bright continuous background

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[12]Applying the well-known spectral laws of Kirchoff and Bunsen to the sun, an element that gives a bright-line spectrum in the chromosphere should have its spectral lines rendered dark by the reversing layer when observed in the photosphere.

[13]"Discovery of Oxygen in the Sun...," p. 76.

[14]Charles Whitney, "Henry Draper," article for the forthcoming Dictionary of Scientific Biography. I wish to thank Prof. Harry Woolf for allowing me to use the associate editor's copy of the author's original prior to its publication.

spectrum? On what physical grounds could their presence be explained? In short, the real question that had to be answered by astronomers was how should the solar spectrum be interpretted?

Less than a week after Draper read the paper congratulatory letters started to pour in. This personal correspondence, with few exceptions, was unabashedly enthusiastic. Holden called it a "brilliant discovery," one which "knocks the bottom out of all Christianity."[15] Young was "delighted," and congratulated Draper "most heartily."[16] Henry Morton, the President of Stevens Institute of Technology, termed it "an admirable contribution...to American science," and dashed off his note at the first opportunity, even "though the night is hot and my pen is very bad."[17] Samuel Pierpoint Langley, the Director of the Allegheny Observatory, claimed that "in itself, and in its bearing on theory, it is, it seems to me, one of the most notable steps in the history of the spectroscope."[18] Newcomb assured Draper that "I have studied it carefully, and am more and more convinced it won't be easily

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[15]Edward S. Holden to HD, July 26, 1877, Draper Papers, NYPL.

[16]Charles A. Young to HD, July 27, 1877, Draper Papers, NYPL.

[17]Henry Morton to HD, July 30, 1877, Draper Papers, NYPL.

[18]Samuel Pierpoint Langley to HD, August 1, 1877, Draper Papers, NYPL.

explained away."[19] In a similar vein, George F. Barker, Professor of Physics at the University of Pennsylvania and an intimate friend of Draper's, wrote that "the evidence is so positive that it must be accepted...Yes...the fact is not to be disguised, disproved or discouraged; there is oxygen in the sun and no mistake."[20] H.C. Vogel, one of Germany's most eminent astronomers, lavished great praise on Draper: "Your discovery is the most important made since Kirchoff['s] and Bunsen's, it opens a new field for sun observations and for physical astronomy in general it gives a quite new idea over the constitution of the sun['s] surface."[21] Similar letters of congratulations came in from William Lassell,[22], C. Piazzi Smyth, the Astronomer Royal of Scotland,[23] and C.H.F. Peters, the Director of the Litchfield Observatory.[24] But perhaps

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[19]Simon Newcomb to HD, August 2, 1877, Draper Papers, NYPL.

[20]George F. Barker to HD, August 15, 1877, Draper Papers, NYPL.

[21]H.C. Vogel to HD, August 16, 1877, Draper Papers, NYPL.

[22]William Lassell to HD, August 25, 1877, Draper Papers, NYPL.

[23]C. Piazzi Smyth to HD, August 28, 1877, Draper Papers, NYPL.

[24]C.H.F. Peters to HD, September 10, 1877, Draper Papers, NYPL.

the most perceptive remark of all came from William Huggins, who saw in this discovery the beginning of a great future for American astronomy: "You Americans have 'l' avenir du Monde,'" he admitted.[25]

The printed responses to Draper's discovery and new solar theory were, as might be expected, couched in a more cautious, guarded tone; they were the result of careful reflection and experimentation, and if they were enthusiastic, they were so in a detached scientific, not personal, manner. The first such response came from Arthur Schuster, some five months after Draper's announcement. Schuster had studied under Kirchoff at the University of Berlin, had worked under Helmholtz there, and was currently a member of the Cavendish Laboratory. From his investigations of the spectra of oxygen conducted there, Schuster found that there were four distinctly different spectra of oxygen, depending on the temperature of the gas. At its highest temperature level, oxygen would give rise to bright lines in the solar spectrum--but only if it was situated in a gaseous envelope located between the reversing layer and the photosphere, and at a higher temperature than the latter. At a lower temperature level, however, oxygen produced what he called its compound line spectrum, and would be marked in the solar spectrum by the familiar

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[25]William Huggins to Edward S. Holden, October 3, 1877, Draper Papers, NYPL.

dark Fraunhofer lines. If oxygen existed in the sun, therefore, it could be identified by bright lines at a high temperature, and by dark lines at a lower temperature.

Schuster accepted Draper's discovery as the bright lines of oxygen at a high temperature, and turned to an examination of the solar spectrum to see if he could find the compound line spectrum of oxygen at a lower temperature, marked by dark lines. His results are given in the table below:[26]

compound line spectrum of oxygen	width	Fraunhofer lines	
		Ångström	Schuster
α 6156.86	± 0.3	6156.70	6156.69
β 5435.55	± 0.3	5435.44	5435.56
γ 5329.41	± 0.6	5329.30	5329.10
δ 4367.62		4367.58	

The first column gives the wavelengths of the compound line spectrum of oxygen as determined from his laboratory experiments. The second column gives the number which has to be added or subtracted from the wavelength in order to get the edge of the lines, since it is their centers which are given in the first column. The third and fourth columns give the wavelengths of the corresponding Fraunhofer lines as observed by Ångström and himself. Thus Schuster believed that oxygen

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[26] Arthur Schuster, "On the Presence of Oxygen in the Sun," Nature 17 (1877-78), table on p. 148. See also Schuster's "On the Spectra of the Metalloids--Spectrum of Oxygen," Phil. Trans. 170 (1879), 37-54 for a fuller treatment of his experiments relating to the four different oxygen spectra.

did exist in the sun, and although it had been heralded by Draper's discovery of bright lines, it could also be identified by his own dark compound lines.

Schuster's explanation of the bright oxygen lines was quickly challenged by a chemist, Raphael Meldola.[27] Meldola argued that the gaseous layer between the photosphere and the reversing layer--the zone wherein Schuster thought the bright-line spectrum of oxygen originated--could not be higher in temperature than the photosphere; it would either be the same temperature or, more likely, lower. But in neither of these cases could it give rise to a bright-line spectrum. Meldola further held that Draper's explanation of the bright lines--viz., that they eminate from an enormously thick layer of oxygen, a stratum so thick that the radiation of the gas overpowers the fierce glare of the photosphere below it--was likewise untenable. Although he believed that Draper had in fact proven the existence of oxygen in the sun, he could not at that time explain why the oxygen lines were bright instead of dark.[28]

Some six months later, however, he came forth with an

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[27]Meldola was a demonstrator at the Royal College of Chemistry. He was also a Fellow of the Royal Astronomical Society and was an assistant to Lockyer and Frankland in their spectroscopic investigations.

[28]Raphael Meldola, "Oxygen in the Sun," Nature 17 (1877-79), 161-62.

explanation. Meldola postulated the existence of what he termed a zone of combustion, lying above the reversing layer, between the chromosphere and the corona. The high temperature of this zone, he argued, renders oxygen incandescent, and this in turn gives rise to a bright-line spectrum. This is possible even in spite of the intense background light of the photosphere and in spite of the fact that the temperature of the zone of combustion in all probability is lower than that of the photosphere, because the light radiated by the latter is greatly weakened before it reaches the zone of combustion. This weakening is due not only to the distance of this region from the photosphere, but also because of the absorption, both selective and general,[29] which the light undergoes in passing through the intervening reversing layer and chromosphere, respectively.

Having apparently explained the bright lines of oxygen discovered by Draper, Meldola went on to explain the dark lines of oxygen discussed by Schuster. The temperature of the region outside the zone of combustion must fall off, he argued, so that any oxygen which might exist there would be at the temperature level associated with the compound line spectrum of oxygen, and would, therefore, give rise to

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[29]Selective absorption is absorption that is related to the wavelength of light, while general absorption is not.

the dark lines Schuster had observed. Meldola thought that his postulation of a zone of combustion was all that was needed to perfectly explain the bright and dark lines observed in the solar spectrum: "Thus the solar spectrum as now known is shown to be in complete accordance with the hypothesis here advanced."[30]

Spurred on by Schuster's and Meldola's acceptance of his discovery, Draper published a letter in January, 1878 in which he alluded to some experiments he had performed to determine the exact location of the oxygen in the sun. If Meldola's theory was correct, he reasoned, then the incandescent oxygen in the zone of combustion should be directly visible spectroscopically in the area between the chromosphere and the corona as bright lines.

Draper had made such an investigation, using a Rutherfurd grating of 17,280 lines to the inch attached to his 12-inch Clark refractor, and had employed the full aperture of the telescope to produce an image of the sun on the slit of the spectroscope. Although he saw a large number of reversed (i.e., bright) lines, he was unable to see any of the bright lines of oxygen. Examining Young's catalogue of bright lines in the chromosphere,[31] Draper noted that Young

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[30]Raphael Meldola, "On a Cause for the Appearance of Bright Lines in the Solar Spectrum," _Phil_. _Mag_. 6 (1878), 58.

[31]Charles A. Young, "Letter to the Superintendent of the United States Coast Survey, containing a Catalogue of

too did not observe any bright lines of oxygen. This corroborated his view that the bright-line spectrum of oxygen must have its upper limit closer to the apparent spectroscopic limb of the sun. Meldola's hypothesis of a zone of combustion was apparently incorrect, because no incandescent oxygen could be observed in the area of the corona.[32]

The total solar eclipse of July 29, 1878 afforded an opportunity to reexamine this conclusion by allowing Draper to investigate the corona to see if it contained incandescent oxygen (or any other incandescent gases), or shone merely by reflected sunlight. If the light of the corona was due to incandescent gases, its spectrum would be a series of bright ring-like images, one ring for each bright line. If, on the other hand, it was due to an incandescent solid or liquid (which was not considered very likely), or was simply reflected sunlight, its spectrum would simply be a long band. A result that produced both rings and a band would signify that the light of the corona was due partly to incandescent gases and partly to reflected sunlight.

Draper's observations of the eclipse were made at Rawlins, Wyoming at a station 6,732 feet above sea-level.

Bright Lines in the Spectrum of the Solar Atmosphere...," Amer. J. Sci. 4 (1872), 356-62.

[32]Henry Draper, "Oxygen in the Sun," Nature 17 (1877-78), 339-40.

His main instrument was a device called a phototelespectroscope, which employed a quadruple achromatic objective of 6-inch aperture. Before the beam of light from the lens reached a focus, it was intercepted by a Rutherfurd grating ruled on speculum metal set at an angle of sixty degrees. This threw the beam to one side, and produced there three images--a central one of the sun, and on either side of it a spectrum of the first and second order. These images were then received on three separate photographic plates.

Immediately after totality, Draper developed his plates and found that the spectrum photographs were continuous bands without the least trace of a ring.[33] Similar findings were reported by Barker,[34] Young,[35] and Lockyer.[36] The obvious conclusion to be drawn from these observations was that the light of the corona was not due to any incandescent gases. Since it was deemed highly unlikely that it was due to either an incandescent solid or liquid, the general conclusion was that the corona shone simply by re-

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[33]Henry Draper, "The Eclipse," _Nature_ 18 (1878), 462-64.

[34]George F. Barker, "On the Results of the Spectroscopic Observations of the Solar Eclipse of July 29, 1878," _Amer. J. Sci._ 17 (1879), 121-25.

[35]Charles A. Young, "Observations upon the Solar Eclipse of July 29, 1878...," _Amer. J. Sci._ 16 (1878), 279-90.

[36]J. Norman Lockyer, "The Eclipse," _Nature_ 18 (1878), 457-62.

flected sunlight (reflected, Draper thought, by a cloud of meteors surrounding the sun). This finding further increased the liklihood that Meldola's postulation of a zone of combustion was incorrect, since once again no incandescent oxygen could be observed in the area of the corona.

Up to this point, nearly a year after the announcement of his findings, Draper's discovery had not been seriously challenged by anyone. Although Schuster and Meldola both disagreed with his explanation of the bright lines, yet no one actually doubted their existence in the solar spectrum. The first serious attack on this front came from Lockyer in May, 1878. In the first place, Lockyer regarded Draper's claim for the discovery of the bright lines as "a very great pity," for their existence was knowledge ten years old, and suggested that had Draper but known this, he would not have proposed his new theory of the solar spectrum:

> I think that, if the very considerable literature touching these bright lines (papers by Young, Cornu, Hennesy, Secchi, and others) had been before Dr. Draper when his paper was written, the necessity for the establishment of a new theory of the solar spectrum, which doubtless cost him very considerable thought, would probably have been less obvious.[37]

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[37] J. Norman Lockyer, "Recent Researches in Solar Chemistry," Phil. Mag. 6 (1878), 174-75. Lockyer's reference to the earlier literature on the bright lines is misleading. John B.N. Hennesy, in a paper "On White Lines in the Solar Spectrum," Proc. R. Soc. 22 (1874), 221-22 and 23 (1875), 259-60 (appendix to the first article), is completely baffled by

Lockyer then summarily dismissed Draper's photograph of the solar spectrum. Due to a serious fault inherent in all silvered-glass diffraction gratings--viz., that as a consequence of their being ruled on the back surface and of the double transmission of the light through the plate, they radically transform the solar spectrum, making real lines disappear and spurious ones appear--he claimed that Draper's photograph was "not one which is competent to settle such an extremely important question."[38] Lockyer did not realize, apparently, that Draper's photographic spectrum was obtained by the use of carbon bisulphide prisms, and not a diffraction grating. Disregarding Draper's photograph, Lockyer turned to an examination of some prismatic spectrum photographs of the sun taken by himself, and was unable to find any bright lines in the region where Draper did.

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their presence, and is quite ready to assume that they result from some instrumental error on his part. Charles A. Young's articles on bright solar lines, viz., "Spectroscopic Observations of the Sun," Nature 3 (1870-71), 34; "Preliminary Catalogue of the Bright Lines in the Spectrum of the Chromosphere," Phil. Mag. 42 (1871), 377-80; and "Letter to the Superintendent of the United States Coast Survey...," op.cit., deal with bright lines in the spectra of prominences, sunspots, and the chromosphere. I am not sure which articles of Cornu and Secchi Lockyer is referring to, but Lockyer states that Secchi's writings were in connection with sunspots (p. 173). The point is that all of these findings are far different from Draper's discovery of bright lines obtained by utilizing light from the entire solar disc. Since these spectroscopists and Draper are talking about two very different things, Lockyer's criticism is essentially unfair.

[38]"Recent Researches in Solar Chemistry," p. 175.

Lockyer next proceeded to explain how Draper might have gotten bright lines in his spectrum. Apparent bright lines are produced, he explained, when the dispersion of the spectroscope is too small. When, however, a very large dispersion is employed, one sees that the bright lines either entirely disappear, or are nothing but empty spaces due to the absence of fine dark lines, spaces where the background of the continuous spectrum shines through. The bright lines, therefore, were not real, but merely apparent. Lockyer's final word on the matter was one of complete scepticism:

> I do not say that Dr. Draper's alleged discovery is no discovery at all; I say (and I think it is my duty to say it, as I have been occupied in closely allied work for some considerable time) that I do not hold it to be established.[39]

A month after the appearance of Lockyer's criticisms, a similar attack was levelled by William H.M. Christie, the chief assistant at the Royal Observatory at Greenwich.[40] Like Lockyer, Christie based his opinion not on Draper's photograph of the solar spectrum, but on some of his own. For his observations, Christie used a half-prism spectroscope, in which a train of two compound half-prisms giving a dispersion of seventy-five degrees was used in conjunction

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[39] Ibid., p. 176.

[40] Christie was then engaged in a program of taking daily photographs of the sun. He became England's Astronomer Royal in 1881.

with the equatorial telescope of the Royal Observatory. Carefully examining the region of the spectrum where Draper observed bright lines, Christie claimed that under the higher dispersion of his instrument, the bright lines were seen to be nothing but the background of the continuous spectrum shining through empty spaces. He was led to this conclusion by the fact that the bright spaces were about ten times the breadth of the dark Fraunhofer lines, showed no trace of fuzziness at the edges as true spectrum lines do, and did not exhibit the usual variations in tint.

Christie realized that the rough coincidence of a large number of lines of oxygen with empty spaces in the solar spectrum might seem sufficient in itself to prove that these spaces were really bright lines, but pointed out that it had to be realized that since there were no coincidences of oxygen lines with dark lines in the solar spectrum, every line of oxygen ipso facto had to correspond approximately to a space. For Draper to show that these spaces did not represent the background of the continuous spectrum but real bright lines of oxygen, he would have to establish an exact coincidence, and not an approximate one.

Moreover, in each of two spaces which Draper identified as bright lines of oxygen (placed at wavelengths 4317 and 4319 by Draper and at 4316.3 and 4318.1 by Christie), Christie found two fine absorption lines in his Greenwich photographs.[41] This discovery of fine dark lines in spaces which Draper identified as bright lines of oxygen opened up a new line of attack of his discovery.

Christie's discovery of four dark lines was followed four months later by the discovery of several additional ones, and the claim was put forward that it was these dark lines, and not the bright ones, which heralded the discovery of oxygen in the sun. This claim was made by none other than John Christopher Draper, Henry's brother.[42] By comparing lines in the spectrum of oxygen he obtained by photographing an electric spark in that gas with Fraunhofer lines observed in his photographs of the solar spectrum, he assigned no less than sixty-five Fraunhofer lines in the solar spectrum to oxygen.

To further argue his case that the dark lines he discovered in the solar spectrum were in fact assignable to oxygen, J.C. Draper noted that many lines in Ångström's solar

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[41]William H.M. Christie, "On the Existence of Bright Lines in the Solar Spectrum," Mon. Not. R. Astr. Soc. 38 (1878), 473-74.

[42]John Christopher, two years Henry's senior, was currently Professor of Analytical and Practical Chemistry at the University of the City of New York. See Theodore Francis Jones, ed., New York University 1832-1932 (New York, 1933), 82-83.

chart were not assignable to any element, and that ten of these lines in particular corresponded very closely with the position of oxygen lines he obtained in his laboratory spectrum. He then presented the close correspondence between these lines in Ångström's chart, those in his own map of the solar spectrum, and his laboratory spectrum of oxygen as proof that these dark lines he had discovered in the solar spectrum were oxygen lines. His results are given in the table below:[43]

J.C. Draper's electric spark spectrum of oxygen	J.C. Draper's solar spectrum	Ångström's solar spectrum
4132.90	4133.00	4133.20
4155.75	4155.60	4155.80
4254.50	4254.30	4254.55
4303.00	4303.00	4303.00
4316.50	4316.60	4316.50
4348.30	4348.20	4347.95
4394.50	4394.50	4394.45
4595.50	4595.40	4595.20
4648.15	4648.15	4648.75
4661.50	4661.50	4661.70

The first column gives the wavelengths of the electric spark spectra of oxygen he obtained in his laboratory. The second and third columns give the wavelengths of the corresponding Fraunhofer lines as observed by himself and Ångström. As a result of the close correlation of all three sets of figures,

[43] John Christopher Draper, "On the Presence of Dark Lines in the Solar Spectrum which correspond closely to the Lines of the Spectrum of Oxygen," Amer. J. Sci. 16 (1878), table on p. 264.

J. C. Draper thought that oxygen did exist in the sun, but that he had discovered it by its dark absorption lines, whereas the bright areas of Henry Draper's spectrum were apparent only, due to the smallness of his dispersion.

J. C. Draper's results were quickly and severely attacked by George F. Barker. In the first place, Barker pointed out a consistent "confusion" in J. C. Draper's paper between Ångström's scale numbers and wavelengths,[44] thus showing that the author did not have a good command of the literature pertaining to his subject of investigation. Secondly, he contended that J. C. Draper's comparison between a diffraction spectrum of the sun and a prismatic spectrum of oxygen was "manifestly of no value."[45] Thirdly, he stated that it was "more than questionable" whether the measurements of the solar spectrum lines and oxygen spectrum lines made by the author were capable of the accuracy he assigned to them.[46]

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[44] Correctly speaking, a given line has a certain wavelength, but the distance between any two lines is given in terms of scale numbers (today, the scale numbers are simply called Ångströms). J.C. Draper was probably more careless here than actually confused.

[45] Such a comparison is very difficult at best, because whereas a diffraction grating gives a normal spectrum, a prism spreads out the blue end of the spectrum more than that of the red.

[46] Since J.C. Draper projected his photographs onto a screen in order to measure the location of the lines, the

Finally, in view of J.C. Draper's insistence on the use of spectra of high dispersion, Barker voiced his "surprise" in finding that he used only two prisms and an observing telescope of 10-inch focal length in obtaining his oxygen spectra. Henry Draper's spectra, which J.C. Draper criticized as being of too-small dispersion, were made with a direct-vision battery of nine prisms[47] and an observing telescope of 42-inch focal length, giving negatives eight or nine times as long as the author's, "and even these were none too large for the proper solution of the question." Barker's final judgment of J.C. Draper's research was devastating:

> It would seem sufficiently obvious from what has been said that the results given in this paper are entirely vitiated by the errors of method and of experiment

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variation in thickness of his glass slides would have necessitated a change in focus in the lantern; this, in turn, would cause a change to occur in the magnifying power. Consequently, the displacement of the lines due to this difference in magnifying power would, in all probability, exceed his limits of measurement.

[47]George F. Barker, "Note on J.C. Draper's Paper 'On the Presence of Dark Lines in the Solar Spectrum which correspond closely to the Lines of the Spectrum of Oxygen,'" Amer. J. Sci. 17 (1879), 164. In his article "On the Use of Carbon Bisulphide in Prisms...," op. cit., Barker claims that Draper's photograph utilized two prisms. In one of his letters, however, Draper states that his spectroscope utilized a direct-vision battery of nine prisms. Draper to Schuster, November 12, 1878, American Philosophical Society (copy of original in the Royal Society of London).

> which it contains. The author must not be confounded, because of the similarity of initials, with the distinguished investigator, Dr. J.W. Draper.[48]

Undaunted, J.C. Draper published two additional papers following Barker's vituperative attack in which he argued the correctness of his views. In both papers, he concentrated on only two areas of the spectrum--the bright spaces at wavelengths 4317 and 4319. After calling attention to the fact that the spaces at wavelengths 4315 and 4321.5 are both brighter than these, J.C. Draper concluded that there must be something in the solar atmosphere which, by absorption, reduces the brilliancy of the spectrum at these spaces. That this absorbing element is oxygen was shown by the correlation of six Fraunhofer lines in these spaces with his laboratory spectrum of oxygen.[49] Beyond noting the reduced brightness in these two spaces, J.C. Draper added nothing essentially new to his earlier investigations in these two papers.

This, then, was the state of affairs in June, 1879, two years after Henry Draper's announcement of his discovery of oxygen in the sun by bright lines and a new theory of the solar spectrum. The existence of the bright lines in the

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[48] "Note on J.C. Draper's Paper...," p. 166.

[49] John Christopher Draper, "On the Dark Lines of Oxygen in the Solar Spectrum on the less refrangible side of G," _Amer_. _J_. _Sci_. 17 (1879), 448-52; "On a Photograph of the Solar Spectrum, showing Dark Lines of Oxygen," _Mon_. _Not_. _R_. _Astr_. _Soc_. 40 (1879-80), 14-17.

solar spectrum had been accepted by Schuster and Meldola who, however, had put forth hypotheses to explain them which differed from each other's and from Draper's. This had been rejected as being apparent only, the result of a too-small dispersion, by Lockyer, Christie, and J.C. Draper. Moreover, both Christie and J.C. Draper had reported finding dark lines in the spaces denoted by Henry Draper as the bright lines of oxygen. During this period of controversy and confusion in the history of spectrum analysis, Henry Draper entered the picture again.

CHAPTER FOUR

OXYGEN IN THE SUN CONTROVERSY, II: LONDON AND RESOLUTION

By the summer of 1879, Draper had been able to obtain photographs of the solar spectrum of greatly increased dispersion. Armed with these, he carried his results directly into the enemy's camp--the Royal Astronomical Society of London. Draper was so anxious to "confront the objectors" that he wrote the Secretary of the Society: "If I could have fifteen or twenty minutes of the Society's time it would probably decide me to make the journey across the Atlantic."[1]

At that time, however, the Society was a house divided, the division centering around the personage of J. Norman Lockyer. Lockyer exerted such great power within the Society that he had gathered around him a dedicated group of supporters, and an equally dedicated group of adversaries. Lockyer's reception of Draper's discovery, therefore, could be expected to set the stage for its reception by some of the Society's other members, a fact of which Draper was not unaware: "I am sorry to say that there is a little party feeling in England with regard to your discovery," he had

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[1]HD to A. Cowper Ranyard, April 4, 1879, Astr. Reg. 17 (1879), 117.

been informed nearly a year earlier.[2] For this reason, Lockyer's position within the Royal Astronomical Society warrants more detailed consideration.

Lockyer and his supporters were in arms primarily for two reasons: first, he had never been awarded the Society's Gold Medal, and secondly, his plans for a government-supported astrophysical observatory were repeatedly voted down by the Society. At the November Council Meeting of the Society in 1870, Lockyer was proposed for the medal by Edwin Dunkin, a first-class assistant at the Royal Observatory, Greenwich. Other recipients were also proposed, however, and lastly John Browning, the instrument maker, proposed that Lockyer and Edward Frankland should both receive the medal for their joint researches in solar physics and the spectra of gaseous bodies, out of which came their discovery of helium in the sun.[3] At the December meeting a ballot was taken, and Lockyer's name was chosen to be submitted for confirmation at the January meeting. But at that meeting, after considerable discussion, the choice was not confirmed, and so no

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[2] A. Cowper Ranyard to HD, July 26, 1878, Draper Papers, NYPL.

[3] See J. Norman Lockyer and Edward Frankland, "Researches on Gaseous Spectra in Relation to the Physical Constitution of the Sun," Proc. R. Soc. 17 (1869), 288-91 and 453-54; ibid., 18 (1870), 79-80.

medal was awarded for 1871.[4]

At the Annual General Meeting in February, 1871, William Lassell, the President of the Society, claimed that the reason the medal was not awarded by the Council was not because they were "unable to find any worthy recipient of it," but because the bye-laws did not give them authority to bestow a joint medal, and that they

> have found it impossible on this occasion to select any individual so pre-eminently distinguished by his own independent researches, that they could recommend the Society to bestow its reward upon him, without danger of doing injustice to others.[5]

Although this was the explanation given at the time, the authorized history of the Society claims that "it is not difficult to infer from the discussions at the Council Meetings, and from subsequent events, that there was a feeling inimical to Mr. Lockyer;"[6] this was the real reason.

Nevertheless, at a Special General Meeting of the Society in June, 1871, a new bye-law was proposed and passed by the Council to the effect that

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[4] J.L.E. Dreyer and H.H. Turner, editors, History of the Royal Astronomical Society 1820-1920 (London, 1923), 172.

[5] Mon. Not. R. Astr. Soc. 31 (1870-71), 134.

[6] History of the Royal Astronomical Society, p. 172. I use the term "authorized history" because it was written by Fellows of the Royal Astronomical Society, and was published by the Society.

> in cases where two or more persons have been jointly concerned in the production of any scientific treatise, or the carrying out of any research, work, or discovery,...the Council may, under these circumstances, receive the nomination of such two or more persons as joint recipients of the Medal.[7]

Accordingly, at the November Council Meeting, Lockyer and Frankland were proposed again for the Gold Medal, this time by Warren de la Rue. The names of other astronomers were also proposed, and of these, the Italian astronomer Giovanni Virginio Schiaparelli was selected at the December meeting and received the medal for 1872 at the Annual General Meeting in February,[8] for his researches on the connection between the orbits of comets and meteors.[9]

The idea of a government-supported astrophysical observatory was a favorite one of Lockyer's, but seems to have come from Lieutenant-colonel Alexander Strange, the Foreign Secretary of the Society. Strange had distinguished himself as Inspector of Scientific Instruments for India, in which capacity he became the first superintendent of the

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[7] *Mon. Not. R. Astr. Soc.* 32 (1871-72), 100.

[8] *History of the Royal Astronomical Society*, p. 173.

[9] Giovanni Virginio Schiaparelli, "Sulla relazione fra le comete, le stelle cadenti ed i meteoriti," *Mem. Inst. lomb.* 12 (1873), 145-68.

depot at Lambeth. There, where an observatory had been erected for him, he did skilled work in designing and testing astronomical instruments. It was at his instance that a Committee of the British Association for the Advancement of Science was appointed at the Norwich meeting in 1868 to inquire into and report on the following questions:

> I. Does there exist in the United Kingdom of Great Britain and Ireland sufficient provisions for the vigorous prosecution of Physical Research?
> II. If not, what further provision is needed? and what measures should be taken to secure it?[10]

Lockyer was not originally a member of the Committee, but was appointed as such by the Committee at its first meeting.[11]

The result of the Committee's inquiry was presented at the Exeter meeting of the British Association in 1869. Although the Committee felt that the existing provisions were "far from sufficient for the vigorous prosecution of Physical Research," it did not feel able to suggest in what manner further facilities should be provided, since this would require an inquiry having a far wider scope than had been found possible. The Committee recommended "that the full influence of the British Association for the Advancement

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[10] _Rep. Brit. Ass._ (1868), p. xlvii.

[11] T. Mary Lockyer, Winifred L. Lockyer, and H. Dingle, _Life and Work of Sir Norman Lockyer_ (London, 1928), p. 53.

of Science should at once be exerted to obtain the appointment of a Royal Commission" to consider the question.[12]

This recommendation bore fruit, for on May 18, 1870, a Royal Commission was appointed, with William Cavendish, the 7th Duke of Devonshire, as its Chairman, to examine

> scientific instruction and the advancement of science, and to inquire what aid thereto is derived from grants voted by Parliament or from endowments belonging to the several Universities in Great Britain and Ireland and the colleges thereof, and whether such aid could be rendered in a manner more effectual for the purpose.[13]

The Commission appointed Lockyer as Secretary in view of his scientific eminence, his administrative experience, and his editorship of _Nature_. The Commission sat for more than five years, during which time it held frequent meetings and examined many witnesses.[14]

Strange thought that the Commission was acting too slowly, however, and decided to take matters into his own hands. In April, 1872 he read a paper before the Royal Astronomical Society in which he asserted that permanent national provision for the cultivation of astrophysics was

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[12] _Rep. Brit. Ass._ (1869), p. 214.

[13] _Life and Work of Sir Norman Lockyer_, p. 54.

[14] It's final report, _The Royal Commission on Scientific Instruction and the Advancement of Science_, 3 volumes (London, 1872-75), helped launch legislation which improved science teaching and faculties in the universities of Great Britain.

urgently needed.[15] At the May Council Meeting, Strange and De la Rue suggested that the following proposal be sent to the Royal Commission on behalf of the Fellows and Council of the Royal Astronomical Society:

> 1. An Observatory, with a laboratory and workshop of moderate extent attached to it, to be established in England for the above researches.
> 2. A certain number of branch observatories, to be established in carefully-selected positions in British territory, in communication with the Central Observatory in England, for the purpose of--first, giving the Photographic Solar Registry that continuity which experience has already proved to be necessary; and, secondly, to investigate the effects of the Earth's Atmosphere on Physico-Astronomical Researches in different geographical regions, and at different altitudes. In these purposes India and the Colonies offer peculiar advantages.[16]

The Council, however, "after long and careful consideration of this subject," extending over four meetings, two of which were convened especially for the purpose, "and including the discussion of points importantly affecting as well the interests of science as the dignity of the Society," passed the following resolutions, proposed by Huggins, on June 28, 1872:

> 1. That the President be authorised, on behalf of the Council and Fellows of

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[15] Alexander Strange, "On the Insufficiency of Existing National Observatories," Mon. Not. R. Astr. Soc. 32 (1871-72), 238-41.

[16] History of the Royal Astronomical Society, p. 175.

> the Royal Astronomical Society, to bring before the Royal Commissioners on Scientific Instruction and on the Advancement of Science, now sitting, the importance of further aid being afforded to the cultivation of the Physics of Astronomy.
>
> 2. The Council think such aid would be most effectually given by increased assistance where needed to existing Public Observatories in the direction recommended by the heads of those observatories, especially that at the Cape of Good Hope, and by the establishment of a new Observatory on the Highlands of India, or in some other part of the British dominions where the climate is favourable for the use of large instruments.
>
> 3. The Council do not recommend the establishment of an independent Government Observatory for the cultivation of Astronomical Physics in England, especially as they have been informed that the Board of Visitors of the Royal Observatory at their recent meeting recommended the taking of Photographic and Spectroscopic records of the Sun at that Observatory.[17]

Thus, although there was strong feeling against the establishment of a Solar Observatory under independent control apart from the Royal Observatory at Greenwich, the opponents were prepared to support an extension of the existing National Observatories. Once again, the authorized history of the Royal Astronomical Society makes clear the real reason behind the opposition: "Though it does not appear on the records, it is known that Mr. Lockyer's name was associated by many with the proposed Solar Observatory."[18]

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[17] Mon. Not. R. Astr. Soc. 33 (1872-73), 189.

[18] History of the Royal Astronomical Society, p. 175n.

Lockyer's opponents were becoming increasingly frightened by his rapidly growing power.

This power struggle within the Society set the stage for the November Council Meeting, 1872. At this meeting, Lockyer, Strange, and De la Rue resigned their Council seats. Moreover, Lockyer's name was put forward for the Gold Medal for the third straight year. It was proposed by Charles Pritchard, the Savilian Professor of Astronomy at Oxford, that Lockyer, Pierre Jules César Janssen, and Lorenzo Respighi should be awarded the medal jointly, in accordance with the bye-law passed in June, 1871. Richard Proctor, the founder of the journal Knowledge, was proposed by his friend E. Becket Denison for his contributions to astronomical literature and his papers on the transit of Venus.[19] Other names were also proposed, but the contest soon developed into one between the supporters of Lockyer, Janssen, and Respighi on the one hand, and those of Proctor on the other. Pritchard withdrew the name of Respighi, and wanted, but was not allowed, to withdraw Lockyer's name. As a result, no consensus could be reached, and consequently it was decided not to award the medal for 1873.[20]

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[19] Richard A. Proctor, "The Transit of Venus in 1874," Mon. Not. R. Astr. Soc. (1869), 211-22 and 306-17; Q.J. Sci. 6 (1869), 370-78.

[20] History of the Royal Astronomical Society, p. 176.

The factious spirit within the Society reached its greatest height, however, in the events surrounding the election of the Council at the Annual Meeting on February 14, 1873. According to custom, the Council prepared a list of names to be submitted to the Society for election. But Strange issued a circular to the Fellows expressing dissatisfaction with the list proposed by the Council, and followed this with an opposition list, from which a good choice of possible new members could be made. A few days later, he issued a balloting list in opposition to the Council's. What followed was probably the stormiest Annual Meeting of the Royal Astronomical Society in the history of the august institution.

The proceedings of the meeting are recorded as follows:

> A long and stormy discussion then ensued in a most crowded meeting...Col. Strange [was] repeatedly challenged to substantiate his statements of the incompetence of the parties objected to, and their combination for party purposes, but contented himself by stating that it was merely his own personal opinion, and that he had every respect for the individuals in question. The resolution [expressing regret for Strange's actions] having been carried, the ballot took place, and occupied nearly two hours before the result was ascertained.[21]

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[21] Astr. Reg. 11 (1873), 66-67.

The result was that the complete Council slate was elected, with only one exception.[22] The affair led the editor of the Astronomical Register to remark "The conduct of the meeting was hardly creditable to the oldest scientific society."[23]

To make matters worse, however, the affair did not end here, but dragged on for the next four months via a series of eleven letters to the editor of the Astronomical Register. In the first, the five Council members whom Strange had accused of being incompetent and of wielding an undue influence (viz., John Browning, Thomas W. Burr, E. Becket Denison, William Noble, and Richard Proctor) charged that Strange's circulars were issued "notoriously with Mr. Lockyer's assistance," and that the attack on them was one "which we have reason to believe had been organized for some time."[24] The five signatories further claimed that the attempt to eject them was a retort for 1) the Council's refusal to award the Gold Medal to Lockyer, and 2) the rejection of Strange's scheme for establishing a Solar Obser-

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[22]The lawyer Thomas William Burr was replaced on the Council by Robert Bellamy, a Professor of Experimental Physics at Oxford.

[23]Astr. Reg. 11 (1873), 58.

[24]Ibid., p. 93.

vatory.[25] As to Lockyer himself, the signatories

> feel bound to inform you that the Society and astronomical science had not the advantage of his presence at a single meeting of the Council during the Session of 1871-2, except the two special meetings at which the establishment of the independent Observatory was discussed. Nor has he contributed a single paper to the proceedings of the Society in the last seven years...[26]

Strange responded with a letter in which he hinted that Proctor had been put up for the Gold Medal in November by a clique of his friends on the Council, and that he was therefore justified in his attempt to purge that body.[27] After this initial exchange of letters, the charges were repeated with greater fervor, and the rhetoric flew. "The malcontents have meddled with the floodgates," Proctor warned, "let them look out for the flood."[28] "Socius Nauseatus," an anonymous adversary of Lockyer, cried out:

> Can they [the Fellows of the Society] fail to recollect that while he was studiously keeping away from the Society, he was hawking the results of that eclipse [the total solar eclipse of December, 1871] about in _Nature_ at 3d.

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[25] _Ibid._, p. 94.

[26] _Ibid._

[27] _Ibid._, pp. 96-97.

[28] _Ibid._, p. 99.

> a copy, and at the Crystal Palace in lectures to those who chose to pay for them.[29]

Furthermore, he continued, when we consider Lockyer's recommendation for the establishment

> at a considerable cost of a kind of astronomical South Kensington (in which Solar Spectroscopy was to be a prominent feature) and that it scarcely needs a ghost to rise from the grave to indicate who would have been thrust forward as its 'Cole, C.B.,' I am sure we shall all appreciate this devotion to our interests...[30]

Lockyer's adversaries were, of course, using this for all it was worth as a means of challenging his rapidly growing power.

Although these events occurred six years before Draper went before the Royal Astronomical Society to read his second paper on the discovery of oxygen in the sun and new theory of the solar spectrum, two later events took place which further raised Lockyer's wrath, and therefore helped perpetuate the division within the Society: 1) Lockyer's name was selected to be submitted for the Gold

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[29] Ibid., p. 101.

[30] Ibid. Further letters in this volume of the Astr. Reg. followed by Proctor (pp. 97-100, 120-22, 128-29, and 181-84); by Browning, Burr, Denison, and Noble (pp. 122-23); by T.B. (pp. 156-57); and by Noble (pp. 129-30 and 184-85). An anonymous article from Lockyer's camp critical of the Council also appeared in the Phil. Mag. 45 (1873), 239-40.

Medal for 1877, but once again the choice was not confirmed, and no medal was awarded for that year,[31] and 2) Draper's name was put up for the 1879 Gold Medal. A. Cowper Ranyard, the Secretary of the Society and Draper's best friend there, was behind this proposal. Although he did not expect it to be successful, he had his reasons for proposing Draper: "I am running you for our Gold Medal though I don't expect to get it for you but it has an excellent educational effect."[32] Although Ranyard was probably sincere in his desire to help Draper by bringing his investigations to the attention of the Council, the net result could only have been a slap in the face to Lockyer, who not only desperately wanted the medal himself, but had publicly and privately discredited Draper's discovery. When Draper came before the Society the following year, therefore, he did not come before an impartial scientific body, but one which had been polarized into two warring camps, with one of these (Lockyer's) dead-set against him. Draper's plan to personally "confront the objectors" was therefore a bold and dangerous one: "I hope

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[31] History of the Royal Astronomical Society, p. 198.

[32] A. Cowper Ranyard to HD, November 25, 1878, Draper Papers, NYPL. The medal for 1878 was awarded to Baron Dembowski for his observations of double stars. History of the Royal Astronomical Society, p. 198. See Baron Dembowski, "Mesures micrométriques des étoiles doubles...," Astr. Nachr. 87 (1874), cols. 161-74; and "Beobachtungen von Doppelsternen," Astr. Nachr. 87 (1876), cols. 191-92, 205-08, 233-38, 253-70, and 339-48.

the Londoners recognized the heroic action and excellent feeling which prompted you," wrote the Astronomer Royal of Scotland.[33] Clearly, Draper had his work cut out for him.

In the paper he read before the Society on June 19, 1879, Draper attempted to answer his critics and restate his case for having discovered oxygen in the sun. To meet the criticism that his 1877 photograph exhibited bright lines which were apparent only, the result of a too-small dispersion, Draper had perfected his apparatus. The final optical system of his spectroscope consisted of a collimator of two-inch aperture and 26-inch focal length, succeeded by two Rutherfurd carbon bisulphide prisms and an observing or photographing lens of 78-inch focal length (see Fig. 4). This improved optical system resulted in a dispersion four times greater than that of his earlier apparatus, and did not cause the bright lines to disappear. On the contrary, the same eighteen bright lines which appeared in his 1877 photographs appeared even more distinctly in the new ones.

To explain the presence of dark lines in these bright spaces, Draper stated that if, as he believed, the stratum which gives rise to the oxygen spectrum in the sun lies deeper than the reversing layer, then there was no physical

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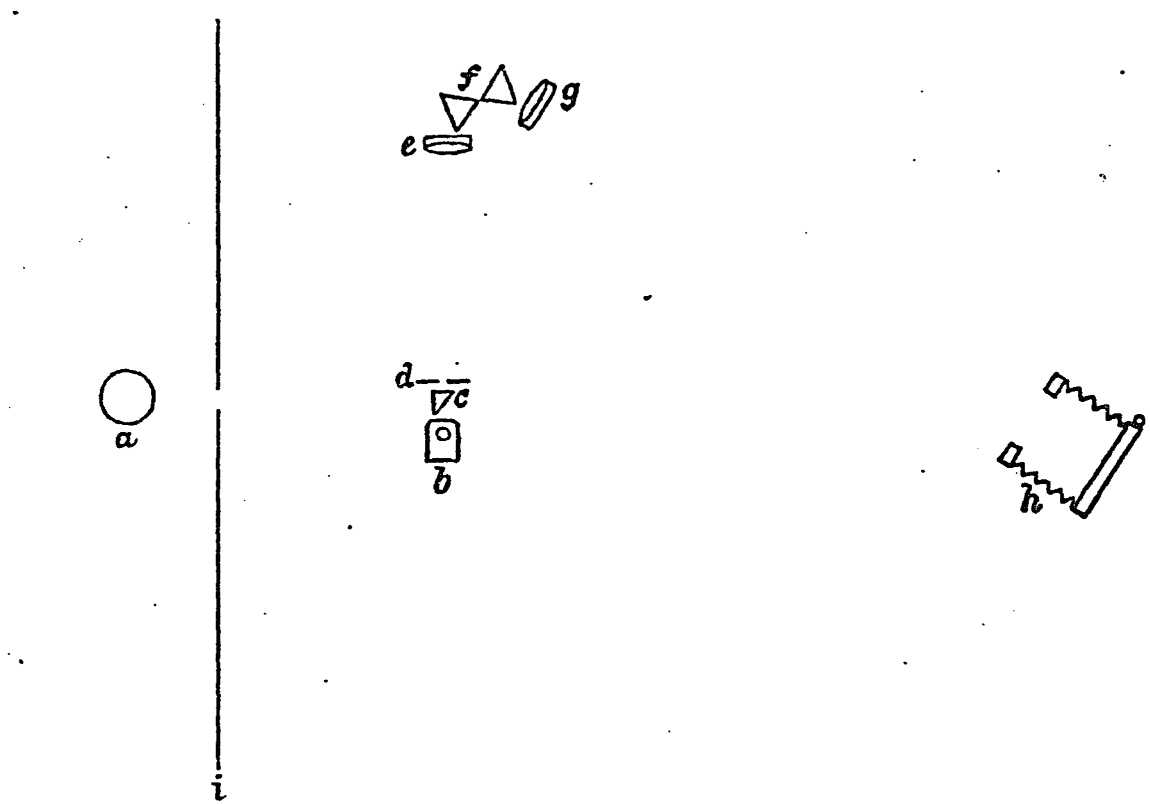
[33] C. Piazzi Smyth to HD, July 22, 1879, Draper Papers, NYPL.



a Heliostat Mirror.
b Spark compressor.
c Right-angled prism.
d Slit.
e Collimator.
f Two bisulphide prisms.
g Photographic objective.
h Camera.
i Window shutter.

Fig. 4 Optical system of Draper's spectroscope, 1879 (From Mon. Not. R. Astr. Soc. 39 (1878-79), 445) reason why a dark absorption line could not fall upon an oxygen bright space. He did not explain why the reversing layer would not also render the oxygen lines dark, but presumably his explanation for this was the same it had been in 1877--viz., that the great intensity of light from the oxygen stratum overpowers the effect of the photosphere below it.

Draper met two additional criticisms by noting that the bright lines of oxygen are not necessarily the brightest parts of the solar spectrum, and that whereas the edges of the bright-line spectrum of oxygen produced in the laboratory may be nebulous or fuzzy, the corresponding space in the solar spectrum might have its edges sharpened by the action of adjacent Fraunhofer lines due to the presence of one or another of the metallic substances in the sun. Having shown photographs of high dispersion which clearly exhibited bright lines, and having met the objections of his critics, Draper drew the following conclusion:

> On the whole, it does not seem improper for me to take the ground that, having shown by photographs that the bright lines of the oxygen spark spectrum all fall opposite bright portions of the solar spectrum, I have established the probability of the existence of oxygen in the sun.[34]

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[34]Henry Draper, "On the Coincidence of the Bright Lines of the Oxygen Spectrum with Bright Lines in the Solar Spectrum," Amer. J. Sci. 18 (1879), 269.

In the two-year interval since the initial announcement of his discovery, Draper saw no reason to alter his earlier conclusion; on the contrary, on the basis of his new high-dispersion photographs, he was more certain than ever of the correctness of his position.

In spite of his certainty, Draper failed to convince everyone present at the Society meeting, and a lively discussion followed his reading. Ranyard, who had earlier warned Draper of the party feeling against him in the Society and had proposed him for the Gold Medal some seven months earlier, argued on his behalf, pointing out that since Draper had increased his dispersion four times, he had not merely increased the probability of his case four times, but had increased the value of every coincidence he showed four times. Since Draper's photograph showed eighteen oxygen lines, the increase of probability on the present occasion, as compared to the former, was 4^{18} to 1 (nearly 69 billion to 1), "a very enormous number." So enormous, in fact, that the presence of oxygen in the sun could not be denied.[35]

Christie was less enthusiastic, and preferred to take the position of a "sceptic," a position he regarded as "perhaps unfortunate, but truly scientific." From this position, he repeated his earlier arguments against the reality of the

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[35] Ibid., Appendix, p. 270.

bright lines--viz., that the bright spaces were perfectly even in tint throughout, that they were not fuzzy at the edges, that one started with the fact that every laboratory line of oxygen had to correspond approximately with a bright space in the solar spectrum, and that there were a few coincidences of dark lines with some of Draper's bright oxygen spaces. He then showed Ranyard that probabilities could also be used against Draper. For if we suppose that the bright lines of oxygen in the sun are truly fuzzy but do not appear so because they are cut off by adjacent Fraunhofer lines, what is the probability of a pair of dark lines falling in every case exactly at the edges of an oxygen line?[36] Ranyard had no answer to this.

Neither did Proctor; nevertheless, he proclaimed his belief that the bright lines were real. But then he confused matters by going on to suggest that the solar spectrum exhibited only bright and dark lines, with no continuous background.[37] This was flatly rejected by Ranyard and John Hall Gladstone, the Fullerian Professor of Chemistry at the Royal Institution.[38] William Noble emphatically declared

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[36] _Ibid._, pp. 271 and 275.

[37] _Ibid._, pp. 272-73.

[38] _Ibid._, pp. 273-74.

the existence of the bright lines, and chided Christie for the consequences of his position:

> If we are to deny the evidence supplied by some of these coincidences,...and accept Mr. Christie's dicta, we literally should have no tangible evidence as to the existence of any element in the sun at all.[39]

Huggins was noncommital. Although Draper's photographs had "overwhelmed" him with a sense of the large amount of conscientious labor and care which had gone into the investigation, he wished to suspend his judgment until he had had an opportunity to reexamine that part of the spectrum.[40] Proctor did not approve of this cautious suspension:

> Huggins was not satisfactory--but, between ourselves, he seldom is. His opinions in such cases are offered like his hand when you meet him--the which he advances always as something to be rather carefully experimented upon.[41]

After a few closing remarks by Draper, the meeting ended and he was cordially thanked for his presentation.

It has already been stated that Draper was not presenting his paper to an impartial scientific audience, but to one that was sharply polarized. Lockyer was apparently not

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[39] Ibid., p. 273.

[40] Ibid.

[41] Richard Proctor to HD, June 20, 1879, Draper Papers, NYPL.

present at that meeting; at any event, he was not a contributor to the recorded discussion. Of the opposing camp, Proctor and Noble were present, and both took a stand diametrically opposed to Lockyer's well-known position. The claim can be made that Proctor and Noble were not arguing so much for Draper as they were against Lockyer, whether he was there or not. Similarly, if Lockyer had been there, he undoubtedly would have argued against anything Proctor, or anyone else in his camp, had said. Indeed, it can be said that the battle lines within the Society were so well-drawn prior to Draper's presentation that it could not have swayed anyone's opinion one way or the other; Draper's "heroic action" was doomed to be in vain.[42] Thus, instead of ending the uncertainty regarding the question of bright oxygen lines in the solar spectrum, the presentation simply perpetuated the debate.

Draper's discovery of oxygen and new theory of the solar spectrum meant a great deal to him. This was his first foray into theoretical astrophysics and he did not wish to come out tarnished. Moreover, it thrust him head-

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[42]Because Lockyer was so influential, his relations with other scientists deserve much greater investigation. A.J. Meadows of the Department of Astronomy, University of Leicester, is currently preparing a general biography of Lockyer, and assures me that his study will deal "pretty extensively" with this matter. Personal communication, November 4, 1969.

long into the center of attention, and he was obviously enjoying the excitement. From London he wrote Newcomb:

> We have received the greatest kindness from people here and are full of engagements for entertainment. We had a very pleasant time at the Greenwich visitation [to the Royal Observatory] and at the dinner afterward the President of the Royal Society was good enough to put me at his left hand.[43]

For these reasons, he was not prepared to let the matter go unsettled. He was very anxious to continue and to extend this line of his research in order to obtain photographs which would make the lines of oxygen so sharp that its existence could not be denied. J. Rand Capron, another Fellow of the Royal Astronomical Society who supported Draper, wrote to him suggesting a definite plan. They would publish a joint article in the journal Observatory, and illustrate it with two photographs: 1) one of Draper's comparison photographs of the laboratory and solar oxygen spectra, and 2) one of Capron's photographs, with less dispersion, perhaps, but exhibiting more of the spectrum. "Whichever [photograph] you may consider the best and most illustrative of your compared spectra...it should be the best of its kind," he exhorted Draper.[44]

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[43]HD to Simon Newcomb, June 10, 1879, Simon Newcomb Papers, Library of Congress.

[44]J. Rand Capron to HD, April 15, 1882, Draper Papers, NYPL.

To this end, Draper built a new physical laboratory, and began investigations of oxygen and other nonmetals with an improved photographic spectroscope.[45] Moreover, he had given up his professorship and was reducing his business obligations in order to devote himself full-time to his research.[46] Just as he seemed ready for his lifework, however, he died on November 20, 1882 at the early age of forty-five. Consequently, his paper read before the Royal Astronomical Society was his last word on the question of oxygen in the sun.

But is was far from being the last word on the matter. For just as Draper was not about to let the oxygen in the sun controversy go unresolved, neither were other scientists. In 1887, John Trowbridge and Charles C. Hutchins, two investigators working in the Jefferson Physical Laboratory of Harvard University, examined the problem but found that the situation had not changed much in the five years following Draper's death. Reviewing the situation, however, they found little reason to believe in the existence of oxygen in the sun.

In the first place, they argued, the fact that the

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[45] George F. Barker, "Henry Draper," Amer. J. Sci. 25 (1883), 91-92.

[46] Ibid., p. 95.

bright bands of Draper's solar spectrum are actually no brighter than the surrounding background prevents them from being interpretted as bright lines. Secondly, when viewed with a spectroscope of high dispersion, the bands are found to be occupied by numerous dark lines. Therefore,

> When we apply to the spectra of the sun and oxygen a dispersion and definition that shows the minute detail of each, the "bright bands" at once vanish, or no longer appear as such, and all the apparent connections between them and the oxygen lines disappear also.[47]

Equally wrong, however, was John Christopher Draper, who claimed that the dark lines found within the bright bands were the true representatives of the oxygen lines. For since the correspondences that he found between oxygen lines in his laboratory spectrum and dark lines in the solar spectrum were no more numerous than one would expect to find by chance, "The hypothesis...is rendered untenable by the lack of any systemmatic connection between the two."[48] Trowbridge and Hutchins thus concluded that there was no real basis on which to believe in the existence of oxygen in the sun.

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[47]John Trowbridge and Charles C. Hutchins, "Oxygen in the Sun," Amer. J. Sci. 34 (1887), 270. Trowbridge stayed on at Harvard, where he became the Rumford Professor of Applied Science in 1888; Hutchins left to become a Professor of Physics at Bowdoin College in Brunswick, Maine.

[48]Ibid.

Shortly afterwards, news of some experiments which cast further doubt on the existence of this element in the sun came from across the Atlantic. In France, Pierre Jules César Janssen, the director of the Meudon Observatory near Paris and the discoverer (independent from but simultaneous with Lockyer) of a method for observing solar prominences in daylight, performed two experiments which led him to believe that oxygen did not exist in the sun. In his first experiment, Janssen set out to examine the effect of the earth's atmosphere on the supposed Fraunhofer oxygen lines in the solar spectrum. To accomplish this, he chose to examine the spectrum of a light at a distance equal to the depth of the atmosphere traversed by the solar rays when the sun is at the zenith. Janssen then noted that the Eiffel Tower was some 7700 meters from the Meudon Observatory, at just the right distance to meet the above-mentioned requirement. He then placed a powerful electric light at the top of the Tower, and examined it with the same spectroscope with which he examined the solar spectrum. Now, if oxygen did in fact exist in the sun, then its lines as exhibited in the solar spectrum should be markedly different from those observed in examining the spectrum of the Tower light. His results, however, showed that the two spectra were so equivalent that he concluded that the dark oxygen lines observed in the solar spectrum were actually telluric

--that is to say, they were due to oxygen in the earth's atmosphere.[49]

To further test this hypothesis, Janssen wished to observe the solar spectrum from the summit of Mont Blanc, above much of the oxygen in the earth's atmosphere. Naturally, the problem of ascending to the top of the mountain presented great difficulties to one at the advanced age of 66:

> I began by excluding all thought of ascending by foot. Ascension by means of an appropriate vehicle would present the immense advantage of not exacting any bodily effort from the observer, of allowing him to use all his forces for intellectual labor, which would be of inestimable value in these high regions, where physical fatigues consume the last reserves of the organism and render all thought and all headwork if not impossible, at least extremely difficult.[50]

The "appropriate vehicle" that he hit upon was the sled, and so Janssen was pulled up the mountain by some of the twenty-two members of his expedition on a sled.

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[49] Pierre Jules César Janssen, "Sur l'origine tellurique des raies de l'oxygène dans la spectre solaire," _C.-R. Acad. sci._ 108 (1889), 1036-37.

[50] P.J.C. Janssen, "Compte rendue d'une ascension scientifique au Mont Blanc," _C.-R. Acad. sci._ 111 (1890), 432 (trans. mine).

At a station near the summit, Janssen observed the solar spectrum with two spectroscopes, one employing a double set of prisms, the other a Rowland diffraction grating.[51] His results showed that the oxygen lines in the solar spectrum diminished in strength in proportion to the height of the observing station, and at the uppermost limits of the earth's atmosphere, would disappear entirely. Janssen therefore felt even more justified than before in concluding that the oxygen lines were telluric, and not solar: "[I am led] to admit the absence of oxygen in the gaseous solar envelopes which rise above the photosphere... I consider that this is a truth definitively acquired."[52]

Nils Christofer Dunér, a Swedish astronomer, also thought that the oxygen lines were telluric, but based his conclusion on quite different grounds. He began his argument by pointing out that the oxygen lines are always visible in the solar spectrum, even when they are observed at stations at high altitudes. It could therefore be sup-

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[51] Henry Augustus Rowland was a Professor of Physics at Johns Hopkins University. He was the discoverer in 1881 of the concave grating (which did away with the necessity of a collimator and view telescope), and devised a machine for ruling gratings which represented the first advance over the Rutherfurd gratings.

[52] "Compte rendu d'une ascension scientifique au Mont Blanc," p. 444 (trans. mine).

posed that there is some oxygen in the sun, and that the observed lines are partly telluric and partly solar. But if this is the case, then the wavelength of the solar part of the line would differ from the telluric part due to the rotation of the sun. This would be most easy to detect in the neighborhood of the solar equator, where the two parts would appear as a double line in a spectroscope of sufficient power. In his researches on the rotation of the sun, Dunér had examined the oxygen lines "hundreds of times," and had never seen them double. Consequently, he was convinced that they were not part solar, but exclusively telluric: "On the whole, I do not hesitate to claim that the [oxygen] bands...are of a purely telluric origin."[53]

Since this rather simple experiment, if valid, would have rendered useless Janssen's long and laborious observations at elevated stations, Janssen quickly retorted that Dunér's experiments were insufficient to give a solution to the problem. He argued that whereas Dunér's experiments would be valid if the oxygen lines were either exclusively solar or telluric, they would not be so if they were partly

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[53] N.C. Dunér, "Y a-t-il de l'oxygène dans l'atmosphère du Soleil?," C.-R. Acad. sci. 117 (1893), 1058 (trans. mine). Dunér, a Professor of Astronomy at Uppsala and the director of the observatory there, had earlier discovered that different regions of the sun rotate at different speeds.

each. For in this case, the displacement of the solar part of the line would be masked by the width of the telluric part, due to the fact that the terrestrial atmosphere gives a very great intensity to the oxygen lines.[54] Janssen then outlined the value and validity of his own researches on the question of oxygen in the sun, and restated his conviction that

> The results of these researches show that the terrestrial atmosphere can be considered as the sole cause of the presence of the oxygen groups in the solar spectrum ...It can therefore be said that the gaseous envelopes of the sun do not contain oxygen.[55]

Amidst this flurry of denials concerning the existence of oxygen in the sun, Arthur Schuster sent a note to the Académie des sciences reminding Janssen and Dunér of his earlier findings on the coincidences of the wavelengths of his compound line spectrum of oxygen and certain Fraunhofer lines in the solar spectrum.[56] Schuster did not want to categorically claim on this basis that oxygen did exist in

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[54] P.J.C. Janssen, "Remarques sur une note de M. Dunér intitulée: 'Y a-t-il de l'oxygène dans l'atmosphère du Soleil?,'" C.-R. Acad. sci. 118 (1893), 55.

[55] Ibid., p. 56 (trans. mine).

[56] A. Schuster, "On the Presence of Oxygen in the Sun," op. cit.

the sun, but felt that these coincidences played such an important role in the question that they should not be overlooked:

> It cannot be said that the coincidence of the lines should suffice to establish the presence or absence of oxygen in the sun, but it seems to me they should be taken into account in the discussion.[57]

As if this were a signal to reevaluate earlier investigations, Trowbridge decided to repeat the experiments that he and Hutchins had carried out nine years earlier, in which they concluded that the bright lines of oxygen discovered by Draper could not be distinguished in the solar spectrum.[58] In his new study, Trowbridge approached the problem from a different angle--viz., to carefully examine the regions in the solar spectrum where the bright lines of oxygen should occur in order to see if any of the fine absorption lines of iron were absent, on the grounds that the bright nebulous oxygen lines would obliterate some of the faint fine lines of iron. His investigation, however, showed that even the faintest iron lines were clearly visible in the spaces where the bright oxygen lines should occur. Thus, for the second time, Trowbridge did not succeed in

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[57]A. Schuster, "Y a-t-il de l'oxygène dans l'atmosphère du Soleil?," C.-R. Acad. sci. 118 (1893), 138 (trans. mine).

[58]J. Trowbridge and C.C. Hutchins, "Oxygen in the Sun," op. cit.

detecting the presence of oxygen in the sun. But whereas he formerly concluded that this element did not exist there, by this time he had changed his mind:

> Notwithstanding the negative evidence which I have brought forward, I cannot help feeling strongly that oxygen is present in the sun and that the sun's light is due to carbon vapour in an atmosphere of oxygen.[59]

While Trowbridge was not able to substantiate this belief, proof was not long in the coming. That very year, 1896, two German physicists, Carl David Tolmé Runge and Friedrich Paschen, wrote the final chapter to the oxygen in the sun controversy by definitely proving its existence there. Runge and Paschen clearly identified a triple set of lines in the spectrum of a vacuum tube filled with oxygen with three Fraunhofer lines in the solar spectrum.[60] Since the relative intensities of both sets of lines accorded to a very high degree, and the area of the triplet in the solar spectrum was marked by few other lines, Runge and Paschen concluded that "There remains little doubt that the

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[59] J. Trowbridge, "Carbon and Oxygen in the Sun," *Phil. Mag.* 41 (1896), 454.

[60] This particular oxygen triplet was discovered by the Astronomer Royal of Scotland, C. Piazzi Smyth. See C. P. Smyth, "Note on Sir David Brewster's Line Y, in the Infra-Red of the Solar Spectrum," *Trans. R. Soc. Edinb.* 32 (1883), 233-38.

coincidences are real."[61] And so, nineteen years after Draper's alleged discovery of oxygen in the sun and his new theory of the solar spectrum, high-dispersion spectroscopy showed that oxygen was present there, but was marked by the familiar dark Fraunhofer lines, and not by bright emission lines.

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[61] C. Runge and F. Paschen, "Oxygen in the Sun," Astroph. J. 4 (1896), 318. Runge is perhaps best noted for his researches on magnetic resolution in spectroscopy, and Paschen for his experimental verification of Sommerfeld's relativistic theory of atoms by studies of the structure of fine x-rays.

CHAPTER FIVE

SCIENTIFIC LEGACY: THE HENRY DRAPER MEMORIAL

In November, 1882 Draper threw a large dinner party for several prominent guests who were in New York for the annual meeting of the National Academy of Sciences. He used the occasion to discuss with Edward C. Pickering, the director of the Harvard College Observatory, the recent photographs of stellar spectra that he had obtained. Pickering expressed his great interest in this work, and offered to reduce[1] the observations if they could be sent to Cambridge.[2] Draper, however, became ill immediately after the dinner, and died within a few days.

Some two months after his death, Pickering wrote his widow restating his offer. After an initial exchange of letters, Mrs. Draper visited Pickering at the Harvard College Observatory at Cambridge early in February, 1883. After examining with a microscope some of the twenty-one photo-

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[1]Observations as actually made always require certain corrections before they can be utilized. These include corrections for any errors or maladjustment of the telescope, spectroscope, and camera, as well as corrections for parallax, refraction, nutation, aberration, precession, etc. This corrective process is called reduction.

[2]Annie J. Cannon, "Mrs. Henry Draper," _op. cit._, p. 382.

graphs of stellar spectra, none more than ¼-inch long, that she had brought with her, Pickering suggested that they publish a list of all of Draper's spectra, together with, for the best photographs, enlarged prints and measurements of the relative positions of the lines and a calculation of their wavelengths.[3] Mrs. Draper agreed, but delayed publication until a detailed introduction by Charles A. Young, pictures of the Hastings Observatory, and excerpts from Draper's research notebooks could be added. The paper was finally published in February, 1884, and contained data on seventy-eight spectra, including reduced wavelengths for twenty-one.[4]

While corresponding with Pickering regarding the publication of this paper, Mrs. Draper also told him of her "real plan":

> My real plan is, as soon as possible to get the work running under my own direction, then when I can buy the place at Hastings where the Observatory is, to do so,--then move the laboratory and all the apparatus there and eventually endow the whole as an institution for original research in astronomical physics to be called the Henry Draper Astronomical & Physical Observatory. As long as I could I should keep

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[3]Lyle G. Boyd, "Mrs. Henry Draper and the Harvard College Observatory: 1883-1887," Harvard Lib. Bull. 17 (1969), 76. Hereafter cited as Boyd. I wish to thank Prof. William Coleman for calling my attention to this article.

[4]Charles A. Young and Edward C. Pickering, "Researches upon the Photography of Planetary and Stellar Spectra, by the late Henry Draper,...," op. cit.

> the direction of the institution myself. It seems to me the only suitable memorial I can erect to Henry, and the only way to perpetuate his name and his work.[5]

Pickering approved of this plan, and wrote her encouraging letters. He even suggested several men as possible assistants in her proposed observatory, including H.M. Paul,[6] W.C. Winlock,[7] and T.C. Mendenhall.[8] Although these and other astronomers and physicists Pickering suggested were obviously competent, none seemed exactly suitable to Mrs. Draper. "Finding the right man (that is, another Henry Draper) was proving extraordinarily difficult."[9]

The correspondence between Mrs. Draper and Pickering regarding the establishment of the Henry Draper Observatory continued for more than three years after his death, but the plans were at a standstill. Sympathizing with her desire to perpetuate her late husband's name and work, her genuine love for and interest in astronomy, and at the same time lacking

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[5]Mrs. Draper to Edward C. Pickering, January 13, 1883, in Boyd, p. 73.

[6]H.M. Paul was then Professor of Astronomy at the University of Tokyo.

[7]W.C. Winlock, the son of Joseph Winlock, the third director of the Harvard College Observatory, was an astronomer at the United States Naval Observatory.

[8]T.C. Mendenhall was then Professor of Physics at Ohio State University.

[9]Boyd, p. 87.

the means to pursue his own research as far as he wished, Pickering decided to suggest a tentative plan for collaboration. He suggested that she appropriate a fund to astronomical physics for research to be carried out at Cambridge under his supervision. She could chose the subject to be investigated, and the results would be published in a single volume, "which would form the best possible monument to the memory of Dr. Draper."[10]

Although Mrs. Draper refused to abandon her plan for establishing the Henry Draper Observatory, she was receptive of Pickering's suggestion. As to the area of investigation to be undertaken, she wrote:

> I would wish to have it in one of the directions that Dr. Draper intended to pursue, that is if in so doing it did not interfere with a line of work since undertaken by someone else.--His plans were: At the Observatory to get his instruments into the best order, and then by means of photography to catalogue and classify the stars by their spectra.[11]

Moreover, should Pickering decide to supervise a catalogue of stellar spectra, this could serve as a nucleus for the future program of the Henry Draper Observatory.

Pickering replied favorably. He estimated that the

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[10] E.C. Pickering to Mrs. Draper, January 24, 1886, in Boyd, p. 90.

[11] Mrs. Draper to E.C. Pickering, January 31, 1886, in Boyd, p. 91.

expenses necessary to carry out this program were as follows:

> We now pay the photographer forty cents an hour for night work. We may expect ten suitable evenings a month, including about sixty hours. The photographic plates and chemicals would cost about as much more. The measuring, identifying and preparing for the press would cost from twenty-five to forty cents an hour, most of it about thirty cents. At least fifty dollars a month would be required to prevent this part of the work from getting behindhand. Miscellaneous expenses are always difficult to estimate...If you authorized expenditures not exceeding two hundred dollars a month, it would be abundant to begin with and could afterwards be increased or diminished according to the progress made.[12]

Ten days later Mrs. Draper wrote that she was willing to go along with that plan, and the following note was added to her letter in Pickering's handwriting: "Date February 14, 1886 adopted as the beginning of the Henry Draper Memorial."[13]

Work on the project began immediately. Mrs. Draper forwarded $1,000 to the President and Fellows of Harvard College, with the promise of additional funds to be sent periodically. This established the Henry Draper Fund, the principal to be used to photograph stellar spectra and to measure, catalogue, classify, and publish the results in the Annals of the Astronomical Observatory of Harvard Col-

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[12] E.C. Pickering to Mrs. Draper, February 4, 1886, in Boyd, pp. 91-92.

[13] Boyd, p. 93.

lege as a memorial volume to Draper. At the Harvard Observatory, new equipment was bought, and new assistants were employed. In May, Mrs. Draper visited Pickering at Cambridge to help arrange the transfer of Draper's 11-inch photographic telescope from the Hastings Observatory, and help plan for the construction of a new building to house it. After making arrangements to regularly meet the project's expenses, Mrs. Draper went to Europe for the summer.[14]

Two months prior to Mrs. Draper's visit, Pickering mailed a circular dated March 20, 1886, to all of the major observatories, astronomers, physicists, scientific societies, and libraries in the United States and Europe, the editors of *Science*, *Nature*, and the *Memorie della Società degli Spettroscopisti Italiani*, as well as to the New York and Boston newspapers, announcing the establishment of the Henry Draper Memorial. In this circular, Pickering outlined his intention of photographing the spectra of all stars from the celestial North Pole down to -30°,[15] and announced his intention of gratuitously distributing from time to time specimens of the photographs obtained in order to keep the astronomical

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[14] *Ibid.*

[15] That is, down to the parallel 30° south of the celestial equator.

public informed of the progress made in this work.[16]

Upon Mrs. Draper's return from Europe, and throughout the autumn of 1886, Pickering's letters reported the progress and triumphs of the project, which pleased her greatly. In January, 1887, Pickering sent her photographs of some recently obtained spectra which had been enlarged to unprecedented size--four inches wide by twenty-four inches long--and which were still sharp and clear. He hastened to add that when distributed, these photographs would undoubtedly "induce other astronomers to undertake the same work." Anticipating important discoveries to be made, and feeling that they should form a part of the investigation already underway and that the whole subject should be associated with Draper's memory, Pickering devised a plan whereby Mrs. Draper might, if she so desired, preempt the entire field. Pickering's plan was that the project should be extended in two additional ways: 1) to include a study of the spectra of faint stars, especially of those that are banded or variable, and 2) to include a study of the comparison of stellar and terrestrial spectra. These extensions would involve an expenditure during the coming year of $5,000 for current expenses, and $3,500 for permanent outfit.[17]

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[16] Edward C. Pickering, "Photographic Study of Stellar Spectra. Henry Draper Memorial," Nature 33 (1885-86), 535.

[17] E.C. Pickering to Mrs. Draper, January 18, 1887, in Boyd, p. 95.

Mrs. Draper readily agreed to the planned extension:

> I quite agree with you in feeling that I should like to appropriate the entire ground that is possible, before any distribution is made of the photographs, and am entirely satisfied to devote nine or ten thousand [dollars] a year to carrying on the work.[18]

What was difficult, however, was the decision to move Draper's 28-inch reflecting telescope to Cambridge, as would be desirable for the investigation of the spectra of faint stars. In the first place, Mrs. Draper felt a special affection for this telescope. Draper had begun its construction the year before they were married, and on the day after their wedding they went on an "expedition" downtown to choose the glass for the mirror; afterwards, they referred to this adventure as "our wedding trip."[19] Moreover, to send the telescope to Cambridge would amount to a final abandonment of her dream of establishing the Henry Draper Observatory. At last, however, she reluctantly made this sacrifice, and the 28-inch telescope was added to the equipment of the Harvard College Observatory, to carry on the photographic study of stellar spectra for the greatly expanded Henry Draper Memorial.

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[18] Mrs. Draper to E.C. Pickering, January 23, 1887, in Boyd, p. 96.

[19] Mrs. Draper to E.C. Pickering, April 10, 1887, in Boyd, p. 97.

On March 1, 1886, Pickering issued a circular describing the progress made during the first year on the Henry Draper Memorial. In it, he described how the original aim had been greatly extended:

> The attempt will be made to include all portions of the subject, so that the final results shall form a complete discussion of the constitution and condition of the stars, as revealed by their spectra, so far as present scientific methods permit.[20]

Pickering used this to notify other astronomers and observatories that Harvard had indeed "preempted the entire field," and that they were not to participate in this investigation: "It is hoped that a greater advance will thus be made than if the subject was divided among several institutions."[21] Furthermore, to ward off any possible argument that the participation of a southern observatory was necessary to complete the investigation by studying stars below -30°, Pickering announced that Harvard intended to establish an astronomical station in the southern hemisphere with that end in mind.

The main instruments employed in the investigation

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[20] Edward C. Pickering, "The Henry Draper Memorial. First Annual Report of the Photographic Study of Stellar Spectra," Nature 36 (1887), 31.

[21] Loc. cit.

were the Bache telescope, which employed an 8-inch Voigtländer lens, reground and mounted by Alvan Clark and Sons,[22] Draper's 11-inch photographic lens, for which Mrs. Draper provided a new mounting and observatory, and the Harvard College Observatory's 15-inch refractor. These instruments were soon supplemented by Draper's 15½-inch and 28-inch reflectors. The spectra were produced by placing a large prism in front of the telescope. While this did not give the definition attainable by usage of a slit, it allowed a large number of spectra to be photographed on a single plate, and gave sufficient definition.[23] Four 15° prisms were used, having clear apertures of nearly eleven inches. Their combined weight was in excess of one hundred pounds, and they were held in place by a brass cubical box measuring a foot on each side. The photographic plates used were the Allen and Rowell "Extra Quick" ones, but these were soon surpassed in speed and replaced by the M.A. Seed Co. "Plate No. 21."[24]

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[22]For a full description of this telescope, which played a very important role in the development of the Henry Draper Memorial, see Edward C. Pickering, "Stellar Photography," _Mem. Amer. Acad. Arts Sci._ 11 (1888), 184-86 et passim.

[23]For a discussion of this method of photographing stellar spectra, see Edward C. Pickering, "The Objective Prism," _Astr. Astroph._ 11 (1892), 199-203.

[24]"First Annual Report...," p. 32.

The photographic work was done by Willard P. Gerrish, an Assistant Professor of Astronomy at Harvard.[25] The reduction of the photographic plates was begun by Miss Nettie A. Farrar, who was aided by the Misses Anna and Louisa Winlock,[26] but was taken over by Mrs. Williamina Paton Fleming in 1886. Mrs. Fleming, a Scotswoman who came to Boston with her husband in the 1870's, soon proved to be so capable of dealing with the computing and the various administrative matters of the Observatory that Pickering placed her at the head of a large staff of computers. Later, as the Henry Draper Memorial and her work on it grew in importance, she was given the official title of "Curator of Astronomical Photographs."

As outlined by Pickering, the investigation was to consist of three main parts. The first was to make a general survey of stellar spectra for all stars north of -25° and brighter than the sixth magnitude. This was a continuation of an investigation already begun by Pickering with the aid of an appropriation from the Bache Fund.[27]

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[25] Gerrish stayed on at the Harvard College Observatory into the present century. Besides his photographic work, he showed great skill in improving mechanical devices by electrically controlling their mechanisms.

[26] Anna and Louisa Winlock were the daughters of Joseph Winlock, the former director of the Harvard College Observatory.

[27] The Bache Fund was administered by the National Academy of Sciences. Pickering's earlier investigation is described in his "Stellar Photography," op. cit., pp. 208-10.

The current study was to use the 8-inch telescope to photograph regions 10° square, with exposures of about five minutes. The second part of the program was a study of the spectra of fainter stars. The 8-inch telescope was used for this also, and exposures of about an hour were utilized to record stars down to the eighth or ninth magnitude. The third part was a more careful study of the brighter stars, using Draper's 11-inch telescope.[28] In his summary of his first of four annual reports issued between 1887 and 1890, Pickering pointed out that through Mrs. Draper's generosity, "a field of work of great extent and promise is open, and there seems to be an opportunity to erect to the name of Dr. Henry Draper a memorial such as heretofore no astronomer has received."[29]

In his second annual report, Pickering announced that these three investigations would be completed in about a year, and he accordingly proposed to send an expedition to the southern hemisphere in the autumn of 1889 to complete the photographic work down to the celestial South Pole. He also reported that Draper's 15½-inch and 28-inch reflectors had been moved to Cambridge, and that the latter instrument

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[28]"First Annual Report...," pp. 33-34.

[29]*Ibid.*, p. 34.

had already been placed in a specially-constructed observatory and was now ready for use. Improvements in the manfacture of dry plates by the M.A. Seed Co. resulted in their "Plate No. 27," which furnished the means to photograph stars nearly a magnitude fainter than possible before; this nearly doubled the number of objects capable of examination. Various other improvements in the photographic processes and in the instruments were also noted.[30]

The next year's report announced that the research undertaken was rapidly nearing completion, and that plans for the study of the southern stars were well underway, and would soon begin. Plans for Draper's 28-inch reflector, however, had to be dropped. Assigned to the study of faint stellar spectra, it was found that the photographic spectra it yielded were no better than those from his 11-inch refractor. Because it was also much slower to operate due to its large size, experiments with it were therefore discontinued. The 8-inch Bache telescope, which was the instrument most heavily relied on in the various investigations, had been sent to Willows, California, where it was used to photograph the total solar eclipse of January 1, 1889. From there,

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[30] Edward C. Pickering, "The Progress of the Henry Draper Memorial. Second Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory," Nature 38 (1888), 306-07.

it was sent to Peru, where the southern observing station was being established. Because its absence was detrimental to the completion of the study, Mrs. Draper had authorized the procurement of a similar lens, which had already been sent to Alvan Clark and Sons for grinding and mounting.

Pickering announced that several new and important researches would be undertaken with this new telescope. He felt that since photography was now used in so many departments of astronomy that a general investigation of the photographic brightness of the stars was desirable. The first part of this investigation was a plan to photograph the entire sky on plates covering an area of five square degrees, measuring the photographic brightness of all stars of the seventh magnitude or brighter. The second part was a plan to photograph the northern sky with longer exposures of about an hour. Each plate would cover a region of nearly ten square degrees, and would measure the photographic brightness of stars down to the fifteenth magnitude. The idea behind these investigations was to secure a series of standards of stellar magnitudes, which would have a special value in connection with the photometric measures of the spectra that were being undertaken. Such plates would be valuable for studies of the distribution of stars and other similar investigations. Pickering was enthusiastic about expansion of the program: "The field of work of the Henry

Draper Memorial, as now extended, is almost boundless. The problems to be investigated relate to the fundamental laws regulating the formation of the stellar system."[31]

By the time the fourth and final report was issued, Pickering could announce that the investigation was nearly completed; the entire catalogue and about half of the table giving the details of the various investigations were already in type, with the remainder nearly ready for the printer. Work on the southern observing station was progressing well. Under the direction of Solon I. Bailey,[32] an expedition had set up the Bache telescope in a station erected on a 6500-foot mountaintop near Chosica, about twenty miles east of Lima, Peru. There the instrument was photographing the entire sky south of -25°, using exposures of about ten minutes, and measuring the photographic brightness of all stars brighter than the tenth magnitude.

At Cambridge, Gerrish was still in charge of the photographic work, and Mrs. Fleming in charge of the reduc-

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[31]Edward C. Pickering, "The Henry Draper Memorial. Third Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory," Nature 40 (1889), 18.

[32]Bailey later became Phillips Professor of Astronomy at Harvard, and served as Acting Director of the Observatory upon Pickering's death in 1919 until 1921, when Harlow Shapley was appointed Director. Bailey is also known for his study The History and Work of Harvard Observatory, 1839 to 1927 (New York and London, 1931).

tions and measurements. Nearly all of the measurements of the photographs taken with the Bache and Draper 8-inch telescopes were made by her. Moreover, the computation and preparation of the catalogue was under her direction. The study and classification of the spectra photographed with the 11-inch telescope was made by Miss Antonia C. Maury, a niece of Henry Draper.

Since work on the catalogue of stellar spectra was well advanced, Pickering decided to publish some of the results yielded by the investigation. One important finding was that so many stars showed spectra exhibiting bright lines that it was found convenient to regard them as constituting a fifth type of spectra,[33] thus extending the classification scheme of Secchi. Pickering further found that nearly all of the stellar spectra could be arranged in a series in which the adjacent spectra were scarcely distinguishable.[34]

The completed _Draper Catalogue of Stellar Spectra_ was published as Vol. 27 of the _Annals of the Astronomical Obser-_

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[33]See Edward C. Pickering, "A Fifth Type of Stellar Spectra," _Astr. Nachr._ 127 (1891), cols. 1-4. For Pickering's early notice of the importance of bright-line stars, see Edward C. Pickering, "Draper Memorial Photographs of Stellar Spectra Exhibiting Bright Lines," _Nature_ 34 (1886), 439-40.

[34]Edward C. Pickering, "Fourth Annual Report of the Photographic Study of Stellar Spectra conducted at the Harvard College Observatory," _Mem. Soc. spettroscop. ital._ 19 (1890), 89.

vatory of Harvard College in 1890. Forming a part of the Henry Draper Memorial, this work contained a catalogue of 28,266 spectra of 10,351 stars on 633 plates photographed with the 8-inch Bache telescope, nearly all of them north of -25°. The classification scheme employed in the catalogue was loosely based on that of Secchi, but was modified by Mrs. Fleming. The stellar spectra were arranged in classes indicated by the letters A to Q. Of these, A through D indicated varieties of Secchi's first type, and E through L varieties of the second. M corresponded to Secchi's third type, and N to the fourth. O was used for stars whose spectra consisted mainly of bright lines, and P for planetary nebulae. Any spectrum which could not be included in any of these classes was indicated by the letter Q.[35]

In addition to the classification of stellar spectra, the Draper Catalogue furnished a great deal of additional information in five tables for each of the 10,351 stars included in it. Table 1 gave the star's number according to the Draper Catalogue, the Bonner Durchmusterung,[36] and the

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[35]The Draper Catalogue of Stellar Spectra as Photographed with the 8-inch Bache Telescope as a part of the Henry Draper Memorial, Ann. Obs. Harvard Coll. 27 (1890), 2-4. Hereafter cited as Draper Catalogue. For a fuller discussion of the classification scheme, see Edward C. Pickering, "The Constitution of the Stars," Astr. Astroph. 12 (1893), 718-22.

[36]The Bonner Durchmusterung is made up of a star cata-

Harvard Photometry.[37] Additional columns gave the star's right ascension[38] and declination[39] carried forward to the year 1900,[40] the number of photographic images obtained of each star, the mean of the photographic magnitudes after being corrected, and any residuals found when the photographic magnitude was subtracted from the values found in the Bonner Durchusterung, the Argentine General Catalogue (or if not present there, then the Uranometria Argentina[41]), and the Harvard Photometry, respectively. Table 2 gave further details of the measurements listed in Table 1, and was followed by lengthy and detailed remarks. Table 3 was

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logue and charts of the positions and magnitudes of about 325,000 stars. It was prepared by Friedrich Wilhelm August Argelander and Eduard Schönfeld, and was completed in 1862.

[37]The Harvard Photometry consists of tables of stellar magnitudes measured at Cambridge under Pickering's supervision. They were published in Vols. 14 and 24 of the Ann. Obs. Harvard Coll.

[38]Right ascension is a coordinate in the equatorial system measured from the vernal equinox eastward to the point where the hour circle of a star intersects the celestial equator.

[39]Declination is another coordinate of the equatorial system, and is the measure of the angular distance of a body from the celestial equator.

[40]It is always necessary to give a star's location relative to a given epoch, for the right ascension and declination of a star are continuously changing due to precession, a slow turning of the earth's axis around the pole of the ecliptic.

[41]The Uranometria Argentina was compiled by Benjamin Apthorp Gould, and published in 1879.

a listing of all large residuals regarding the photographic magnitude explained above. Table 4 was an index of the Greek letters assigned to the brighter stars by Johann Bayer[42] and their corresponding number in the Draper Catalogue. Finally, Table 5 was a statement regarding the number of stars included in the study.

The following year, 1891, Pickering published the Preparation and Discussion of the Draper Catalogue. In it, he gave a description of the Bache telescope, a catalogue of the plates taken with this instrument before it was sent to Peru, a description of the classification of these plates, and an explanation of the various methods of measurement and reduction. In addition, three separate chapters were devoted to some important comparisons and discussions of these plates: 1) a chapter telling how the spectra were distributed in the heavens, 2) one giving a comparison of the Draper Catalogue with visual magnitudes, and 3) one giving a comparison of the Draper Catalogue with visual spectra.

Pickering found that for stars down to magnitude 6.25 their distribution among the different classes of spectra was as follows:

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[42] In his Uranometria, published in 1603, Bayer introduced a system of cataloguing stars in the order of their brightness, using Greek letters.

Class	Percent
A	61
B	2
F	12
G	5
K	18
M	1.3
"Peculiar"	0.7

Grouping them according to Secchi's classification scheme, that is, placing classes A through D in the first type, E through L in the second, M in the third, and N in the fourth, he found that 75 percent of these stars were of Type 1, 23 percent were of Type 2, 1 percent were Type 3, and 1 percent were peculiar.[43]

By dividing the sky into 48 equal zones, Pickering found that the northern regions contained far more fainter stars than the southern. He attributed this to the greater atmospheric absorption near the southern horizon, and the slower motion of stars near the pole.[44] He also found that the Milky Way was an aggregate of Type 1 stars, whereas the sun was of Type 2. He thus concluded that "The Milky Way must therefore be described as a distinct cluster of stars to which, from its composition or age, the sun does not seem

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[43]Edward C. Pickering, Preparation and Discussion of the Draper Catalogue, Ann. Obs. Harvard Coll. 26, Part I (1891), 151.

[44]Ibid.

to belong."[45] Finally, an attempt to give the location in space of the sun gave inconclusive results, and the problem was left to later investigators.

In the chapter dealing with visual magnitudes, the magnitudes in the Draper Catalogue were compared with those in the Bonner Durchmusterung, the Uranometria Argentina, and the Harvard Photometry. The stars were grouped according to their class of spectra, magnitude, and position. The numbers of each of these was given for each of the 48 zones, and from this Pickering attempted to deduce a mathematical law relating the spectral class to the number of stars in that class for the various zones.[46] His results, however, were inconclusive.

Finally, in the chapter on visual spectra, comparisons were made between the classification scheme embodied in the Draper Catalogue and the schemes of H.C. Vogel and Nicolaus von Konkoly. As to the former, Pickering made the following identification:

Vogel Classification	Draper Catalogue Classification
Ia	A
Ib	B
IIa	E,G,H,I,K
IIIa	M
IIIb	N

[45] Ibid., p. 152.

[46] Ibid., pp. 168-69.

Vogel's classes Ic and IIb, for stars with bright lines in their spectra, rarely occurred in the Draper Catalogue.[47] Of 57 stars which appeared to be of one type according to Vogel and of another in the _Draper Catalogue_, a second examination confirmed Vogel in 35 cases and the _Draper Catalogue_ in 22.[48] Konkoly's classification system closely followed that of Vogel, but resulted in more numerous disagreements when compared to the _Draper Catalogue_. Of 87 discordant stars, a second examination confirmed Konkoly in 20 cases and the _Draper Catalogue_ in 67. The reason for this large discrepancy was that many stars considered to be of Vogel's first type by both Vogel and the _Draper Catalogue_ were regarded by Konkoly as belonging to the second type.[49]

The discrepencies between the catalogues might be accounted for by changes in the spectra themselves, Pickering noted, especially in light of the fact that some astronomers suspected that changes in the spectral form or type took place in moderately short periods of time. But Pickering did not feel that this result was confirmed by the large amount of photographic material so far collected, except in certain special cases of variable stars and close binaries.

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[47] _Ibid._, p. 176.

[48] _Ibid._, p. 188.

[49] _Ibid._, pp. 178 and 188-89.

The differences could generally be explained, he felt, from the nearly imperceptible blending of the different types of spectra, and from the faintness of the photographs of the faint stars.[50]

In 1897, Pickering published the Miscellaneous Investigations of the Henry Draper Memorial. This was devoted to illustrations of portions of some of the more recent work. Here, progress made in photographing charts and spectra of the fainter stars, especially at the Harvard Station in Arequipa, Peru, was illustrated. The Arequipa station, at an elevation of about 8000 feet above sea level, had the cost of its establishment and the greater part of its maintenance defrayed by the Boyden Fund of the Observatory.[51] It was established by William H. Pickering,[52] Edward's younger brother, who had charge of the station from 1891 to 1893; since then, Solon I. Bailey had been in charge. Other investigations in this volume included measurements of the position and brightness of various stars and novae, and

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[50] Ibid., pp. 189-90.

[51] Uriah A. Boyden, an engineer and inventor, left a bequest of more than a quarter of a million dollars for the establishment of an observatory at a high altitude. The Boyden trustees turned the fund over to Harvard in 1887.

[52] William Henry Pickering was instrumental in resuming earlier attempts at stellar photography at the Harvard Observatory, utilizing new techniques. Besides establishing the Arequipa station, he also helped establish a mountain station on Wilson's Peak, California.

examinations of the distribution and spectra of stars in clusters.[53]

Pickering's first annual report on the progress of the Henry Draper Memorial indicated that the general survey of stellar spectra for all stars north of -25° and brighter than the sixth magnitude was one of three parts of the investigation. The second part was a study of the spectra of fainter stars. This was started at the same time as the previous work, and the observations were nearly completed by the end of the third year, 1889. Except for the fact that one-hour exposures were used in this study instead of five-minute ones, the method of photographing, examination, reduction, and classification was essentially the same in both investigations.

The third program of study was a detailed investigation of the spectra of the brighter stars. This investigation, as we have already noted, was assigned to Miss Antonia C. Maury, who joined the Observatory staff as a research associate in 1888. The instrument used in this study was the 11-inch Draper telescope. The work began in 1888 and was not completed until 1895.

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[53] Edward C. Pickering, Miscellaneous Investigations of the Henry Draper Memorial, Ann. Obs. Harvard Coll. 26, Part 2 (1897).

Measuring the spectral lines obtained in the investigation with the aid of a microscope and a scale etched on glass, Miss Maury and her team were overwhelmed by the number and variety of lines visible. For this reason she decided not to use the classification scheme embodied in the *Draper Catalogue*, but to evolve one of her own. In her *Spectra of Bright Stars Photographed with the 11-inch Draper Telescope as a part of the Henry Draper Memorial*, she placed the stars into the following 22 groups, with nearly imperceptible gradations:

Groups I-V	Stars of the Orion type.[54]
Group VI	Stars intermediate between the Orion type and Secchi's first type.
Group VII-XI	Stars of Secchi's first type.
Group XII	Stars intermediate between Secchi's first and second types.
Groups XIII-XVI	Stars of Secchi's second type.
Groups XVII-XX	Stars of Secchi's third type.
Group XXI	Stars of Secchi's fourth type.
Group XXII	Stars of Pickering's fifth class.[55]

In addition, many of the groups were subdivided into Division a, b, or c depending on the width and intensity of the spectral lines. Division c distinguished very narrow and strongly

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[54] The "Orion lines" were realized to be helium lines after terrestrial helium was discovered by Sir William Ramsay in 1895.

[55] Antonia C. Maury, *Spectra of Bright Stars Photographed with the 11-inch Draper Telescope as a part of the Henry Draper Memorial*, *Ann. Obs. Harvard Coll.* 28, Part 1 (1897), 14.

defined lines, Division b lines which were relatively wide and hazy, and Division a lines intermediate between the two.[56]

Between 1891 and 1899, a similar investigation was undertaken by the Peruvian team on bright southern stars. These results were analyzed by Miss Annie Jump Cannon. Instead of following Miss Maury's elaborate classification scheme, however, she found that the stars could be more conveniently classified according to the original scheme of the *Draper Catalogue*, with a modification so that intermediate classes could be indicated.

In her *Spectra of Bright Southern Stars Photographed with the 13-inch Boyden Telescope as a part of the Henry Draper Memorial*, she classified the spectra as follows:

P Spectra of planetary nebulae.
Q Peculiar spectra having bright lines.
O Spectra of stars of Pickering's fifth class, consisting mainly of bright lines.
B Spectra in which the Orion lines are as intense as the hydrogen lines.
A Spectra exhibiting weak solar lines and intense hydrogen lines.
F Spectra in which the prominent calcium lines are the most conspicuous features, while the hydrogen lines are still more intense than the solar lines.

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[56] *Ibid.*, pp. 4-5. The importance of the Division c stars was shown later. In 1900, Lockyer noted that spectral lines he called "enhanced lines" were the same ones that had been found to be strong in Division c stars. At around the same time, Ejnar Hertzsprung found that these stars were distinguished by imperceptible parallaxes and small, nearly imperceptible proper motions. This meant that these stars were very distant and hence must have a high luminosity. Such stars are now called "supergiants."

G Spectra of the solar type. The calcium lines are the most conspicuous features, while the hydrogen lines are still as intense as the solar lines.

K Spectra in which the calcium lines are still very conspicuous, while the hydrogen lines are now fainter than the solar lines.

M Banded spectra.[57]

In addition, there were decimal divisions between these classes. Thus, the spectra of class B1A, for instance, would be very nearly like those of Class B, while those of class B9A would show only slight differences from those of class A.[58] Further observations carried out on faint northern stars and analyzed by Miss Cannon form a supplement to this work.[59]

Thus, by 1912 there were six seperate publications forming parts of the Henry Draper Memorial, embodying two essentially different classification schemes. Pickering therefore thought it desirable to collect in a single catalogue a description of all the stellar spectra which could be classified on the basis of the photographs of the Henry Draper Memorial. The ensuing work, <u>The Henry Draper Cata-</u>

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[57] Annie J. Cannon, <u>Spectra of Bright Southern Stars Photographed with the 13-inch Boyden Telescope as a part of the Henry Draper Memorial</u>, <u>Ann. Obs. Harvard Coll.</u> 28, Part 2 (1901), 139-42.

[58] <u>Ibid.</u>, p. 140.

[59] Annie J. Cannon, <u>Classification of 1,477 Stars by Means of their Photographic Spectra</u>, <u>Ann. Obs. Harvard Coll.</u> 56, No. 4 (1912).

logue, was published in Vols. 91-99 of the *Annals of the Astronomical Observatory of Harvard College* between 1918 and 1924 (with two extensions up to 1949).

The spectra classified in this catalogue included all of the spectra from the earlier investigations, plus some additional spectra taken from later plates, where faint stars had not been classified previously. The total number of spectra classified is 242,093, relating to about 222,000 stars. The greater portion of the northern stars were classified from 709 plates taken with the 8-inch Draper telescope, mounted at Cambridge. For the southern stars, 1,409 plates were taken with the 8-inch Bache telescope, mounted at Arequipa, Peru.

The task of classifying nearly a quarter of a million spectra was undertaken by Miss Cannon, who began the job in October, 1911, and completed it in October, 1915. Although she was aided by several assistants, the average number being five, she took on those portions of the investigation which could not readily be undertaken by the others. This included the classification, the revision, and the supervision of the whole catalogue. For this accomplishment, Miss Cannon was awarded an honorary D.Sc. degree from Oxford University.[60]

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[60]Solon I. Bailey, "Astronomy, 1877-1927" in *The Development of Harvard University since the Inauguration of Presi-*

In her classification scheme, Miss Cannon retained the system employed in both the original Draper Catalogue and her own catalogue of bright southern stars. The main sequence of spectra was divided into classes B, A, F, G, K, and M. Two classes, viz. P designating gaseous nebulae, and O, stars of the fifth class, were added to the sequence preceeding class B. Two more classes, viz. R for stars showing dark carbon bands, and N, stars exhibiting dark cyanogen bands, were added to the end of the sequence. Finally, two additional classes were noted: "Continuous" designated spectra which were apparently continuous, and was mostly made up of spectra of nebulae without any bright lines; "Peculiar" categorized all spectra which could not be assigned to another class, and consisted of the spectra of novae, a few variables, and some very red stars.[61] As before, intermediate spectra were indicated by numbers representing tenths of the interval. As an example, A5 would represent a spectrum midway between A0 and F0. This system was unanimously adopted by an International Committee appointed by the Solar Union,[62] but was later modified

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dent Eliot, 1869-1929, ed. Samuel Eliot Morison (Cambridge, 1930), p. 296, note 1.

[61] Annie J. Cannon and Edward C. Pickering, The Henry Draper Catalogue, Ann. Obs. Harvard Coll. 91 (1918), 5-11.

[62] Ibid., p. 3.

by the Committee of the International Astronomical Union on Spectral Classification.[63]

The importance of the Henry Draper Memorial cannot be overemphasized. In the estimation of two contemporary astrophysicists,

> The Harvard classification [as embodied in the Henry Draper Memorial] is the greatest single work in the field of stellar spectroscopy...After nearly 50 years, every astrophysicist still relies heavily upon *The Henry Draper Catalogue*, its more recent Harvard extensions, and several other catalogues built on the Harvard system of classification...In the light of the success the Harvard classification still enjoys today, we must recognize the wisdom of the two observatory directors, E.C. Pickering and H. Shapley, who withstood the temptation to embark upon new, and in some respects more exciting, astronomical ventures and did not lose sight of their goal: providing as complete a history of the sky as possible.[64]

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[63] *Trans. Int. Astr. Union* 1 (1922), 97, cited in Brian Gee, "The Harvard Studies on Stellar Astronomy, 1840-1890," unpublished M.Sc. dissertation (Department of the History and Philosophy of Science, University of London, 1968), p. 267b. I wish to thank Mr. Gee for helping me to obtain a copy of his dissertation.

[64] Otto Struve and Velta Zebergs, *Astronomy of the Twentieth Century* (New York and London, 1962), pp. 190-94. Struve, who died in 1963, was one of America's leading astrophysicists. He was best noted for his interstellar studies, and had discovered interstellar hydrogen in 1938. Since 1959, he had been the Director of the National Radio Astronomy Observatory at Green Bank, West Virginia, where Mrs. Zebergs was a member of the scientific staff.

Needless to say, we must also admire the wisdom of Anna Draper who, by funding the Henry Draper Memorial,[65] succeeded brilliantly in her endeavor to erect a "suitable memorial" to Henry, one that would "perpetuate his name and his work."[66]

A few year after Draper's death, John A. Brashear visited the Hastings observatory,

> where I spent two grand, aye, glorious hours...two hours that will linger in my memory as long as life can last. No one outside the Draper family has ever visited that sacred spot that appreciated it, enjoyed it, drank in its reminiscences, its story of labor, toil, and anxious waiting for breaking clouds, more than I did... When I stood by the grand twenty-eight-inch [telescope] and thought of its maker and the blotting-out of his noble life, I could not repress a tear of sorrow and I asked myself the question, "Does death end all?"[67]

Thanks to the sagacity of his wife, in the case of Henry Draper we can answer: "no."

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[65] Mrs. Draper appropriated $237,700 to the Harvard College Observatory during her lifetime, and bequeathed an additional $150,000 to be designated as the Henry Draper Memorial Fund upon her death. See "Annual Report of the Director of the Observatory to the President," _Report to the President and the Treasurer of Harvard College_ (Cambridge, 1886-1917).

[66] Mrs. Draper to E.C. Pickering, January 13, 1883, in Boyd, p. 73.

[67] John A. Brashear, _The Autobiography of a Man Who Loved the Stars_, _op. cit._, pp. 56-57.

CHAPTER SIX

RETROSPECT

In the middle of the nineteenth century, the refractor telescope was the basic instrument in both national and private observatories. A census of forty-seven British observatories at this time shows that forty possessed a refractor, while only seven possessed a reflector.[1] Amateurs like Lord Rosse, William Lassell, and Warren de la Rue, who had the time, money, and skill necessary to build large reflectors, were more the exception than the rule. The various problems intrinsic to speculum metal--its low reflectivity, its heaviness, and the fact that it tarnishes very quickly--were nowhere near solution. Although alternative reflecting surfaces had been experimented with from time to time, these had met with little success.

In 1851, however, globes and vases were displayed at the Great Crystal Palace Exhibition held in London which had been successfully silvered on their insides. The process by which this had been accomplished was revived a few years

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[1] Astr. Reg. 4 (1866), 91. Cited in Henry C. King, The History of the Telescope (Cambridge, Mass., 1955), 261.

later by the German chemist, Justus von Liebig.[2] In its essentials, Liebig's method is the same as that used today. Liebig, however, did not apply his process to astronomical mirrors.

That step was first taken in 1856 by Carl August von Steinheil in Germany and Léon Foucault in France. Steinheil made silvered-glass mirrors ranging in size from 4 inches to 12 3/4 inches,[3] while Foucault's largest mirror was 31 inches.[4] Foucault's greatest contribution to the reflecting telescope, however, was his invention of a simple yet accurate technique to test the curvature of the mirror.[5] Foucault's test enabled him to produce mirrors equal in definition to the finest refractor objectives, and is still used today by amateur telescope makers throughout the world. Silvered-glass mirrors soon became popular in Europe, and with few exceptions, entirely replaced metal specula. Henry Draper introduced the silver-on-glass reflector to Americans

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[2]Justus von Liebig, "Über Versilberung und Vergoldung von Glas," Ann. Chim. Pharm. 98 (1856), 132-39.

[3]Carl August von Steinheil, "On the Advantages to be Derived from the Use of Silver Mirrors for Reflecting Telescopes," Mon. Not. R. Astr. Soc. 19 (1859), 56-60.

[4]Léon Foucault, "Note sur un télescope en verre argenté, C.-R. Acad. sci. 44 (1857), 339-42.

[5]Léon Foucault, "Mémoire sur la construction des télescopes en verre argenté," Ann. Obs. Paris 5 (1859), 197-237.

through his highly successful Smithsonian publication of 1864. By showing amateur astronomers how to make large and precise instruments, his publication was an important landmark in the history of telescope making.

Draper was also the first person to exploit the photographic possibilities of the silvered-glass reflector, for he shared his father's interest in celestial photography. Shortly after Dominique François Arago made the first public announcement of Louis Jacques Mandé Daguerre's process of fixing camera images in a speech to the Académie des sciences in 1839, John William Draper succeeded in taking the first daguerreotype of the moon that showed any indications of the lunar maria:

> There is no difficulty in procurring impressions of the moon by the daguerreotype beyond that arising from her motion. By the aid of a lens and a heliostat, I caused the moonbeams to converge on a plate, the lens being three inches in diameter. In half an hour a very strong impression was obtained. With another arrangement of lenses I obtained a stain nearly an inch in diameter, and of the general figure of the moon, in which the places of the dark spots might be indistinctly traced.[6]

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[6]John William Draper, "On the Process of Daguerreotype, and Its Applications to Taking Portraits from the Life," Phil. Mag. 17 (1840), 222. See further, Daniel Norman, "The Development of Astronomical Photography," Osiris 5 (1938), 560-61. See also Norman's "John William Draper's Contributions to Astronomy," The Telescope 5 (1938), 11-16.

John William sent this last photograph (or a similar one) to the New York Lyceum of Natural History (later, the New York Museum of Natural History) on March 23, 1840. The Secretary of the Lyceum later sent Henry the following extract from the Lyceum's minutes:

> March 23d, 1840. Dr. Draper announced that he had succeeded in getting a representation of the moon's surface by the Daguerreotype...The time occupied was 20 minutes, and the size of the figure about 1 inch in diameter. Daguerre had attempted the same thing, but did not succeed. This is the first time that anything like a distinct representation of the moon's surface has been obtained.[7]

Unfortunately, this photograph, which launched the great age of astronomical photography, was destroyed in a fire that ravaged many of the Lyceum's treasures.

John William's daguerreotypes of the moon were not surpassed for a decade. In the winter of 1849, William Cranch Bond (then the Director of the Harvard College Observatory) and his son George Phillips Bond (who succeeded his father as Director in 1859) induced John A. Whipple, one of the best-known daguerreotypists of his time, to attempt celestial photography with Harvard's 15-inch refractor, then the largest telescope in the world. On the night of December 18, 1849, Whipple succeeded in obtaining the

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[7]Henry Draper, "On the Construction of a Silvered-Glass Telescope...," _op. cit._, p. 33.

first of a series of daguerreotypes of the moon of such excellence that they created a "veritable furore" when they were shown in Europe, and were promptly awarded a prize medal at the Great Crystal Palace Exhibition of 1851.[8] The press of other work and the building of a more accurate driving mechanism for the telescope occupied the attention of the Bonds for a considerable time after this, however, and for some years no further attempts were made at celestial photography.

Inspired by the Bond's photographs, Warren de la Rue became interested in lunar photography in 1852. Using the new collodion plates, he immediately obtained good photographs.[9] By the end of the following decade, Lewis Morris Rutherfurd[10] and Henry Draper had improved the techniques involved in lunar photography to such an extent that their photographs compare favorably with those taken in very recent times. Both Rutherfurd and Draper were active in

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[8] Edward S. Holden, *Memorials of William Cranch Bond and George Phillips Bond*, *op. cit.*, p. 262. See further, "History and Description of the Obervatory, 1840-1855," *Ann. Obs. Harvard Coll.* 1, Part 1 (1855), and Solon I. Bailey, *The History and Work of Harvard Observatory, 1839 to 1927*, *op. cit.*

[9] "Report of the Council to the Thirty-fourth Annual General Meeting," *Mon. Not. R. Astr. Soc.* 14 (1854), 134.

[10] Lewis Morris Rutherfurd, "Astronomical Photography," *Amer. J. Sci.* 39 (1865), 304-09.

the American Photographical Society, and it is likely that their practice of airing their photographic problems before the Society benefited them in their endeavors.[11]

Another area of astronomical photography in which Henry Draper pioneered was that of nebular photography. Draper succeeded in taking the first photograph of a nebula (the Great Nebula of Orion) in 1880, and by 1882 had taken a photograph of this nebula which showed stars down to magnitude 14.7. In England, A.A. Common was following a similar and no less successful line of inquiry. Using a 36-inch silvered-glass mirror made for him by George Calver, Common first attempted to photograph the Great Nebula in January, 1880. Although stars were in focus in this photograph, irregularities in the clock drive made them appear as short lines, while a faint stain represented the nebula.[12] On March 17, 1882, he succeeded in photographing the faint filaments of the nebula; this photograph caused considerable excitement at the May meeting of the Royal Astronomical Society.[13]

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[11]This point is stressed in Deborah Jean Warner, "The American Photographical Society and the Early History of Astronomical Photography in America," Phot. Sci. Engin. 11 (1967), 342-47.

[12]"Address Delivered by the President on Presenting the Gold Medal of the Society to Mr. Common," Mon. Not. R. Astr. Soc. 44 (1884), 221-22.

[13]Ibid., p. 222.

This annoyed Mrs. Draper, who thought that Henry's photograph was being unfairly overlooked:

> In regard to Mr. Common's photograph of the Orion Nebula, the one you refer to is I presume the one he presented at the May meeting of the [Royal] Astronomical Society...As Mr. Ranyard, Henry's only friend in the Society was in Egypt [to photograph the solar eclipse of May 17, 1882], no reference was made to the picture we had presented the year before.[14]

Upon his return to London, however, Ranyard examined both photographs, and wrote Mrs. Draper that Common's showed more detail. This led her to ruefully remark: "When a man opens a new line of research how little time passes, before others take it up and improve upon what he has done."[15] A year later Common obtained a still better photograph of the nebula, which earned him the Royal Astronomical Society's Gold Medal in 1884.

Besides direct celestial photography, Henry Draper also pioneered in spectrum photography. In this field too, however, he followed in his father's footsteps. Early in 1843, John William obtained daguerreotypes of the solar spectrum that revealed new Fraunhofer lines in both the infrared and ultraviolet regions. By allowing weak diffused

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[14]Mrs. Draper to Edward C. Pickering, February 22, 1883, in Boyd, op. cit., p. 77.

[15]Mrs. Draper to Edward C. Pickering, March 26, 1883, in Boyd, p. 79.

light to fall on the photographic plate during exposure, he found that the plate became more sensitive. It was by this process that he took the first precision photographs in the infrared region of the solar spectrum, and discovered three very prominent Fraunhofer lines there, which he called α, β, and γ.[16] This discovery was subsequently confirmed by Léon Foucault and Hippolyte Fizeau. He also photographed lines in the ultraviolet at about the same time or slightly later than Edmond Becquerel. In addition, he secured some of the earliest photographs of the Fraunhofer lines between these two extremes, but here too it seems he was just anticipated by Becquerel.[17]

John William was not entirely satisfied with his prismatic spectrum photographs, however, since they did not yield a normal spectrum. So in May, 1843, he had Joseph Saxton, an eminent mechanician at the U.S. Mint in Philadelphia, rule a diffraction grating for him. With this grating, which was of glass and five-eighths of an inch by one-third of an inch in size, John William took the first diffraction-spectrum photograph of the sun in 1844.[18] He

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[16] John William Draper, "On a New System of Inactive Tithonographic Spaces in the Solar Spectrum Analogous to the Fixed Lines of Fraunhofer," Phil. Mag. 22 (1843), 360-64.

[17] Donald Fleming, John William Draper and the Religion of Science, op. cit., pp. 38-39.

[18] John William Draper, "On the Interference Spectrum,

later silvered the grating with mercury-tin amalgam, and showed that when used as a reflection grating, it produced much brighter spectra.[19] By 1850, Lewis Morris Rutherfurd was producing gratings coated with silver, and also diamond-ruled speculum-metal reflection gratings that were far superior to those which John William possessed. It was, in fact, with a Rutherfurd grating that Henry Draper took his unrivaled diffraction-spectrum photograph of the sun in 1873.

In the area of stellar spectrum photography, Henry Draper pursued a line of investigation which was uniquely his own in America. His earliest rival in this field was William Huggins in England. Huggins began his highly original work examining stellar spectra more than a decade before Draper began his:

> I soon became a little dissatisfied with the routine character of ordinary astronomical work and in a vague way sought about in my mind for the possibility of research upon the heavens in a new direction, or by new methods...It was just at this time...that the news reached me of Kirchoff's great discovery of the nature and the chemical constitution of the sun from his interpretation of the Fraunhofer lines. Here at last presented

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and the Absorption of the Tithonic Rays," Phil. Mag. 26 (1845), 465-78.

[19] John William Draper, Scientific Memoirs (New York, 1878), 117.

> itself the very order of work for which in an indefinite way I was looking--namely, to extend his novel methods of research upon the sun to the other heavenly bodies.[20]

In his investigations, Huggins used an 8-inch Clark refractor, which was mounted equatorially and provided with a clock drive by Thomas Cooke, and a two-prism spectroscope.

With his friend W.A. Miller, Huggins examined the spectra of the brighter stars and of the sun, moon, and planets. Early in 1863, they sent a preliminary note to the Royal Society describing their work.[21] On the same day as their paper was read, news arrived that similar observations had been made a month earlier by Lewis Morris Rutherfurd.[22] At about this time, Angelo Secchi at Rome and a little later H.C. Vogel at Potsdam entered into stellar spectroscopic investigations.

In 1864, Huggins and Miller published their second paper on stellar spectra.[23] By carefully comparing stellar

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[20]William Huggins, _Publications of Sir William Huggins's Observatory_ 1 (1899), 6-7. Quoted in Henry C. King, _op. cit._, p. 285.

[21]William Huggins and W.A. Miller, "On the Lines of the Spectra of some of the Fixed Stars," _Proc. R. Soc._ 12 (1863), 444-45.

[22]Lewis Morris Rutherfurd, "Astronomical Observations with the Spectroscope," _Amer. J. Sci._ 35 (1863), 71-77.

[23]William Huggins and W.A. Miller, "On the Spectra of some of the Fixed Stars," _Phil. Trans._ 154 (1864), 413-35.

spectra with laboratory spectra, many stellar lines were identified. Although they obtained photographs of the spectra of Sirius and Capella on wet collodion plates, only faint impressions were recorded, which did not show any Fraunhofer lines. Henry Draper's success in obtaining a photograph of the spectrum of a star which showed Fraunhofer lines in 1872 was not matched by Huggins until 1876.

Draper's plans at the time of his untimely death in 1882 were twofold:

> At the Observatory to get his instruments into the best order, and then by means of photography to catalogue and classify the stars by their spectra...Here in the [New York City] Laboratory he intended to continue the research, on the examination of the Sun's spectrum for the non-metals and see if he could find in it any others than the Oxygen.[24]

Both of these lines of investigation were carried out by other astronomers--the former resulted in the Henry Draper Memorial, the latter in the eventual discovery of oxygen absorption lines in the solar spectrum by Carl Davie Tolmé Runge and Friedrich Paschen in 1896.

Henry Draper was highly regarded in his day by the leading scientific figures. In 1874 he was appointed Director of the Photographic Department of the Transit of

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[24]Mrs. Draper to Edward C. Pickering, January 31, 1886, in Boyd, p. 91.

Venus Commission. The following year he received international recognition by election to the Astronomische Gesellschaft. In 1876 he served as one of the judges in the Photographic Section of the Centennial Exhibition held in Philadelphia. In 1877 he was made a member of the American Philosophical Society and elected to the prestigious National Academy of Sciences. He was elected a Fellow of the American Association for the Advancement of Science in 1879, and an Associate Fellow of the American Academy of Arts and Sciences in 1881. In 1882, the year of his death, he received the degree of Doctor of Laws almost simultaneously from the University of Wisconsin and from his alma mater, the University of the City of New York.

And yet, although his scientific accomplishments were substantial, he is now often condescendingly characterized as a mere amateur, as Nathan Reingold quite correctly points out.[25] In a sense, of course, he was. He had no formal training in astronomy, did not teach the subject, and did not seek outside support for his research. His medical training, moreover, did not give him the mathematical background which was necessary for any meaningful theoretical work in astronomy by the late nineteenth century. Yet,

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[25] Nathan Reingold, Science in Nineteenth-Century America. A Documentary History (New York, 1964), 253.

judged in terms of his devotion, his skill, and his contributions, Henry Draper was clearly more than an amateur. Indeed, whereas many of his contemporary professional astronomers did not leave the traditional boundaries of classical astronomy, Draper was in the forefront of research in the new astronomy--astrophysics. It is for this reason that his scientific work deserves greater attention than it has hitherto received.

A BIBLIOGRAPHICAL NOTE: THE PROBLEM OF WRITING ON NINETEENTH-CENTURY AMERICAN SCIENCE

Since 1948, when Richard Shryock published his seminal and controversial essay on "American Indifference to Basic Science in the Nineteenth Century,"[1] a number of significant essays dealing with the history of American science have appeared. Most notable among these are A. Hunter Dupree's "The History of American Science: A Field Finds Itself,"[2] and "Science in America--A Historian's View;"[3] Edward Lurie's "Science in American Thought,"[4] and "An Interpretation of Science in the Nineteenth Century: A Study in History and Historiography;"[5] Donald Fleming's

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[1]Richard Shryock, "American Indifference to Basic Science in the Nineteenth Century," _Arch_. _Intern_. _Hist_. _Sci_. 2 (1948-49), 50-65.

[2]A. Hunter Dupree, "The History of American Science: A Field Finds Itself," _Amer_. _Hist_. _Rev_. 71 (1966), 863-74.

[3]A. Hunter Dupree, "Science in America-- A Historian's View," _J_. _World Hist_. 8, Part 4 (1965), 613-19. The entire issue is devoted to "Science in the American Context."

[4]Edward Lurie, "Science in American Thought," _ibid_., pp. 638-64.

[5]Edward Lurie, "An Interpretation of Science in the Nineteenth Century: A Study in History and Historiography," _ibid_., pp. 681-706.

"American Science and the World Scientific Community;"[6] and I. Bernard Cohen's "Science in the United States,"[7] "The New World as a Source of Science for Europe,"[8] "Science in America: The Nineteenth Century,"[9] and "Some Reflections on the State of Science in America During the Nineteenth Century."[10]

In addition to these essays, a number of recently published monographs are devoted to the history of American science. Prominent among these are Dupree's _Science in the Federal Government: A History of Policies and Activities to 1940_;[11] Howard S. Miller's _Dollars for Research: Science and Its Patrons in Nineteenth-Century America_;[12] and George

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[6] Donald Fleming, "American Science and the World Scientific Community," _ibid._, pp. 666-78.

[7] I. Bernard Cohen, "Science in the United States," _Science in the Nineteenth Century_, ed. René Taton (New York, 1965), 563-70.

[8] I. Bernard Cohen, "The New World as a Source of Science for Europe," _Actes IX^{e} Cong. Intern. Hist. Sci._ (Barcelona, 1959), 95-130.

[9] I. Bernard Cohen, "Science in America: The Nineteenth Century," _Paths of American Thought_, Arthur Schlesinger, Jr., and Morton White, eds. (Boston, 1963), 167-89.

[10] I. Bernard Cohen, "Some Reflections on the State of Science in America During the Nineteenth Century," _Proc. Nation. Acad. Sci._ 45 (1959), 666-77.

[11] A. Hunter Dupree, _Science in the Federal Government: A History of Policies and Activities to 1940_ (Cambridge, 1957).

[12] Howard S. Miller, _Dollars for Research: Science and Its Patrons in Nineteenth-Century America_ (Seattle, 1970).

H. Daniels' American Science in the Age of Jackson,[13] which examines the influence of Baconian philosophy on American scientific thought between 1815 and 1845, and Science in American Society: A Social History,[14] which surveys the interaction of science and the "democratic experience" in America from colonial days to the present. Two recently edited works also deal with the history of American science: Science and the Emergence of Modern America, 1865-1916,[15] edited by Dupree, examines the changing relationship between science and technology; and Science and Society in the United States,[16] edited by David D. Van Tassel and Michael G. Hall, represents an attempt to integrate scientific developments into general American history. Finally, Science in America: Historical Selections,[17] edited by John C. Burnham, is a collection of documents designed to augment university courses in the history of American science.

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[13] George H. Daniels, American Science in the Age of Jackson (New York, 1968).

[14] George H. Daniels, Science in American Society: A Social History (New York, 1971).

[15] A. Hunter Dupree, ed., Science and the Emergence of Modern America, 1865-1916 (Chicago, 1963).

[16] David D. Van Tassel and Michael G. Hall, eds. Science and Society in the United States (Homewood, Ill., 1966).

[17] John C. Burnham, ed., Science in America: Historical Selections (New York, 1971).

In spite of all of these recent publications, however, there is as yet no well-documented synthetic treatment of the history of American science for the period after 1820 comparable to Raymond Phineas Sterns's Science in the British Colonies of America,[18] or Brooke Hindle's The Pursuit of Science in Revolutionary America, 1735-1789.[19]

For this reason, one wishing to write on nineteenth-century American science has to rely heavily on manuscript sources. Fortunately, good general guides are available to the researcher, such as the U.S. Library of Congress' National Union Catalogue of Manuscript Collections,[20] and the U.S. National Historical Publication Commission's A Guide to Archives and Manuscripts in the United States.[21] A recent catalogue published by the Center for History and Philosophy of Physics of the American Institute of Physics, A Selection of Manuscript Collections at American Reposi-

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[18]Raymond Phineas Stearns, Science in the British Colonies of America (Urbana, 1970).

[19]Brooke Hindle, The Pursuit of Science in Revolutionary America, 1735-1789 (Chapel Hill, 1956).

[20]U.S. Library of Congress, National Union Catalogue of Manuscript Collections (Washington, 1962-).

[21]U.S. National Historical Publication Commission, A Guide to Archives and Manuscripts in the United States, ed. Philip M. Hamer (New Haven, 1961).

tories[22] is extremely helpful in locating scientific manuscripts. An updated version of the astronomy and astrophysics sections of this catalogue, "Source Materials for the Recent History of Astronomy and Astrophysics: A Checklist of Manuscript Collections in the United States,"[23] has just been published. Nathan Reingold's Science in Nineteenth-Century America. A Documentary History[24] is a valuable index to various important collections, as well as a useful biographical and interpretive guide. So too are his articles on various manuscript depositories, such as "The National Archives and the History of Science in America,"[25] and "Research Possibilities in the U.S. Coast and Geodetic Survey Records."[26] The growing concern for the preservation and use of science manuscripts is indi-

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22 Center for History and Philosophy of Physics, American Institute of Physics, A Selection of Manuscript Collections at American Repositories, ed. Joan Nelson Warnow (New York, 1969).

23 Charles Weiner and Joan Nelson Warnow, eds., "Source Materials for the Recent History of Astronomy and Astrophysics: A Checklist of Manuscript Collections in the United States," J. Hist. Astr. 2 (1971), 210-18.

24 Nathan Reingold, Science in Nineteenth-Century America. A Documentary History, op. cit.

25 Nathan Reingold, "The National Archives and the History of Science in America," Isis, 46 (1955), 22-28.

26 Nathan Reingold, "Research Possibilities in the U.S. Coast and Geodetic Survey Records," Arch. Intern. Hist. Sci. 11 (1958), 336-37.

cated by the "Conference on Science Manuscripts" sponsored by the History of Science Society, held at Washington, D.C., May 5-6, 1960.[27]

Finally, several useful bibliographical sources which help to locate materials relating to the development of science in America in the nineteenth-century are available. Two good general guides are the Royal Society of London's Catalogue of Scientific Papers, 1800-1900,[28] and Johann Christian Poggendorff's Biographisch - literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften.[29] The Isis Cumulative Bibliography,[30] when available, will be an invaluable general guide. For a study of astronomy in particular, the Bibliographie générale de l'astronomie,[31] edited by J.C. Houzeau and A. Lancaster, is indispensable,

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[27] See Isis, 53, Part 1 (1962), the entire issue of which is devoted to the "Conference on Science Manuscripts."

[28] Royal Society of London, Catalogue of Scientific Papers, 1800-1900, 19 vols. (London, 1867-1902).

[29] Johann Christian Poggendorff, Biographisch - literarisches Handwörterbuch zur Geschichte der exacten Wissenschaften (Leipzig, 1863-).

[30] The first two volumes of the Isis Cumulative Bibliography, edited by Magda Whitrow for the History of Science Society, deal with personalities and institutions, and are due to be published on January 19, 1972. Two further volumes, arranged first in order of periods and secondly in order of subjects, are in the course of active preparation.

[31] J.C. Houzeau and A. Lancaster, eds., Bibliographie générale de l'astronomie, 2 vols. in 3 (London, 1964).

as is Houzeau's Vade-mecum de l'astronomie.[32] For the field of spectroscopy, Alfred Tuckerman's Index to the Literature of the Spectroscope[33] and Herbert McLeod's "Bibliography of Spectroscopy"[34] should be consulted.

In preparing this dissertation on Henry Draper, it has been necessary to rely heavily on sources and materials located through use of the above-mentioned manuscript and bibliographical guides, since the secondary literature is not particularly helpful. The problem of writing on nineteenth-century American science, while real, is not insurmountable. An exciting and rewarding experience awaits those historians who enter this field.

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[32] J.C. Houzeau, Vade-mecum de l'astronomie (Brussels, 1882).

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[34] Herbert McLeod, "Bibliography of Spectroscopy," Rep. Brit. Ass. (1881), 328-422; (1884), 295-350; (1889), 344-422; (1894), 161-236; (1898), 439-519; and (1901), 155-206.

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VITA

Howard Neil Plotkin was born on June 3, 1941 in Detroit, Michigan. His early education was in the Detroit public school system, and he received his high school diploma from Oak Park High School, Oak Park, Michigan in 1959. His undergraduate training was taken at the University of Michigan, Ann Arbor, Michigan from 1959 to 1964, except for the academic year 1961-62, which was spent abroad at the University of Aberdeen, Aberdeen, Scotland. At Michigan, he received a B.A. in History in 1964. From 1964 to 1966 he attended the University of Wisconsin, Madison, Wisconsin as a graduate student in the Department of the History of Science. While there, he held a Science-Writing Assistantship. In 1966 he entered The Johns Hopkins University, Baltimore, Maryland as a graduate student in the Department of the History of Science. There, he was a National Science Foundation Graduate Trainee from 1966 to 1970.

In July, 1970 he became a Lecturer in the Department of the History of Medicine and Science at the University of Western Ontario, London, Ontario. His teaching responsibilities there include an undergraduate survey and a graduate seminar in the history of science, and an undergraduate course in the history of astronomy which he initiated. His main research interests are in the history of astronomy, the development of the physical sciences in America in the nineteenth century, and the relations between science and society. He is a member of the History of Science Society, the British Society for the History of Science, the American Association for the Advancement of Science, the American Historical Association, and the Canadian Society for the Study of the History and Philosophy of Science.

He married the former Donna Karen Reder in 1967, and they have one daughter, Rachel Jill, born in 1970 in London, Ontario. Among his hobbies are antiques, bluegrass music, camping, and photography.