FOREWORD TO THE SECOND EDITION

MARY Somerville (1780-1882)[1] wanted to produce a second edition (and indeed, a second volume) of this historically important work. She reveals in the first draft of her handwritten autobiography that it would be the *Mechanism of the Heavens* (1831), and nothing else for which future ages would remember her: "*All my other books will soon be forgotten, by this my name will be alone remembered…I heartily regret having written on popular science. The calculus was my strong point. I ought to have made a new edition of the "Mechanism of the Heavens"…*"[2] Somerville was in her 89th year when she penned these reflections. She understood that the *Mechanism of the Heavens*, written nearly four decades earlier, did more than introduce Laplace to the English speaking world. What was more important was the language Somerville chose to bring forth her rendition[3] (as Somerville always referred to her book) of the inspiration for Pierre Simon Laplace's "world formula" as expressed in his *Mécanique céleste*.[4] That language was the calculus in its highly evolved continental form, as developed initially by G. W. Leibniz[5] and brought to a high degree of perfection in its application to the problems of celestial mechanics by Euler,[6] Lacroix,[7] Lagrange,[8] Legendre,[9] Laplace,[10] and others. But the language of calculus did not flourish in the United Kingdom during the same period. As J. F. W. Herschel[11] remarks in his critique of Somerville's work in the *Quarterly Review*:[12] "*Whatever might be the causes* [of the decline of British science and mathematics] *however, it will hardly be denied by any one versed in this kind of reading, that the last twenty years of the eighteenth century were not more remarkable for the triumphs of both the pure and applied mathematics abroad, than for their decline, and, indeed, all but total extinction, at home*." In her autobiography Somerville identifies the reason for this decline as a "*reverence for Newton* [that] *had prevented scientific men from adopting the calculus which had enabled foreign mathematicians to carry astronomical and mechanical science to the highest perfection*."[13]

Somerville's work marked a significant turning point. As Herschel comments in his article in the *Reviews* section of this volume, a series of elementary texts designed to address this deficiency had been introduced to England during the first decades of the 19th century. And, as Somerville recalls in her autobiography, a letter she received from Professor Peacock on February 14, 1832 announced that, " '*Mr. Whewell and myself have already taken steps to introduce* [The *Mechanism of the Heavens*] *into the* [advanced mathematics] *Course of our studies at Cambridge, and I have little doubt that it will immediately become an essential work to those of our students who aspire to the highest places in our examinations.' Peacock,*[14] *Whewell*[15] *and Babbage*[16] *had only a few years earlier introduced the calculus as an essential branch of science at the University of Cambridge*."[17] Indeed, most of the 750 copies made for the first and only press run of the *Mechanism* were employed in the resuscitation of mathematics at the university that had taken the lead in reform and had the proudest mathematical tradition. The *Preliminary Dissertation* was printed separately both in England,[18] and as a pirate edition in the United States.[19] There are no records of the numbers of printed or sold copies of the independently produced *Preliminary Dissertation*.

While there was to be neither a second edition nor second volume of the *Mechanism of the Heavens* during her lifetime, Somerville did begin a second exercise in celestial mechanics shortly after finishing her first edition. As Herschel says in his review, topics not treated in depth in Somerville's work would be suited for a future project: "*The development of the theory of the tides, and the precession of the equinoxes, the attraction of spheroids and the figure of the earth, appear to be reserved for a second volume.*" Somerville indeed did leave an unpublished 408 page manuscript, *On the Figure of the Celestial Bodies,*[20] which may have been intended for that purpose. The idea for that manuscript had been suggested in an 1832 letter to Somerville[21] from the eminent French mathematician Siméon Poisson.[22]

Mary Somerville never regarded herself as an original thinker: "*I was conscious that I had made no discovery myself, that I had no originality. I have perseverance and intelligence but no genius, that spark from heaven is not granted to the sex, we are of the earth, earthy, whether higher powers may be allotted to us in another state of existence God knows, original genius in science at least is hopeless in this.*"[23] Ironically, it is in her popular writings–the works she "*regrets having written*"– that I find Somerville's most important historical contribution to astronomical science, and concrete evidence that belies her modest claim. In referring to the perturbations of the recently discovered Uranus, the outermost known planet when the *Mechanism of the Heavens* was published, Somerville makes this prediction based initially on an anomalous motion in the orbit of Uranus observed first by Alexis Bouvard (1767-1843) and noted in his tables published in 1821 (see note 11, *Bk. III, Chap. II*): "*Those of Uranus, however, are already defective, probably because the discovery of that planet in 1781 is too recent to admit of much precision in the determination of its motions, or that possibly it may be subject to disturbances from some unseen planet revolving about the sun beyond the present boundaries of our system. If, after a lapse of years, the tables formed from a combination of numerous observations should be still inadequate to represent the motions of Uranus, the discrepancies may reveal the existence, nay, even the mass and orbit, of a body placed for ever beyond the sphere of vision.*"[24] Four years after that 1842 prediction, astronomer John Adams[25] calculated the orbit of this unseen planet, Neptune. As Somerville's recalls in her autobiography, Adams acknowledged reading her prediction and it was this that led him to "*calculate the orbit of Neptune.*"[26] Somerville's confidence later extended to a second prediction. In subsequent editions of her *Connexion*[27] text she writes: "*The prediction may now be transferred from Uranus to Neptune, whose perturbations may reveal the existence of a planet still further removed, which may for ever remain beyond the reach of telescopic vision-yet its mass, the form and position of its orbit, and all the circumstances of its motion may become known, and the limits of the solar system may still be extended hundreds of millions of miles.*" The ninth planet, Pluto, remained undiscovered until 1930.[28]

After publication of the *Mechanism of the Heavens* Mary Somerville began to move in the highest scientific circles both in the United Kingdom and on the continent. Aside from the names mentioned above, a short list of distinguished contemporaries Somerville counted as peers, colleagues or acquaintances must also include:[29] Andre Ampère (1775-1836), Dominique Arago (1786-1853), Antoine Becquerel (1788-1878), Jean Biot (1774-1862), Sir David Brewster (1781-1868), Georges Cuvier (1769-1832), Charles Darwin (1809-1882), Michael Faraday (1791-1867), Joseph Gay-Lussac (1778-

1850), Sir William Hamilton (1805-1865), Joseph Henry (1797-1897), Caroline Herschel (1750-1848), Washington Irving (1783-1859), Lady Ada Byron Lovelace (1815-1852), Sir Charles Lyell (1797-1875), Harriet Martineau (1802-1876), James Clerk Maxwell (1831-1879), William Milne Edwards (c. 1776-1842), John Stuart Mill (1806-1873), Florence Nightingale (1820-1910), and Sir Charles Wheatstone (1802-1875).

How did a woman of modest means and with no formal training in mathematics achieve such recognition? The universities were closed to women–a brutal reality that Somerville always resented: "*From my earliest years my mind revolted against oppression and tyranny and resented the injustice of the world in denying those privileges of education which were denied to my sex which were so lavishly bestowed on men*."[30] For a time as a young lady Somerville pursued an interest in art under the direction of landscapist Alexander Nasmyth (1758-1840). A casual remark by Nasmyth set Somerville on the course of her life's work: "*…you should study Euclid's Elements of geometry, the foundations not only of perspective, but of astronomy and all mechanical science.*"[31] Somerville followed that advice and began to study on her own. While the pressures to conform to the social strictures of her day discouraged such interest–her father forbade her reading mathematics–Somerville persevered. After the death of her first husband in 1807, a chance meeting with Professor John Playfair (1748-1819),[32] a leading figure in Edinburgh mathematics, culminated in her introduction to, and a longstanding mentor relationship with, Edinburgh mathematician William Wallace.[33] Her exchanges with Wallace included studies of French mathematics and in particular Laplace's *Mécanique céleste*. It was during this period that Somerville, now in her late 20's, became part of the reform-minded Edinburgh intellectual scene[34] where she met some of the men associated with the liberal journal the *Edinburgh Review*. Somerville first encountered Henry Brougham[35] during this period. In 1827 Brougham approached her with a request to prepare an "account" of the *Mécanique céleste* for his newly established Society for the Diffusion of Useful Knowledge. The Society proposed to "*bring sound literature and self improvement within the reach of all by publishing cheap and worthy treatises*."[36] Although Somerville, now 47, had studied Laplace's work for 20 years, she accepted Brougham's request with reluctance. It took three years to complete her rendition. Unfortunately, the length of the final manuscript made it unsuitable for Brougham's popular series. After consultation with her longtime friend Sir John Herschel, she decided to publish the work independently.[37] The critical success of the first edition of *Mechanism of the Heavens*,[38] as documented in the *Reviews* section at the end of this volume, established Somerville's reputation as a brilliant scientific author. Her next book, *On the Connexion of the Physical Sciences*,[39] published in 1834, ran into ten editions, and sold over 15,000 copies. It was also translated into French, German and Italian, and a pirated copy was published in the United States.[40] Her other major work, *Physical Geography*,[41] first published in 1848, sold 16,000 copies in seven editions. Somerville began her last scientific work, *On Molecular and Microscopic Science*,[42] when she was 89, and completed the book shortly before her death at the age of 92.

This second edition of the *Mechanism of the Heavens* is designed to address not only its scarcity, but several deficiencies reflected in the first edition. More than 140 published errata were reported in the first edition. These are corrected in the second edition. In our review of the first edition at least twice as many unidentified printing errors were uncovered along with several page repeats, mislabeled chapters, and other errata. These have all been addressed and reflected in notes at the end of each chapter. But perhaps the most serious deficiency in the original work is one identified by J. Herschel in his critique at the end of this volume. Although lavish in his praise for Somerville's work, Herschel makes the following comment: "…*the most considerable fault we have to find with the work before us consists in an habitual laxity of language, evidently originating in so complete a familiarity with the* <u>*quantities*</u> *concerned, as to induce a disregard of the* <u>*words*</u> *by which they are designated, but which, to any one less intimately conversant with the actual analytical operations than its author, must have infallibly become a source of serious errors, and which at all events, renders it necessary for the reader to be constantly on his guard*."

This "*laxity of language*" criticism addresses a style reflected in the technical body of the work, but one not found in the *Preliminary Dissertation*. The *Dissertation* not only addresses a broader more general audience, it also reflects Somerville's lifelong curiosity and love of science and the "*mutual dependence and connection in many branches of science*."[43] Somerville carries this style and feeling for mutual dependence in her *Connexion of the Physical Sciences*. That work not only reflects its title in content, it *defines* the boundaries amongst the branches of the physical sciences (physical and descriptive astronomy, matter, sound, light, heat, and electricity and magnetism) at a time when such definitions were only beginning to emerge. The writing is clear, careful, and directed to the student of science.

James Clerk Maxwell,[44] the most influential scientist of the 19th century, cites Somerville's *Connexion* as one of those "…*suggestive books, which put into definite, intelligible and communicable form, the guiding ideas that are already working in the minds of men of science, so as to lead them to discoveries, but which they cannot yet shape into a definite statement*."[45] Over 100 pages of the *Connexion* covers material in celestial mechanics addressed in the *Mechanism* but in language more suited to the student. For that reason those topics in astronomy in her second book could serve, and do serve in this second edition, as introductory summaries for ideas and topics covered in the four books of the *Mechanism of the Heavens*.

Somerville says in her *Introduction* (p. 41), "…*the object of this work is rather to give the spirit of Laplace's method*…" I believe that the inclusion of Somerville's carefully crafted summaries, incorporated in this edition as forewords to each of her four books, not only conforms with Somerville's original objective, but also unifies the work stylistically, by carrying forward the enthusiasm embodied in the *Preliminary Dissertation* to the remainder of her work. The inclusion of this new material also addresses Herschel's concern about a "*laxity of language*." It should now be possible to capture "*the spirit of Laplace*" from Somerville's work by reading the *Preliminary Dissertation* together with the forewords to each of the four books, without recourse to the branches of higher mathematics.

The four books of the *Mechanism of the Heavens* address the topics of Dynamics, Universal Gravitation, Lunar Theory, and the Satellites. Except for the inclusion of the four forewords keyed to each of these books from materials drawn from the relevant sections of Somerville's *Connexion of the Physical Sciences* (10th edition, 1877), the addition of annotations (as notes placed at the end of each chapter so as not to disturb the integrity of the original work), short biographies of important figures referred to by Somerville in the text, the highlighting of articles and equation numbering, minor changes in the spacing of text and equations, spelling and punctuation, changes in pagination (which begins with the *Preliminary Dissertation* as part of the main text–the first edition uses roman numerals), and the correction of errata (as noted above), the structure of this second edition is identical to that of the first edition with respect to article and equation numbering, chapter and subsection headings, and the use of 116 figures (which have all been redrawn). Chapters II, III, and IV of Book IV were erroneously numbered VII, VIII and IX in the first edition. These have been renumbered to reflect the author's original intent. This volume also contains a Glossary of Symbols, a Basic Bibliography of key references, a Table of Contents, and a Name Index–none of which was incorporated in the first edition. The entries in the Subject Index (labeled "Index" in the first edition) are the same entries used by Somerville in the first edition, but refer to article numbers rather than page numbers. Finally, the name of the author, identified as "Mrs. Somerville" on the title page of the first edition, now reads "Mary Fairfax Greig Somerville."

Notes

[1] Somerville, Greig Fairfax Mary, (1780-1872), mathematician, born in Jedburgh and raised in Burntisland, Scotland. Mary was the daughter of Margaret Charters and vice-Admiral Sir William George Fairfax. Somerville married naval officer Samuel Greig in 1804. In Mary's words her first husband, "had a very low opinion of the capacity of my sex, and had neither knowledge of, nor interest in, science of any kind" (Martha Somerville, *Personal Recollections from Early Life to Old Age of Mary Somerville*, London, 1873). She married William Somerville in 1812 after the death of her first husband in 1807. William, an inspector of hospitals, was supportive of Mary's interest in science and played a leading role as her assistant. William and Mary lived in Edinburgh where she studied mathematics, botany, geology, French and Greek. Mary's circle of friends in Edinburgh included William Wallace (1768-1843), John Playfair (1748-1819), John Leslie (1766-1832), and Sir David Brewster (1781-1868). During this period Mary read Newton's *Principia* and Laplace's *Mécanique céleste*. After moving to London in 1816 Mary became acquainted with a range of leading figures in science including William Herschel (1738-1822), John Herschel (1792-1871), George Biddell Airy (1801-1892), George Peacock (1791-1858), and Charles Babbage (1791-1871). Through these acquaintances and in visits to Paris she met Jean-Baptiste Biot (1774-1862), Dominique Arago (1786-1853), Pierre-Simon Laplace (1749-1827), Siméon Poisson (1781-1840), Louis Poinsot (1777-1859) and Emile Mathieu (1835-1890). The many honours Somerville received included memberships in the Royal Astronomical Society, the Royal Irish Academy and the American and Italian Geographical Societies. She was also elected honorary Member of the Société de Physique et d'Histoire Naturelle de Genève. For her achievements she was awarded an annual pension of 200 pounds in 1834 (increased later to 300 pounds). In 1838 Mary and William moved to Italy, where she remained for the rest of her life. During her lifetime Mary wrote four significant scientific texts (*see notes 38-42 below*) and influenced many of the leading scientists of her day, including James Clerk Maxwell (1831-1879). In her writings Somerville predicted the existence of an unseen planet beyond the orbit of Uranus. John Adams (1819-1892) later calculated the exact position of the planet (Neptune) on the basis of Somerville's prediction (*See note 39, Bk. II, Foreword*). Somerville later predicted a ninth planet (Pluto), which remained undiscovered until 1930 (*see note 28 below*). Mary died in Naples in her ninety-second year on 29 November 1872. She is buried in the English Cemetery at Naples beneath a monument erected by her daughter Martha. Although informal consent from the Dean of Westminster Abbey was obtained for Mary's burial there, the formal request was denied by the then Astronomer Royal, who was not familiar with her works. Somerville Hall (now Somerville College) at Oxford University and the Mary Somerville scholarship in mathematics were established in 1879. (*Based on materials drawn from the School of Mathematics, University of St. Andrews, Scotland, and the references in notes 2, 29 and 34 below.*)

[2] Dep c.355, 22, MSAU-2: p.57, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[3] A fully annotated five volume English *translation* of Laplace's work was undertaken between 1829-1839. (Bowditch, Nathaniel, (1773-1838), *Mécanique céleste. By the marquis de La Place ... Tr., with a commentary, by Nathaniel Bowditch*, Boston, Hillard, Gray, Little, and Wilkins, 1829-39.)

[4] Laplace, Pierre Simon, Marquis de, 1749-1827, mathematician and astronomer, born in Beaumont-en-Auge, France. Laplace was professor of mathematics at the Ecole Militaire, Paris. His five-volume *Mécanique céleste* (1799-1825) was considered the most important contribution to applied mathematics since Newton's *Principia*. In 1773 Laplace announced that the mean motions of the planetary motions were invariable in spite of perturbations. In 1786 he demonstrated the self-correcting nature of certain periodic planetary perturbations. In 1787 he removed what was the last theoretical threat to the stability of the earth-moon system by showing how the moon's acceleration depends upon eccentricity of the earth's orbit. The stability of the system impressed Laplace immensely and led to his famous and highly influential expression of a "world formula" stated in his *Essai philosophique sur les probabilités* (1814): "*A mind that in a given instance knew all the forces by which nature is animated and the position of all the bodies of which it is composed, if it were vast enough to include all these data within his analysis, could embrace in one single formula the movements of the largest bodies of the universe and the smallest atoms; nothing would be uncertain for him; the future and the past would be equally before his eyes.*" (Hayek, F.A. *The Counter Revolution of Science*, Liberty Fund, 2nd ed. p. 201, 1979.)

[5] Leibniz, Gottfried, Wilhelm, (1646-1716), philosopher and mathematician, born in Leipzig, Germany. Isaac Newton and Leibniz were involved in a bitter controversy over who first developed integral and differential calculus. Leibniz employed the now familiar notation used in calculus in a manuscript written in 1675. The first printed use of the "d" notation and the rules for differentiation appeared in the journal *Acta Eruditorum* in 1686. The first use in print of the $\int$ notation appeared in the same journal the following year. Newton's rival but equivalent method of "fluxions" was written much earlier, in 1671. However Newton's work did not appear in print until 1736. Leibniz is also considered the founder of dynamics, an approach in which kinetic energy is substituted for the conservation of movement or momentum. Leibniz also disputed Newton's idea of absolute space, advocating instead a complete relativism.

[6] Euler, Leonhard, 1707-1783, mathematician, born in Basel, Switzerland. Euler studied mathematics under Jean Bernoulli. Later he taught physics (1731) and mathematics (1733) at the St Petersburg Academy of Sciences. Euler published over 800 different books and papers on mathematics, physics and astronomy including his *Institutiones calculi differentialis* (1755) and *Institutiones calculi integralis* (1768-70). Euler made several important advances in integral calculus and in the theory of trigonometric and logarithmic functions. Euler also introduced much of the notation used in mathematics today, including the symbols Σ (sum), p, i for $\sqrt{-1}$ and e for the base of natural logarithms. Euler wrote works on the calculus of variations, the moon's motion and planetary orbits.

[7] See note 26, *Bk. I, Chap. II.*

[8] See note 16, *Preliminary Dissertation.*

[9] See note 60, *Bk. II. Chap. XIV.*

[10] See note 4.

[11] See note 64, *Preliminary Dissertation.*

[12] See the *Reviews* section at the end of this volume.

[13] Dep c.355, 22, MSAU-2: p. 57, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[14] Peacock, George, (1791-1858), mathematician, born in Denton, England. In 1815, as an undergraduate at Cambridge, Peacock with John Herschel, and Charles Babbage established the Analytical Society with the goal of bringing advanced continental methods of analysis to Cambridge. The following year the Society produced a translation of a book on calculus by Lacroix. In 1817 Peacock became an examiner at Cambridge and Lowndean professor of astronomy and geometry (1836).

[15] Whewell, William, (1794-1866), scholar, born in Lancashire, England. Whewell held posts at Cambridge in mineralogy and moral theology. His works include his *History of the Inductive Sciences* (1837).

[16] Babbage, Charles, (1791-1871), mathematician, born in London, England. Babbage became Lucasian Professor of Mathematics at Cambridge in 1827, a post held originally by Newton and today (2000) by Stephen W. Hawking (1942-). Babbage is most remembered for his pioneering work on mechanical

computers. He constructed a "difference engine" in 1822, and in 1834 he completed the drawing for a more powerful "analytical engine," considered the prototype of the modern digital computer. The design included a capacity for memory storage and was intended to operate on modern programming principles by receiving instructions from punched cards. Although no operational version of this machine was ever constructed in his lifetime, the principles of its design were proven correct.

[17] Dep c.355, 22, MSAU-2: p. 165, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[18] Somerville, Mary, *Preliminary Dissertation to 'The Mechanism of the Heavens'*, Clowes, London, 1831.

[19] Somerville, Mary, *A Preliminary Dissertation on the Mechanism of the Heavens*, Philadelphia, 1832.

[20] Dep b.207-8, *On the Figure of the Celestial Bodies*, Mary Somerville Collection, Bodleian Library, Oxford University.

[21] Dep c.355, 22, MSAU-2: p. 193, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[22] See note 1, *Bk. I, Chap VI.*

[23] Dep c.355, 5, MSAU-3: p. 34, *Mary Somerville Autobiography (final draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[24] See note 44, *Bk. I, Foreword.*

[25] See note 39, *Bk. II, Foreword.*

[26] Dep c.355, 22, MSAU-2: p. 222, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[27] See note 39.

[28] As Somerville predicted, the planet Pluto was discovered, based on errors in the motions of Uranus and Neptune, in 1930 by Clyde W. Tombaugh (1906-) at Lowell Observatory in Arizona.

[29] Patterson, Elizabeth Chambers, *Mary Somerville and the Cultivation of Science*, International Archives of the History of Science, Martinus Nijhoff Pub., 1983. See also *Name Index* (p. 783) for short biographies.

[30] Dep c.355, 22, MSAU-2: p. 31, *Mary Somerville Autobiography (first draft)*, Mary Somerville Collection, Bodleian Library, Oxford University.

[31] *Op cit.*, p. 34.

[32] See note 17, *Preliminary Dissertation.*

[33] Wallace, William (1768-1843), mathematician, born in Dysart, Scotland. Wallace, like Somerville, was self taught. He was appointed professor of mathematics at Edinburgh University in 1819. He wrote two books including his *Geometrical Theorems and Analytical Formulae*. He also wrote articles on astronomy. Wallace and Somerville maintained a mathematical correspondence by mail.

[34] McKinley, Jane, *Mary Somerville 1780-1872*, Scotland Cultural Heritage, University of Edinburgh, 1987.

[35] Brougham, Henry Peter, Baron Brougham and Vaux, (1778-1868), jurist and politician, born in Edinburgh, Scotland. Brougham helped found the *Edinburgh Review.* As a peer he introduced several important reform measures. Brougham also established the *Society for the Diffusion of Useful Knowledge*.

[36] Patterson, Elizabeth Chambers, *Mary Somerville and the Cultivation of Science*, International Archives of the History of Science, Martinus Nijhoff Pub., p. 50, 1983.

[37] McKinley, Jane, *Mary Somerville 1780-1872*, Scotland Cultural Heritage, University of Edinburgh, p. 15, 1987.

[38] Somerville, Mrs., *Mechanism of the Heavens*, John Murray, London, 1831.

[39] Somerville, Mary, *On the Connexion of the Physical Sciences*, John Murray, London, 1834, 1835, 1836, 1837, 1840, 1842, 1846, 1849, 1858, 1977.

[40] Somerville, Mary, *On the Connexion of the Physical Sciences*, Philadelphia, 1834.

[41] Somerville, Mary, *Physical Geography*, John Murray, London, 1848, 1849, 1851, 1858, 1862, 1870, 1877.

[42] Somerville, Mary, *On Molecular and Microscopic Science*, John Murray, London, 1873, 1874.

[43] McKinley, Jane, *Mary Somerville 1780-1872*, Scotland Cultural Heritage, University of Edinburgh, p. 15, 1987.

[44] See note 5, *Bk. IV, Foreword.*

[45] Maxwell, James Clerk, 'Grove's Correlation of Physical Forces', *The Scientific Papers of J. Clerk Maxwell*, ii 401, Cambridge, 1890 .