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(*b*. Madura, Madras presidency, India, June 1806; *d*. London, England, 18 March 1871),

mathematics.

De Morgan's father was a colonel in the Indian Army; and his mother was the daughter of John Dodson, a pupil and friend of Abraham de Moivre, and granddaughter of James Dodson, author of the *Mathematical Canon*. At the age of seven months De Morgan was brought to England, where his family settled first at Worcester and then at Taunton. He attended a succession of private schools at which he acquired a mastery of Latin, Greek, and Hebrew and a strong interest in mathematics before the age of fourteen. He also acquired an intense dislike for cramming, examinations, and orthodox theology.

De Morgan entered Trinity College, Cambridge, in February 1823 and placed first in the first-class division in his second year; he was disappointed, however, to graduate only as fourth wrangler in 1827. After contemplating a career in either medicine or law, De Morgan successfully applied for the chair of mathematics at the newly formed University College, London, in 1828 on the strong recommendation of his former tutors, who included Airy and Peacock. When, in 1831, the college council dismissed the professor of anatomy without giving reasons, he immediately resigned on principle. He resumed in 1836, on the accidental death of his successor, and remained there until a second resignation in 1866.

De Morgan's life was characterized by powerful religious convictions. While admitting a personal faith in Jesus Christ, he abhorred any suspicion of hypocrisy or sectarianism and on these grounds refused an M.A., a fellowship at Cambridge, and ordination. In 1837 he married Sophia Elizabeth Frend, who wrote his biography in 1882. De Morgan was never wealthy; and his researches into all branches of knowledge, together with his prolific output of writing, left little time for social or family life. However, he was well known for his humor, range of knowledge, and sweetness of disposition.

In May 1828 De Morgan became a fellow of the Astronomical Society; he was elected to the council in 1830, serving as secretary (1831–1838; 1848–1854). He helped to found the London Mathematical Society, becoming its first president and giving the inaugural lecture in 1865. He was also an influential member of the Society for the Diffusion of Useful Knowledge from 1826. De Morgan was a prolific writer, contributing no fewer than 850 articles (onesixth of the total production) to the *Penny Cyclopaedia* and writing regularly for at least fifteen periodicals.

De Morgan exerted a considerable influence on the development of mathematics in the nineteenth century. As a teacher he sought to demonstrate principles rather than techniques; and his pupils, who included Todhunter, Routh, and Sylvester, acquired from him a great love of the subject. He wrote textbooks on the elements of arithmetic, algebra, trigonometry, calculus, complex numbers, probability, and logic. These books are characterized by meticulous attention to detail, enunciation of fundamental principles, and clear logical presentation.

De Morgan's original contributions to mathematics were mainly in the fields of analysis and logic. In an article written in 1838, he defined and invented the term "mathematical induction" to describe a process that previously had been used — without much clarity—by mathematicians.

In *The Differential and Integral Calculus* (1842) there is a good discussion of fundamental principles with a definition of the limit which is probably the first precise analytical formulation of Cauchy's somewhat intuitive concept. The same work contains a discussion of infinite series with an original rule to determine convergence precisely when simpler tests fail. De Morgan's rule, which is proved rigorously, is that if the series is given by

then if

the series converges for $e>1$ but diverges for $e\leq 1$.

Among his other mathematical work is a system that De Morgan described as "double algebra." This helped to give a complete geometrical interpretation of the properties of complex numbers and, as Sir William Rowan Hamilton acknowledged, suggested the idea of quaternions.

De Morgan's greatest contribution to scientific knowledge undoubtedly lay in his logical researches; and the subsequent development of symbolic logic, with its powerful influences on both philosophy and technology, owes much to his

fundamental work. He believed that the traditional method of argument using the Aristotelian syllogism was inadequate in reasoning that involved quantity. As an example De Morgan presented the following argument:

In a particular company of men

most men have coats most
men have waistcoats

∴ some men have both coats and waistcoats.

He asserted that it was not possible to demonstrate this true argument by means of any of the normally accepted Aristotelian syllogisms.

The first attempt to extend classical logic by means of quantifying the predicate and reformulating logical statements in mathematical terms was made by George Bentham in 1827. He rephrased the statement "Every *X* is a *Y*" in to the eqation "*X in to toto = Y ex parte*" with the algebraic notation "$tX = pY$." It was more usual at this time, however, for logicians to make more classical attempts to broaden the Aristotelian syllogistic; and De Morgan's work, which commenced in the 1840's, can be seen as the bridge between this older approach and Boole's analytical formulation. Boole acknowledged his debt to De Morgan and Hamilton in the preface to his first logical work, *The Mathematical Analysis of Logic* (1847).

The Scottish philosopher Sir William Hamilton (not to be confused with Sir William Rowan Hamilton) worked out a system for quantifying the predicate a short time before De Morgan did and unjustly accused him of plagiarism. He had no shred of evidence to support his charge, and De Morgan's work was superior to his in both analytical formulation and subsequent development.

De Morgan invented notations, which he sometimes varied, to describe simple propositions. Objects with certain properties were denoted by capital letters *X, Y, Z*,... and those without this property by the corresponding small letters *x, y, z*,..., One of his notations was

A Every *X* is a *Y* as *X)Y*

E No *X* is a *Y* as X.Y

I Some *X*'s are *Y*'s as *XY*

O Some *X*'s are not *Ys* as *X:Y*

the symbols *A, E, I, O*, having their usual Aristotelian meaning. He then worked out rules to establish valid syllogistic inferences. Such results were then written in the form

$X)Y + Y)Z = X)Z$

$Y:X + Y)Z = Z:X$

$X)Y + Z)Y = xz$

and so on. This notation was superseded by Boole's more algebraic one, but it helped De Morgan to establish valid inferences not always obtainable through the traditional rules. Using the notation of Boolean algebra, the two equations $(A \cap B)' = A' \cup B'$ and $(A \cup B)' = A' \cap B'$ are still referred to as the De Morgan formulas.

De Morgan was also the first logician to present a logic of relations. In a paper written in 1860 he used the notation *X..LY* to represent the statement that *X* is one of the objects in the relation *L* to *Y*, while *X.L Y* meant that *X* was not any of the *L*'s of *Y*. He also presented the idea *X..(LM)Y* as the composition of two relations *L,M*, and of the inverse relation L^{-1}. This extension of the idea of subject and predicate was not adopted by any of De Morgan's successors, and the idea lapsed until Benjamin Peirce's work of 1883.

De Morgan was steeped in the history of mathematics. He wrote biographies of Newton and Halley and published an index of the correspondence of scientific men of the seventeenth century. He believed that the work of both minor and major mathematicians was essential for an assessment of mathematical development, a principle shown most clearly in his *Arithmetical Books* (1847). This work describes the many arithmetical books in the author's possession, refers to the work of 1,580 arithmeticians, and contains detailed digressions on such subjects as the length of a foot and the authorship of the popular *Cocker's Arithmetick*. De Morgan's book was written at a time when accurate bibliography was in its infancy and was probably the first significant work of scientific bibliography. Despite a lack of means, he collected a library of over 3,000 scientific books, which is now at the London University library.

De Morgan's peripheral mathematical interests included a powerful advocacy of decimal coinage; an almanac giving the dates of the new moon from 2000 b.c. to a.d. 2000; a curious work entitled *Budget of Paradoxes*, which considers, among other things, the work of would-be circle squarers; and a standard work on the theory of probability applied to life contingencies that is highly regarded in insurance literature.

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John M. Dubbey