CHAPTER 1

Peirce's Life in Science: 1859–1891

> … the writer … may almost be said to have inhabited a laboratory from age six until long past maturity; and having all his life associated mostly with experimentalists, it has always been with a confident sense of understanding them and of being understood by them. – *Peirce in 1905, EP2:332*

Biography is irrelevant to philosophy, normally. For the purpose of understanding Peirce's thought, however, it is helpful to know the extent to which he had been immersed in mathematics and scientific research from childhood onward. This history is well known to students of Peirce's philosophy, yet his philosophical writings are seldom interpreted in light of the scientific milieu in which they were written. Hence the present chapter. By describing his scientific work and enumerating his accomplishments in diverse fields, I hope to render plausible this book's unusual orientation.

Of the history here recounted, I say nothing original.[1] As it would be misleading to omit Peirce's philosophical essays and lectures within the same period, I mention them also; however, philosophical or scientific matters discussed in later chapters are treated briefly. My explications of technical subjects may be too concise to help some readers, but one who reads through the chapter will get the gist, which is all for the present purpose that matters.

[1] In what follows, every undocumented biographical claim is derived from one or more of these sources: what has been published of Peirce's scientific work in the chronological edition of his Writings and in Volume 7 of the Collected Papers; the introductions, by Max Fisch and others, but especially the quite detailed ones by Nathan Houser, to various volumes of the Writings; Joseph Brent's biography of Peirce (Brent 1993; there is a later edition, but I prefer the first); Victor Lenzen's 'Charles S. Peirce as Astronomer' (in Moore and Robin, eds., 1964); and Ian Hacking's survey of Peirce's many-sided encounters with probability (1990, Ch. 23).

A

Charles Sanders Peirce, rhymes with 'curse', was born on September 10, 1839, the second of Benjamin and Sarah Mills Peirce's five children. Benjamin Peirce (1809–1880) was a Harvard professor of mathematics and astronomy, the only creative mathematician in the United States of his day and the second American mathematician, after his teacher Nathaniel Bowditch, to be internationally recognized. He was a friend of Emerson and Longfellow but was especially close to Louis Agassiz, the Swiss expatriate and naturalist who founded the Harvard Museum of Comparative Zoology and the last major biologist never to be converted to Darwinism. Benjamin was close also to Henry James, Sr., a Swedenborgian mystic who is remembered today primarily for his sons, the philosopher, William, and the novelist, Henry, Jr. Charles was thus raised in a scientific milieu, but not one narrowly scientific.

Together with Agassiz and other leading scientists, Benjamin in 1863 founded the National Academy of Sciences. For seven years, while retaining his Harvard professorship, he served as a superintendent of the US Coast Survey (later, the Coast and Geodetic Survey; today, the National Oceanic and Atmospheric Administration). He was elected president of the American Association for the Advancement of Science, convinced Abbot Lawrence to endow the Lawrence Scientific School at Harvard, and founded the Harvard Observatory under Coast Survey auspices. It was within these institutions, which owed so much to his father, that Charles studied and worked.

Benjamin's oldest son, James Mills, became like his father a professor of mathematics at Harvard. Yet, as the boys were growing up, it was with Charles that Benjamin would discuss his own researches. For, early on, he discovered in Charles the marks of genius. He raised him accordingly, instilling in the boy a habit of intense and prolonged concentration. Benjamin and his mathematical colleagues believed that Charles had a stronger mind for mathematics than did his father.

After desultory study at Harvard, graduating near the bottom of his class in 1859, Peirce earned a Bachelor of Science degree in chemistry *summa cum laude*, from the Lawrence Scientific School, in 1863. Between Harvard and the Lawrence School, he worked as a temporary aide to the Coast Survey, then spent half a year studying taxonomy with Agassiz. After the Lawrence School, he attained a regular position in the Coast Survey. His work at the Survey, being in the national interest, excused him from service in the Civil War. He would have made a terrible soldier.

From July 1861 to June 1867, Peirce worked for the Coast Survey as a 'computer'. At first, much of this was at the Harvard Observatory, reducing observations of occultations of the Pleiades by the moon, thereby correcting earlier determinations of longitudes (by triangulation from time differences in such observations taken at different locations). This was a full-time job, but during that period, he had also completed his degree at the Lawrence Scientific School, married, and published a brief paper on 'The Chemical Theory of Interpenetration' (W1:95–100). In 1865, he gave a series of twelve lectures at Harvard on 'The Logic of Science' (W1:162–302), and a different series of twelve under almost the same title at the Lowell Institute the next year (W1:358–504). These lectures intermix comment on the views of Kant and mainly English philosophers with various forays into syllogistic logic, Boole's new calculus of logic, and probability theory.

Perhaps of most interest, the 1865 lectures announced a third mode of inference, in addition to deduction and induction, named 'hypothesis' (comparable to Karl Popper's idea of 'conjecture' propounded nearly a century later). William Whewell had emphasized the importance of hypothesis; Peirce turned it into a form of inference. This tripartite division of inference is frequently repeated throughout the rest of his career, during which hypothesis became renamed 'retroduction' (less often, 'presumption') and, finally, 'abduction'. Abduction is variously defined as well as variously named, but, roughly, it either introduces an explanatory hypothesis or provides a reason either for tentatively accepting it or for examining and testing it. Confirmation of a hypothesis is inductive. At this time, it was in terms of syllogistic logic that Peirce distinguished the three forms of inference: induction is one and abduction is another of well-known deductive fallacies.[2] What counts as a fallacy or, conversely, what counts as validity, is relative to the aim of inference: in deduction, the aim is to conserve truth; in induction and abduction, it is to extend knowledge. To extend knowledge, error must be risked; the hope is that in the long run errors will be eliminated, growth of knowledge being the residue of the process. The analogies, to diversifying risks in investment and to selection among chance mutations in biological evolution, have often been made – but only many years after Peirce wrote.

[2] 'All A is B. All B is C. Therefore, all A is C' is deductively valid; while 'All A is B. All A is C. Therefore, all B is C' is deductively invalid but is the pattern of induction, and 'All A is C. All B is C. Therefore, all A is B', also deductively invalid, is the pattern of abduction (for, if all B is C, then A's being B's would explain why A's are C's).

At the beginning of 1867, upon being elected to the American Academy of Arts and Sciences, Peirce read or otherwise presented five remarkably concise papers (W2:12–97), published in its *Proceedings* of 1868. In these, some of the topics discussed in his lectures were separately treated and further developed. 'On an Improvement in Boole's Calculus of Logic' makes important amendments to Boole's new notation (adapting the signs and rules of arithmetic to logic), increasing its expressiveness and facilitating its application to probabilities. 'On the Natural Classification of Arguments' is a study of syllogistic logic that includes induction and abduction (named 'hypothesis'). 'Upon the Logic of Mathematics' sketches a formal deduction of mathematics from 'propositions … taken as definitions of [mathematical] objects' (W2:59). It is not logicism, as in the attempt by Frege and Whitehead/Russell to deduce mathematics from logical axioms; instead, it is closer to what the logicist program ended up being, where one or another axiom is nonlogical. I think the most interesting paper is the last, 'Upon Logical Comprehension and Extension'. It has received little comment but represents a deep strand of Peirce's thought that was further developed in later years, in his doctrine that symbols grow in meaning ('comprehension') while not losing, or even while also growing in, their range of reference ('extension'), thus embodying growth of knowledge (in this essay named 'information'). The third of the American Academy papers, 'On a New List of Categories' (EP1:Ch.1), is the one most celebrated by his philosophical readers, as, in it, he seems to have anticipated so much of his later thought: it is examined in Chapter 5.

Beginning in 1867, Peirce published a number of book reviews on mathematical, scientific, and philosophical works in the *North American Review* and then, after 1868, a great many in the *Nation*. An 1867 review (W2:98–102) was among the first to recognize the importance of the frequency theory of probability, proposed by John Venn in 1866. That theory is an alternative to the classical conception of probability (Pascal, Bernoulli, Laplace, et al.). Classically, a probability is a rational number determined a priori on the basis of ignorance; for example, we have no reason to expect heads more or less than tails, so the probability of a flipped coin's landing heads-up is 1/2. On Venn's account, a probability is a real number, viz., the limit toward which an actual ratio – say, of heads to flips – tends over the long run. It is approximated empirically by examining as much of the run as we can. The frequency theory is one that Peirce thereafter maintained consistently but often revised: it is of enormous importance to many departments of his thought.

Two further items, out of a great many that might be mentioned, indicate Peirce's range. In a letter of 1869 to the *Chemical News*, he proposed a table of chemical elements (W2:282–84). Much attention was then being given to the question of how to classify the elements. Peirce's scheme might have been of some importance had it not been eclipsed, almost immediately, by the Periodic Table that Mendeleev presented to the Russian Chemical Society in the same year. And in 1870, he reviewed, sympathetically, *The Secret of Swedenborg*, by his father's friend, Henry James, Sr., a book notoriously more obscure than the mystical doctrine it was meant to elucidate (W2:433–38).

B

In June 1867, Peirce's astronomical work changed, from computation exclusively, to include observation as well. From that time until 1875, he participated in a variety of astronomical observations and measurements at the Harvard Observatory and from other vantage points under the auspices of the Coast Survey. The results to which he contributed, including micrometric measurements of celestial positions, were published in Observatory reports and other journals. 'The investigations included double stars, nebulae, satellites, asteroids, comets, and occultations of stars and planets by the moon' (Lenzen 1964, p.36). The Observatory acquired a spectroscope in 1867, of which Peirce made much use, including making, in April 1869, the first spectroscopic analysis of an aurora borealis. In August 1869, he was part of a Coast Survey expedition to Kentucky to observe a solar eclipse. In June 1870, Peirce traveled to the Mediterranean to find suitable sites for observing the solar eclipse predicted for December, and he was part of the party, under the direction of his father, that made the observations from Sicily (another party did the same from Spain). These included determining the polarization of the solar corona.

It should be understood that the use of instruments in scientific measurement involves painstaking work, many calculations, and fresh thought. This work is not mechanical and requires theoretical reasoning. For example, photographs were taken and micrometric measurements made of the 1869 eclipse to determine the radii of sun and moon, but Peirce found that the results were uncertain, due to unsystematic variations in the tilt of the photographic plates relative to the optical axis of the telescope. In connection with this work of 1869, he also devised a graphical method by which to map the moon's shadow, minute by minute, as it crossed the United States.

Let me pause here to emphasize a point. This work done in 1869 illustrates two quite different but complementary aspects of Peirce's overriding interest in logic: problems in making accurate observations and techniques of representation. For, while we can look at what we cannot comprehend, we can observe (make an observation of) only what we can represent (e.g. name, describe, or conceive of), and knowledge is therefore advanced by these two means. Both to observation and to representation, Peirce in all of his remaining years gave persistent, penetrating, and highly original attention. We will pay special attention in Chapter 7 to his studies of observation; his general study of representation in all its forms is to be found in his theory of signs or 'semeiotic'.

Also in 1869, Peirce delivered fifteen lectures at Harvard, on 'British Logicians', in which William of Ockham, Duns Scotus, and other medieval logicians were prominently featured (only some fragments survive: W2:310–47, 533–38). His historical studies of logic were being taken deeper in time; eventually, they would reach beyond the medieval period through the Hellenistic age to classical Athens; but at this point, the thirteenth century predominated. That was not without an influence on his philosophy. Already in 1868–1869, he had published a series of three papers in the *Journal of Speculative Philosophy*,[3] in which he launched an attack on Descartes and, through Descartes, on all of modern philosophy (EP1:Chs.2–4). Although not endorsing the views of medieval logicians, he compared favorably their style of thought to that of Descartes and his successors and, in stunning paradox, associated the pattern of their inquiry with that of modern science (*vide infra*, Ch.5, A). This critique of modern philosophy was explicitly logical and implicitly moral. It issued in a novel theory of cognition and reality, and also in a novel theory of the self, in which the individualism and egoism of the modern age were challenged. But these are themes I develop in later chapters.

C

Now, we must begin to describe Peirce's contributions to formal deductive logic. In order to appreciate their importance, the reader should know that there had been no major addition to formal deductive logic for over two millennia, from the founding of that subject by Aristotle in the fourth-century BC to the year 1847. To be sure, well before 1847, there had

[3] This quarterly journal, published in St. Louis, was the first philosophical journal in the English-speaking world (W2:xxv). Peirce's 1868 papers appeared in its second year of publication.

been additions to Aristotle's theory of the syllogism; most importantly, his brief remarks on propositional logic were developed by his student, Theophrastus, and then by others. During the course of the Hellenistic period and the Middle Ages, there had been a profusion of subtle studies of logic; a far greater share of intellectual energy was devoted to logic in those centuries than has been devoted to it since. And yet, there was no advance either in the techniques of formalization or in the range of deductive logic. Then, from 1847 to 1935, there occurred a revolution in logic resulting in a stream of stunning discoveries: that mathematics cannot be reduced to logic; that mathematical truth, even with respect to arithmetic alone, cannot be defined as what may be deduced from axioms, logical or nonlogical; and that reasoning cannot be wholly reduced to routine, that is, to rules mechanically applied.

As to techniques of formalization: in 1847 and in 1854, George Boole, a self-taught English mathematician of humble origin, published two books that formalized logic in the style of arithmetical algebra. However, Boole's algebra of logic was limited to the range of Aristotle's syllogistic and propositional logic, though he also applied these techniques to probabilities; it did not cover inferences concerning relations. Boole's class logic and Aristotle's syllogistic embrace the logic of predicates taking subjects one at a time, such as 'x is red' and 'x explodes'. But there is a need for a logic of predicates taking subjects two or three or more at a time, such as 'x is larger than y', 'x is y's father', and 'x gives y to z'. We may thus speak of predicates, and of the properties or relations they represent, as being of different 'orders' or 'adicities': monadic (Rx, where R is something predicated of a single subject, x), dyadic (Rxy, where R is predicated of an ordered pair of subjects, x and y), triadic (Rxyz), etc. Without extending logic to dyadic relations, we cannot show that even so simple an inference as 'All men are animals, therefore the head of a man is the head of an animal' is valid. The example is due to the English mathematician, Augustus De Morgan, who used it in 1860 to show the inadequacy of syllogistic logic.

Earlier, De Morgan, Peirce, and others had attempted to extend the principles of syllogistic to inferences concerning relations. De Morgan published his 1860 memoir in 1864, which Peirce read in 1868 (W2:xliv). He began working on a non-syllogistic logic of relations in the late 1860s and in 1870 published a long paper (W2:359–432) with a long title – 'Description of a Notation for the Logic of Relatives, Resulting from an Amplification of the Conceptions of Boole's Calculus of Logic' (in the *Memoirs of the American Academy of Arts and Sciences*) – in which he

https://doi.org/10.1017/9781009223508.004 Published online by Cambridge University Press

developed a logic of relations in Boole's style.[4] He was the first to have done so. Subsequent papers, published in the *American Journal of Mathematics*, in 1880 (W4:163–209) and 1885 (W5:162–90), refined and extended that system. Thereby, he established the subject. The importance of this to the development of modern mathematical logic cannot be overstated; there could not have been a logical analysis of mathematics without it. Peirce's only equal in developing a logic of relations was the German, Ernst Schröder, whose later work made use of Peirce's. Schröder's writings, in turn, were fundamental to Russell and Whitehead's *Principia Mathematica* (1910–1913) and hence to the revolution in modern logic.

D

In the year 1870, as well as traveling twice to Europe in connection with observing the solar eclipse and in addition to publishing his first major paper on the logic of relations, Peirce wrote and saw published a long review of a new edition of the works of Bishop Berkeley (W2:462–87). This review is of generally acknowledged importance. It marks a further depth taken in his studies of medieval logic and a correspondingly stronger criticism of modern individualism. In these pages (anticipated in his 1868 article, at EP1:52–53), he derived from medieval discussions a definition of 'real' – as that which is independent of what anyone thinks about it – by which to make sense of the medieval controversy between realism and nominalism, as to whether individual things alone are real. He took the side of the realists, that is, of those who affirmed the reality of that which cannot be reduced to any finite collection of individuals, such as types of quality and types of individual. His realism continued to grow in later years, in both depth and breadth. But we will discuss realism at length later (Chapters 4 and 8).

In 1872, Peirce began two new assignments at the Coast Survey. One, continuing through 1875, was to determine the 'magnitudes', that is, relative brightness, of stars instrumentally. Always previously, differences in magnitude were judged by eye, unaided. The ultimate purpose of this study was to determine the shape of our galaxy, the pattern of distribution of stars of various magnitudes in it, and our own location within

[4] For detailed comparison of this paper to De Morgan's work, in which the logic of relations had begun to be formalized albeit in a different and less satisfactory way, and also to the elder Peirce's *Linear Associative Algebra*, which appeared with Charles' help in the same year, see Daniel D. Merrill's introduction to W2, W2:xlii–xlviii.

it. It resulted in the only book Peirce ever published of his own work, *Photometric Researches* (1878). As Lenzen reports, 'In his pioneer contribution, based upon scant data, Peirce deduces general forms of the surfaces of equal star-density throughout the [galactic] cluster' (Lenzen 1964, p.48 – but all of pages 48 and 49 should be consulted for the technical details and also regarding recognition by later astronomers of the importance of this work). In this book, Peirce described his experiments correlating judgments of brightness to differences in light energy, confirming Fechner's psychophysical hypothesis that the strength of sensation varies as a logarithm of the strength of the physical stimulus. He also summarized the results of his research in 1875–1876 in European libraries, examining ancient and medieval star catalogues, and included translations of the major catalogues, the translation of Ptolemy's being his own. These psychophysical experiments and historical comparisons attested to the objectivity of judgments seemingly subjective: see Chapter 7.

The other assignment was to measure the Earth's force of gravity at various points on its surface, by which to determine the distribution of mass in the Earth. This was done by timing the period of a swung pendulum. As with the preceding example, these measurements were extremely exacting, requiring much adjustment of the apparatus and training of the observer, as well as complex calculations by which raw data were reduced to scientifically meaningful data. After 1875, Peirce's work at the Survey was wholly devoted to gravity measurements, partly including the training and supervision of assistants. The pendulum apparatus was a major concern, and several variants of it were tried. Extensive trips were made to Europe in 1875–1876, 1877, 1880, and 1883, to measure gravity from different locations, to pick up an improved apparatus from a firm in Hamburg and later to bring a design of Peirce's own to that firm, and to communicate, to a geodesy conference in Paris,[5] his finding that a flexure in the support of the pendulum affected the period. That source of error was corrected in the apparatus Peirce designed, on which two pendulums are swung simultaneously in opposite direction.

During these and his earlier trips to Europe – two-and-a-half years *in toto* – Peirce took advantage of the opportunity to meet with various mathematicians and logicians such as De Morgan, to consult with Clerk Maxwell and other scientists on geodesy, and to visit the great libraries to read rare

[5] 'The first international scientific association was geodetic' – it was founded in 1864 – and Peirce was 'the first invited American participant in the committee meetings of an international scientific association' (Fisch, W3:xxiv–xxv).

https://doi.org/10.1017/9781009223508.004 Published online by Cambridge University Press

manuscripts in logic and in the early history of science, particularly but not only the early star catalogues. This included early studies of magnetism; he made a translation, now lost, of Petrus Peregrinus' thirteenth-century treatise on the loadstone. The fine arts were not neglected; indeed, his puritanical first wife, who disapproved of his attending the opera, returned, for that or for other reasons, in haste to the United States. In addition, he began learning Arabic and was tutored in Médoc by a French sommelier.

E

The eclipses observed in 1869 and 1870 posed a problem for use of the method of least squares. All measurements, to the extent that they purport to be exact, are liable to be wrong. Exactness is improved by making many measurements of the same quantity and then taking the true measure to be the value from which the actual measurements (discarding those far from the mean) vary least (i.e., the number which is such that the sum of the squares of its differences from each actual measurement is least). But this method presupposes that errors will tend to occur more or less symmetrically on either side of the true value. And that is not the case when observing the time at which a star or other body emerges from occultation. Peirce's paper addressing this problem, 'On the Theory of Errors of Observation', appeared in 1873 (W3:114–60). It is remarkable for applying the logic of relations to probability and probability to the analysis of inductive inference. That treatment of induction was further developed in later papers, discussed below.

The 1873 paper is remarkable, also, for reporting an experimental study, carried out by Peirce himself, of the effect of training on improving an observer's accuracy in observing a phenomenon 'not seen coming on', like the emergence of a star from behind the moon. This and a later study, in connection with his photometric researches, of the effect of training on judgments of brightness, were Peirce's first forays into experimental psychology. Both are discussed in some detail in Chapter 7.

The science of experimental psychology had only recently been initiated in Germany – in fact, from the beginning of the century, but Fechner's important book did not appear until 1860 and Wundt did not formally establish what is often said to be the first laboratory in experimental psychology until 1879. William James, who had studied with Wundt in Germany, began his experimental studies in psychology in about 1874; there is no exact date at which his laboratory in experimental psychology can be said to have been established, but its beginnings were no earlier than 1875 (Perry 1935, Vol. II, pp.12–15). Peirce's 1873 paper thus preceded

James in this type of inquiry. It might, however, have been James who, returning from Germany in the late 1860s, alerted his friend to the new developments taking place there. One generalization we might make from this and preceding examples (Boole, Venn, DeMorgan, and Whewell) is that Peirce was always quick to pick up on a new idea and to extend it further; another example of this was provided by Darwin's theory, of which we shall later make much (Chapters 2, 6, and 9).

F

The years 1872–1878 were occupied in large part by scientific work, often making geodetic observations with aides under adverse conditions in a variety of locations, including a failed attempt in a deep vertical mine shaft. In 1877, Peirce was elected to the National Academy of Sciences. In 1877–1878, he published a series of six articles in the *Popular Science Monthly*, under the general title, 'Illustrations of the Logic of Science'. The first two of these are his best-known philosophical essays, 'The Fixation of Belief' and 'How to Make Our Ideas Clear'. 'How to' is supposed to contain the first published statement of pragmatism, though that term was not used. The remaining four essays develop themes begun earlier. The third is on the frequency theory of probability, and the last reformulates the three classes of argument, still syllogistically. The fourth essay, to which the fifth is a religio-cosmological codicil, deserves separate mention, as follows.

'The Probability of Induction' applies the frequency theory of probability to an analysis of inductive inference, developing a line of thought already evident in the paper on errors of observation. An induction can result in a false conclusion from true premisses. Why, then, should anyone make inductions? Peirce said that if there is a reality, then repeated inductions will tend over the long run to correct short-run errors and thus approximate to the truth – a truth not already contained in the premisses. But his argument is not so facile as such a summary statement may seem to suggest. It applies the mathematics of probability to the case where induction consists in taking the proportion of a pre-designated (this qualification is essential) characteristic in a randomly selected sample of pre-designated size to be the proportion of that characteristic in the entire, perhaps indefinitely large population. Refined in 1883, in 'A Theory of Probable Inference' (W4:408–49), in 1902 (2.102, 2.773–791), and in 1905 (2.755–772), this account anticipated the idea of 'confidence interval estimation' advanced in the 1930s by Jerzy Neyman and E. S. Pearson (see Hacking 1980 and Levi 2004).

https://doi.org/10.1017/9781009223508.004 Published online by Cambridge University Press

Although not the first to claim that induction is self-corrective (Laudan 1973), Peirce was the first to make the statistical argument, and in such a way as distinguishes his view from, for example, the later view of Reichenbach (Levi 1980). In this way, he supported a theme that he had stated much earlier, especially at the conclusion of his three 1868–1869 essays, and continued to maintain the rest of his life, that types of argument essential to the growth of knowledge, namely, induction and abduction, are not valid in the short run. The implication, which he drew in dramatic form, is that logic itself requires us to transcend egoism, by taking an interest in the long run, which is a run one does not live to see completed. Except as contributing to what others will eventually believe, our inductive and abductive inferences are illogical. This extreme conclusion was implicitly modified in his later work, but its anti-egoistic spirit was retained.

G

In 1877–1878, Peirce developed what he named a 'quincuncial projection' of the Earth: a two-dimensional map in which the angles found on a globe between any two points are preserved, as they are not in other two-dimensional projections (see W4:69, where the map, a thing of beauty, is reproduced).

In 1879, continuing to 1884, Peirce was appointed a part-time Lecturer in Logic at the newly formed Johns Hopkins University, in Baltimore, still continuing his full-time work for the Survey. The lectureship appears to have stimulated his work in formal logic. In addition to the aforementioned long papers of this period on the logic of relations (1880 and 1885), he published two shorter papers in *The American Journal of Mathematics*, 'On the Logic of Number' and 'Associative Algebras', as well as a number of short pieces privately or locally published.

Johns Hopkins was the first university formed in the United States on the model of the German research universities, something that Benjamin Peirce many years previously had urged should be done. It attracted an especially able and eager group of students, including John Dewey and Thorstein Veblen, neither of whom seems at that time to have been greatly influenced by Peirce. Those he did influence include Allan Marquand, Christine Ladd, B. I. Gilman, Joseph Jastrow, and O. H. Mitchell. About Jastrow, more in a moment. The other four are represented in a book Peirce edited while at Johns Hopkins, *Studies in Logic* (Boston, 1883), consisting of essays by his students and one of his own ('A Theory of Probable Inference', mentioned earlier, to which he added two appendices; the second appendix, 'The Logic of Relatives' is long and also important). The students' papers are impressively sophisticated. One of Marquand's two was on logic machines; the other students produced original investigations in the algebra of relations. Marquand later founded Princeton University's art museum and Gilman became director of the Museum of Fine Arts in Boston. Christine Ladd, due to her sex, was permitted at Johns Hopkins only by special arrangement; she later, as Christine Ladd-Franklin (having married another of Peirce's students), achieved some renown as a logician, mathematician, and psychologist. She remained in touch with Peirce on matters of logic. Her papers in psychology pertain to color vision, one of Peirce's special interests.

The most important paper in the collection is that by O. H. Mitchell, which introduced a system of quantification into the logic of relations (incorporated with modifications in Peirce's 1885 paper). A formal theory of quantification – universal quantification expressed in ordinary English by the words 'any', 'every', or 'all' and existential quantification expressed by the words 'some' or 'there exists a' – was essential to the development of modern logic. Thereby, for example, it can be shown why the inference, from 'There is a woman whom all men love' to 'Every man loves some woman', is valid, while the converse inference, from 'Every man loves some woman' to 'There is a woman whom all men love', is invalid. The example is Peirce's.

It is impossible to tell how much Mitchell, who died not long after, owed to his teacher, but the debt must have been great. Quantification was first developed by Gottlob Frege in 1879, but his work was little noted – Peirce was certainly unaware of it – until the twentieth century, and the Mitchell-Peirce system was the first to have had an influence on other logicians, for example, Leopold Löwenheim and Thoralf Skolem in their important work (done independently of Russell and Whitehead's *Principia*, though published in 1915 and later). Frege's system was, however, the one cited by Russell and Whitehead, and for that reason and because of his priority he has usually been given sole credit for the invention of quantification. Peirce's contributions to the development of modern formal logic were for a time mostly forgotten but have recently been recovered (see Putnam 1990, Ch.18, Hintikka 1997, and Sowa 2007).

H

Peirce also guided a single student, Joseph Jastrow, in setting up and carrying out an experiment that holds a place of importance in the history of psychology (7.21n1). The resulting paper, 'On Small Differences of Sensation', published in 1884, presents their experimental findings and argues against the assumption (by Fechner and others) of a 'least perceptible difference' or *Unterschiedsschwelle* of nerve excitations (*vide infra*, Ch.7). As well as its conclusion, the design of the experiment was important. It 'was the first experiment in which the sequence of trials was chosen by an artificial randomizer … built into the analysis of the data' (Hacking 1990, p.205). Jastrow, who cited this experiment as his introduction to the possibility of making an experimental study of a psychological problem, went on to become a leading American psychologist. Philosophers remember him as the source of the 'duck-rabbit' of which Wittgenstein made so much.

In 1880, Peirce was elected to the London Mathematical Society, and in 1881 to the American Association for the Advancement of Science. In 1883, he was made a contributing editor to the newly conceived and very ambitious *Century Dictionary* (twenty-four large volumes, 1889–1891), responsible for all definitions in logic, metaphysics, mathematics, mechanics, astronomy, and weights and measures. In addition, he contributed to definitions in several other areas of philosophy, science, and education, especially words pertaining to universities. Eventually, he wrote, contributed to, or edited over 15,000 entries, many of them quite long (the *Century Dictionary*'s 'definitions' are akin to encyclopedia articles, technical and condensed). From October 1884 to February 1885, Peirce was in charge of the United States Office of Weights and Measures.

It should be noted that this outline omits the many short papers Peirce published, especially in the years 1879–1884, on logical, mathematical, and scientific topics. He was the first to propose using a wavelength of light as a unit of measure – a unit that, unlike the standard meter, would not be subject to change by physical causes (W4:269–98). In addition, he knew many languages, had an interest in Shakespearean pronunciation, wrote on recent developments in economics (Hoover and Wible 2020), and perhaps had an influence on geology (Baker 2009).

Toward the end of this period, Peirce's thought took a dramatic turn, toward an evolutionary cosmology. This began in about 1883 and was first expressed in a lecture, 'Design and Chance' delivered at Johns Hopkins in 1884 (EP1:Ch.15). It culminated in a series of five articles published in the *Monist* in 1891–1893 (EP1:Chs.21–25).[6] The idea, briefly, is that the fact that

[6] *The Monist* was the second philosophical journal in the United States. Both it and *The Journal of Speculative Philosophy* were founded in the Midwest; neither had academic affiliation; both had Germanic roots, the first in the philosophy of Hegel, the second in the theological interests of a German immigrant industrialist named Hegeler.

there are laws of nature – and these particular laws rather than others – requires to be explained, and that the only way to explain laws without presupposing other laws is to suppose that they evolved from out of chaos. As Chapter 6 examines this hypothesis and its devolution, I will say no more about it here, except to note, as it is germane to our present theme, that the attempt grew out of concern with the baffled state of physics in the 1880s and was based on earlier advances in nineteenth-century science, in physics and biology. That is to say, it was not a 'philosophical' speculation formed independently of the then current state of scientific knowledge.

I

This chapter is about Peirce's life in science and not his life generally, but the reader, I fear, will demand to know why his scientific career ended so abruptly when he was only fifty-two. He lost his position at Johns Hopkins in 1884 and his position in the Coast and Geodetic Survey in 1891. He never again held a post in any institution, academic or scientific. He earned a living, meagerly, by writing articles, book reviews, and dictionary definitions. For a time, he and his wife, Juliette, lived in New York City, fugitives from Pennsylvania justice, where they were sued for nonpayment of debts for work done on a house purchased there in the small town of Milford. At one point, Peirce threatened suicide. Eventually those debts were paid by his brother, enabling Charles and Juliette to return to their house, retiring in rural seclusion. They lived in deepening poverty, hungry and cold, dependent on charity organized by and sustained largely, if not wholly, by William James, by that time a celebrated Harvard professor of psychology and then of philosophy.

James, sometimes privately expressing exasperation with Peirce's improvidence, recognized his friend's genius and, in the late 1890s, did what he could to revive his career. In a lecture of 1898, in California, James announced a new doctrine, named 'pragmatism', which he attributed to Peirce. It was instantly popular. In the same year, he arranged a series of lectures for Peirce to deliver at a private house in Cambridge, Massachusetts. Peirce was not, at that time, permitted on the campus of Harvard College. Then, in 1903, James finally prevailed on President Eliot to allow Peirce on campus and he arranged another series of lectures by Peirce, this time on pragmatism. Each series of lectures was moderately remunerated.

The causes of Peirce's downfall have not been exactly determined, but there are many possibilities. He was arrogant, contemptuous of mediocrity, ill-tempered, and inclined to offend his superiors and colleagues. As long as his father lived, he had protection, but his father died in 1880. Perhaps more importantly, he was impractical in managing the financial and other details of life, careless with Survey apparatus and of his obligations to others, increasingly tardy in completing his assigned tasks, and had an irregular marital history. This last – it was discovered that he had lived with his second wife before they were married – was almost certainly why Johns Hopkins found it necessary to reorganize its program, finding slots in the new arrangement for every existing faculty member except Peirce. In the case of the Survey, his reports were long overdue. One, when finally completed, received a damning review by Simon Newcomb, a celebrated astronomer and mathematician who had been a prize student of Benjamin's and with whom Charles' relations always were rocky. And at the Survey there were a couple of public relations disasters partly Peirce's fault (see Houser, W5:xxviii–xxx, W6:xxx–xxxii). It is clear that Peirce was tired of the Survey work and desired an academic position in logic, but after Johns Hopkins terminated his employment, he was not employable in any college or university.

We are the beneficiaries. Freed from other duties, Peirce, after some years fruitlessly seeking ways of using his scientific expertise to make a fortune, worked full time, unremunerated, in logic and philosophy. In logic, he developed his system of 'existential graphs' – a complete system of truth-functional logic and first-order polyadic predicate logic with identity, with some suggestions for extensions into second-order predicate logic and modal logic.[7] This system is, as advertised, graphical, as Venn diagrams are; but it bears the same relation to the latter as the palace at Versailles bears to a grass hut. In philosophy, he developed the new sciences of phaneroscopy (see Chapter 8) and semeiotic, and framed a conception of three 'normative' sciences (Chapter 9). Under the rubrics 'pragmatism', 'pragmaticism', and 'critical common-sensism', he produced his most deeply considered accounts of scientific inquiry.

[7] An excellent introduction to the existential graphs is Roberts (1973), in which, additionally, metatheorems of consistency and deductive completeness are proven for some parts of the system. See also Shin (2002) and Bellucci and Pietarinen (2016).