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(*b*. Cambridge, Massachusetts, 10 September 1839; *d*. Milford, Pennsylvania, 19 April 1914)

logic, geodesy, mathematics, philosophy, history of science.

Peirce frequently asserted that he was reared in a laboratory. His father, Benjamin Peirce, was professor of mathematics and natural philosophy at Harvard University at the time of Charles's birth; he personally supervised his son's early education and inculcated in him an analytic and scientific mode of thought. Peirce attended private schools in Cambridge and Boston; he was then sent to the Cambridge High School, and, for a term, to E. S. Dixwell's School, to prepare for Harvard. While at college (1855–1859), Peirce studied Schiller's *Aesthetische Briefe and Kant's Kritik der reinen Vernunft*, both of which left an indelible mark on his thought. He took the M.A. at Harvard (1862) and the Sc.B. in chemistry, *summa cum laude*, in the first class to graduate from the Lawrence Scientific School (1863). Despite his father's persistent efforts to encourage him to make a career of science, Peirce preferred the study of methodology and logic.

Upon graduation from Harvard, Peirce felt that he needed more experience in methods of scientific investigation, and he became a temporary aide in the U.S. Coast Survey (1859). For six months during the early 1860's he also studied, under Louis Agassiz, the techniques of classification, a discipline that served him well in his logic research. Like Comte, Peirce later set up a hierarchy of the sciences in which the methods of one science might be adapted to the investigation of those under it on the ladder. Mathematics occupied the top rung, since its independence of the actualities in nature and its concern with the framing of hypotheses and the study of their consequences made its methodology a model for handling the problems of the real world and also supplied model transforms into which such problems might be cast and by means of which they might be resolved.

Peirce was appointed a regular aide in the U.S. Coast Survey on 1 July 1861 and was thereby exempted from military service. On 1 July 1867 he was appointed assistant in the Survey, a title he carried until his resignation on 31 December 1891. In the early days his assignments were diverse. He observed in the field the solar eclipse of 1869 in the United States and selected the site in Sicily from which an American expedition₵headed by his father and including both himself and his wife₵observed the solar eclipse of 22 December 1870. He was temporarily in charge of the Coast Survey Office in 1872, and on 30 November of that year his father appointed him to "take charge of the Pendulum Experiments of the Coast Survey." Moreover he was to "investigate the law of deviations of the plumb line and of the azimuth from the spheroidal theory of the earth's figure." He was further directed to continue under Winlock the astronomical work that he had begun in 1869, while an assistant at the Harvard College Observatory; his observations, completed in 1875, were published in 1878 in the still important *Photometric Researches*. He was an assistant computer for the nautical almanac in 1873, and a special assistant in gravity research from 1884 to 1891. During the 1880's however, Peirce found it increasingly difficult, under the changing administration of the Survey, to conform to the instructions issued him; in 1891 he tendered a forced resignation and left government service. (In 1962 a Coast and Geodetic Survey vessel was named for him, in somewhat belated recognition of his many contributions).

Peirce's astronomical work, which he began in 1867, was characterized as "pioneer" by Solon I. Bailey, director of the Harvard Observatory in 1920. Peirce attempted to reform existing scales of magnitudes with the aid of instrumental photometry, and he investigated the form of the galactic cluster in which the sun is situated, the determination of which was "the chief end of the observations of the magnitude of the stars."

From April 1875 to August 1876 Peirce was in Europe to learn the use of the new convertible pendulum, "to compare it with those of the European measure of a degree and the swiss Survey," and to compare his "invariable pendulums in the manner which has been usual by swinging them in London and Paris." In England he met Lockyer, Clifford, Stokes, and Airy; and in Berlin, Johann Jacob Baeyer, the director of the Prussian Geodetic Institute, where Peirce compared the two standards of the German instrument and the American one. He was invited to attend the meetings of the European Geodetic Association held in Paris during the summer of 1875, and there made a name as a research geodesist. His discovery of an error in European measurement, which was due to the flexure of the pendulum stand, led to the important twenty-three-page report that Plantamour read for him at Geneva on 27 October 1877. The first Peirce pendulum was invented in June 1878 and superseded the Repsold model used in the Coast and Geodetic Survey. Although the United States did not become a member of the International Geodetic Association until 1889, Peirce's geodetic work was widely recognized. His paper on the value of gravity, read to the French Academy on 14 June 1880, was enthusiastically received, and he was invited to attend a conference on the pendulum of the Bureau des Longitudes.

In 1879 Peirce succeeded in determining the length of the meter from a wavelength of light. Benjamin Peirce described this feat, an adumbration of the work of Michelson, as "the only sure determination of the meter, by which it could be recovered if it were to be lost to science." By 1882 Peirce was engaged in a mathematical study of the relation between the variation of gravity and the figure of the earth. He claimed that "divergencies from a spherical form can at once be detected in the earth's figure by this means," and that "this result puts a new face on the relation of pendulum work to geodesy."

Peirce's mathematical inventiveness was fostered by his researches for the Coast Survey. His theory of conformal map projections grew out of his studies of gravity and resulted in his quincuncial map projection of 1876, which has been revived by the Coast Survey in chart no. 3092 to depict international air routes. This invention represented the first application of elliptic functions and Jacobian elliptic integrals to conformal mapping for geographical purposes. Peirce was further concerned with topological mapping and with the "Geographical Problem of the Four Colors" set forth by A. B. Kempe. The existential graphs that he invented as a means of diagrammatic logical analysis (and which he considered his *chef d'oeuvre*) grew out of his experiments with topological graphic elements. These reflect the influence on his thought of Tait's historic work on knots and the linkage problems of Kempe, as well as his own belief in the efficacy of diagrammatic thinking.

Peirce's interest in the linkage problem is first documented in the report of a meeting of the Scientific Association at the John Hopkins University, where Peirce was, form 1879 to 1884, a lecturer in logic and was closely associated with members of the mathematics department directed by J. J. Sylvester. (It was Sylvester who arranged for the posthumous republication, with addenda and notes by Charles Peirce, of Benjamin Peirce's *Linear Associative Algebra.)* Peirce had persuaded his father to write that work, and his father's mathematics influenced his own. J. B. Shaw has pointed out that two other lines of linear associative had been followed besides the direct one of Benjamin Peirce, one by use of the continuous group first announced by Poincare and the other by use of the matrix theory first noted by Charles Peirce. Peirce was the first noted by Charles Peirce. Peirce was the first to recognize the quadrate linear associative algebras identical with matrices in which the units are letter pairs. He did not, however, regard this combination as a product, as did J. W. Gibbs in his "Elements of Vector Analysis" of 1884. Gibbs's double-dot product, according to Percey F. Smith, "is exactly that of C. S. Peirce's vids, and accordingly the algebra of dyadics based upon the double-dot law of multiplication is precisely the matricular algebra" of Peirce. In his *History of Mathematics*, Florian Cajori wrote that "C. S. Peirce showed that of all linear associative algebras there are only three in which division is unambiguous. These are ordinary single algebra, ordinary double algebra, and quaternions, from which the imaginary scalar is excluded. He showed that his father's algebras are operational and matricular." Peirce's work on nonions was to lead to a priority dispute with Sylvester.

By the time Peirce left the Johns Hopkins University, he had taken up the problem of continuity, a pressing one since his logical analysis and philosophical interpretation required that he deal with the infinite. In his 1881 paper "Logic of Number," Peirce claimed to have "distinguished between finite and infinite collections in substantially the same way that Dedekind did six years later." He admired the logical ingenuity of Fermat's method of "infinite descent" and used it consistently, in combination with an application of De Morgan's syllogism of transposed quantity that does not apply to the multitude of positive integers. Peirce deduced the validity of the "Fermatian method" of reasoning about integers from the idea of correspondence; he also respected Bolzano's work on this subject. He was strongly impressed by Georg Cantor's contributions, especially by Cantor's handling of the infinite in the second volume of the *Acta Mathematica*. Peirce explained that Cantor's "class of *Mächtigkeit* afeph-null is distinguished from other infinite classes in that the *Fermation inference* is applicable to the former and not to the latter; and that generally, to *any smaller class some mode of reasoning is applicable which is not applicable to a greater one*." In his development of the concept of the orders of infinity and their aleph representations, Peirce used a binary representation (which he called "secundal "secundal notation") of numbers. He eventually developed a complete algorithm for handling fundamental operations on numbers so expressed. His ingenuity as an innovator of symbolic notation is apparent throughout this work.

Peirce's analysis of Cantor's *Menge* and *Mächtigkeit* led him to the concept of a supermultitudinous collection beyond all the alephs—a collection in which the elements are no longer discrete but have become "welded" together to represent a true continuum. In his theory of logical criticism, "the temporal succession of ideas is continuous and not by discrete steps," and the flow of time is similarly continuous in the same sense as the nondiscrete superpostnumeral multitudes. Things that exist form an enumerable collection, while those *in futuro* form a denumerable collection (of multitude aleph-null). The possible different courses of the future have a first abnumeral multitude (two raised to the exponent aleph-null) and the possibilities of such possibilities will be of the second abnumeral multitude (two raised to the exponent "two raised to the exponent aleph-null"). This procedure may be continued to the infinitieth exponential, which is thoroughly potential and retains no relic of the arbitrary existential—the state of true continuity. Peirce's research on continuity led him to make an exhaustive study of topology, especially as it had been developed by Listing.

Peirce's philosophy of mathematics postulated that the study of the substance of hypotheses only reveals other consequences not explicitly stated in the original. Mathematical procedure therefore resolves itself into four parts: (1) the creation of a model that embodies the condition of the premise; (2) the mental modification of the diagram to obtain auxiliary information; (3) mental experimentation on the diagram to bring out a new relation between parts not mentioned in its construction; and (4) repetition of the experiment "to infer inductively, with a degree of probability practically amounting to certainty, that every diagram constructed according to the same precept would present the same relation of parts which has been observed in the diagram experimented upon." The concern of the mathematician is to reach the conclusion, and his interest in the process is merely as a means to reach similar conclusions, whereas the logician desires merely to understand the process by which a result may be obtained. Peirce asserted that mathematics is a study of what is or is not logically possible and that the mathematician need not be concerned with what actually exists. Philosophy, on the other hand, discovers what it can from ordinary everyday experience.

Peirce characterized his work in the following words: "My philosophy may be described as the attempt of a physicist to make such conjecture as to the constitution of the universe as the methods of science may permit. . . The best that can be done is to supply a hypothesis, not devoid of all likelihood, in the general line of growth of scientific ideas, and capable of being verified or refuted by future observers." Having postulated that every additional imporvement of knowledge comes from an exercise of the power of perception, Peirce held that the observation in a necessary inference is directed to a sort of diagram or image of the facts given in the premises. As in mathematics, it is possible to observe relations between parts of the diagram that were not norticed in its construction. Part of the business of logic is to construct such diagrams. In short, logical truth has the same source as mathematical truth, which is derived from the observation of diagrams. Mathematics uses the language of imagery to trace out results and the language of abstraction to make generalizations. It was Peirce's claim to have opened up the subject of abstraction, where Boole and De Morgan had concentrated on studies of deductive logic.

In 1870 Peirce greatly enlarged Boolean algebra by the introduction of a new kind of abstraction, the dyadic relation called "inclusion"—"the connecting link between the general idea of logical dependence and the idea of sequence of a quantity." The idea of quantity is important in that it is a linear arrangement whereby other linear arrangements (for example, cause and effect and reason and consequent) may be compared. The logic of relatives developed by Peirce treats of "systems" in which objects are brought together by any kind of relations, while ordinary logic deals with "classes" of objects brought together by the relation of similarity. General classes are composed of possibilities that the nominalist calls an abstraction. The influence of Peirce's work in dyadic relations may be seen in Schroder's *Vorlesungen über die Algebra der Logik*, and E. V. Huntington included Peirce's proof of a fundamental theorem in his "Sets of Independent Postulates for the Algebra of Logic" and in *The Continuum* refered to a statement that Peirce had published in the *Monist*. Peirce's contribution to the foundations of lattice theory is widely recognized.

In describing multitudes of systems within successive systems, Peirce reached a multitude so vast that the individuals lose their identity. The zero collection represents germinal possibility; the continuum is concrete-developed possibility; and "The whole universe of true and real possibilities forms a continuum upon which this universe of Actual Existence is a discontiuous mark like a point marked on a line."

The question of nominalism and realism became for Peirce the question of the reality of continua. Nature syllogizes, making inductions and abductions—as, for example, in evolution, which becomes "one vast succession of generalizations by which matter is becoming subjected to ever higher and higher laws." Laws of nature in the present form are products of an evolutionary process and logically require an explanation in such terms. In the light of the logic of relatives, Peirce maintained, the general is seen to be the continuous and coincides with that opinion the medieval Schoolmen called realism. Peirce's Scotistic stance—in opposition to Berkeley's nominalism—caused him to attack the nominalistic positions of Mach, Pearson, and Poincaré. Peirce accused the positivists of confusing psychology with logic in mistaking sense impressions, which are psychological inferences, for logical data. Joseph Jastrow tells of being introduced by Peirce "to the possiblity of an experimental study of a psychological problem," and they published a joint paper, "On Small Differences in Sensation," in the *Memoirs of the National Academy of Sciences* (1884).

William James was responsible for Peirce's worldwide reputation as the father of the philosophical doctrine that he originally called pragmatism, and later pragmaticism. Peirce's famous pragmatic maxim was enunciated in "How to Make Our Ideas Clear," which he wrote (in French) on shipboard before reaching Plymouth on the way to the Stuttgart meetings of the European Geodetic Association in 1877. The paper contains his statement of a laboratory procedure valid in the search for "truth"—"Consider what effects, that might conceivably have practical bearings, we conceive the object of our conception to have. Then, our conception of these effects is the whole of our conception of the object." In a letter to his former student Christine Ladd-Franklin, Peirce emphasized that "the meaning of a *concept* . . . lies in the manner in which it could *conceivably* modify purposive action, and *in this alone*." Moreover "pragmatism is one of the results of my study of the formal laws of signs, a study guided by mathematics and by the familiar facts of everyday experience and by no other science whatever." John Dewey pointed out that reality, in Peirce's system, "means the object of those beliefs which have, after prolonged and cooperative inquiry, become stable, and 'truth,' the quality of these beliefs, is a logical consequence of this position." The maxim underlies Peirce's epistemology, wherein the first procedure is a guess or hypothesis (abductive inference) from which are set up subsidiary conclusions (deductive inference) that can be tested against experimental evidence (inductive inference).

The results of the inductive process are ratios and admit of a probability error, abnormal occurrences corresponding to a ratio of zero. This is valid for infinite classes, but for none larger than the denumeral. Consequently, induction must always admit the possibility of exception to the law, and absolute certainty is unobtainable. Every boundary of a figure that represents a possible experience ought therefore to be blurred, and herein lies the evidence for Peirce's claim to priority in the enunciation of a triadic logic.

Morris Cohen has characterized Peirce's thought as germinal in its initiation of new ideas and in its illumination of his own "groping for a systematic view of reason and nature." Peirce held that chance, law, and continuity are basic to the explanation of the universe. Chance accounts for the origin of fruitful ideas, and if these meet allied ideas in a mind prepared for them, a welding process takes place—a process called the law of association. Peirce considered this to be the one law of intellectual development.

In his educational philosophy Peice said that the study of mathematics could develop the mind's powers of imagination, abstraction, and generalization. Generalization, "the spilling out of continuous systems of ideas," is the great aim of life. In the early 1890's he was convinced that modern geometry was a rich source of "forms of conception," and for that reason every educated man should have an acquaintance with projective geometry (to aid the power of generalization), topology (to fire the imagination), and the theory of numbers (to develop the power of exact reasoning). He kept these objectives in view in the mathematics textbooks that he wrote after his retirement from the Coast Survey; these works further reflect the influence of Arthur Cayley, A. F. Mobius, and C. F. Klein. Peirce's adoption of Cayley's mathematical "absolute" and his application of it to his metaphysical thought is especially revealing. "The Absolute in metaphysics fulfills the same function as the absolute in geometry. According as we suppose the infinitely distant beginning and end of the universe are *distinct, indentical*, or *nonexisten* we have three kinds of philosophy, hyperbolic, parabolic, or elliptic." Again "the first question to be asked about a continuous quantity is whether the two points of its absolute coincide." If not, are they in the real line of the scale?" The answers will have great bearing on philosophical and especially cosmogonical problems." For a time Peirce leaned to a Lobachevskian interpretation of the character of space.

Peirce once wrote to Paul Carus, editor of the *Monist*, "Few philosophers, if any, have gone to their work as well equipped as 1, in the study of other systems and in the various branches of science." In 1876, for example, Peirce's thought on the "economy of research" was published in a Coast and Geodetic Survey report. It became a major consideration in his philosophy, for the art of discovery became for him a general problem in economics. It underlay his application of the pragmatic maxim and became an important objective in his approach to problems in political economy, in which his admiration of Ricardo was reflected in his referring to "the peculiar reasoning of political economy" as "Ricardian inference," Peirce's application of the calculus approach of Cournot predated that of Jevons and brought him recognition (according to W. J. Baumol and S. W. Goldfeld) as a "precursor in mathematical economics."

Peirce also sought systems of logical methodology in the history of logic and of the sciences. He became known for his meticulous research in the scientific and logical writings of the ancients and the medieval Schoolmen, although he failed to complete the book on the history of science that he had contracted to write in 1898. For Peirce the history of science was an instance of how the law of growth applied to the human mind. He used his revised version of the Paris manuscript of Ptolemy's catalogue of stars in his astronomical studies, and he included it for modern usage in *Photometric Researches*. He drew upon Galileo—indeed, his abductive inference is identical twin to Galileo's *il lume naturale*—and found evidence of a "gigantic power of right reasoning" in Kepler's work on Mars.

Peirce spent the latter part of his life in comparative isolation with his second wife, Juliette Froissy, in the house they had built near Milford, Pennsylvania, in 1888. (His second marriage, in 1883, followed his divorce from Harriet Melusina Fay, whom he had married in 1862). He wrote articles and book reviews for newspapers and journals, including the *Monist, Open Court*, and the *Nation*. As an editorial contributor to the new *Century Dictionary*, Peirce was responsbile for the terms in logic, metaphysics, mathematics, mechanics, astronomy, and weight and measures; he also contributed to the *Dictionary of Philosophy and Psychology*. He translated foreign scientific papers for the Smithsonian publications, served privately as scientific consultant, and prepared numerous papers for the National Academy of Sciences, to which he was elected in 1877 and of which he was a member of the Standing Committee on Weights and Measures. (Earlier, in 1867, he had been elected to the American Academy of Arts and Sciences). Peirce also lectured occasionally, notably at Harvard (where he spoke on the logic of science in 1865, on British logicians in 1869–1870, and on pragmatism in 1903) and at the Lowell Institute. None of his diverse activities was sufficient to relieve the abject poverty of his last years, however, and his very existence was made possible only by a fund created by a group of friends and admirers and administered by his lifelong friend William James.

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