Es ist klar, daß die ursprünglichen Interpretationsbegriffe eine starke Inkongruenz aufweisen. Ihr gegenseitiges Verhältnis kann nur mit Hilfe einer Metatheorie begriffen werden, die Ursprung, Entwicklung und Funktion dieser Begriffe klären würde. Es war das Ziel dieses Beitrages, auf die Zweckmäßigkeit einer solchen Metatheorie hinzuweisen.

THE ROLE OF SCIENCE IN THE PHILOSOPHY OF C. S. PEIRCE

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Since the publication of the *Collected Papers of Charles Sanders Peirce*, philosophers have given critical attention to that noted American thinker. Peirce has been presented to the philosophical world as the founder of the classic period in American philosophy. (1.) He is celebrated as a creator in mathematical logic, as the originator of Pragmatism, as an exponent of indeterminism in natural phenomena. In accounts of the development of Peirce's philosophy, his intensive study of Kant's first Critique and of the Scholastic logicians has been amply recognized, also his competence in mathematics. Inadequate attention, however, has been given to the influence of Peirce's scientific practice upon his philosophical doctrines. It does not appear to have been sufficiently recognized that Charles Peirce was by profession an astronomer, a physicist and a geodesist. To be sure, biographical sketches of Peirce have cited items of scientific work during his lifetime, and in "Charles S. Peirce — Nineteenth Century Man of Science," Carolyn Eisele has given a survey of Peirce's scientific activities. (2.) It is the aim of the present paper to set forth a synoptic account of Peirce's scientific contributions, and to indicate a number of ways in which his attempt to clarify the concepts and methods of science influenced his philosophy.

I

Charles Peirce manifested an interest in chemistry at an early age and while a schoolboy set up his own chemical laboratory. Subseqently, after receiving the degree of bachelor of arts from Harvard University, he obtained the degree of bachelor of science, summa cum laude, in chemistry. Peirce's interest in a science of fundamental natural phenomena was paralleled by an enthusiastic study of logic as the science of reasoning, which he conceived to include the methods of science. He applied himself to a thorough study of Kant's transcendental analytic and the influence of Kant's logic is manifested in his lists of categories. In spite of his early interest in chemistry, there appear to be no contributions in this field, except for an early paper, by Peirce. Instead, he applied his native ability and training in mathematics to the mathematically developed fields of physical science: to astronomy, physics, and geodesy. It was a step towards foundations.

Peirce's scientific career primarily consisted of service as a member of the United States Coast and Geodetic Survey. In 1859, when he first joined the Survey in the temporary position as aid to a party in the field, the Coast Survey, as it was then called, probably was the principal institution for research in the physical sciences in the United States. For mathematics, astronomy, and physics are important factors in the pursuit of geodesy. Peirce's continuing service in the Coast Survey began with an appointment as of July 1, 1861. His initial task was to assist his father, Benjamin Peirce, Perkins Professor of Astronomy and Mathematics in Harvard University, in computations for the Coast Survey for the determination of the longitude of American with respect to European stations from observations of occultations of the Pleiades by the moon. For several years the son cooperated with his father in these computations and is credited with corrections to Benjamin Peirce's work. Thus Charles Peirce acquired training in theoretical astronomy, including the method of least squares which astronomers used in the reduction of observations. Peirce thus was led early in his scientific career to study the theory of probability which enters into the theory of errors of observation. A further impetus to his interest in probability was given by the publication of Venn's *Logic of Chance*, which Peirce reviewed and to which he made reference in this paper, "On an Improvement in Boole's Calculus of Logic" (1867). His first independent memoir for the Coast Survey was "On the Theory of Errors of Observation", Appendix 21 to the Report of the Superintendent for 1870 (1873), and it included an account of experiments which applied specifically to observations of phenomena, such as the occultation of a star. Peirce adopted a frequency theory of probability, which is suited to experimental physics, and founded thereon a theory of inductive inference. His initial interpretation of the frequency theory was nominalistic, but gradually under the influence of his physical researches, as well as his studies of Duns Scotus, he eventually adopted a concept of probability which commentators now call his realistic theory. (3.)

II

During this period in American science, the Coast Survey cooperated with the Observatory of Harvard College. Accordingly, in 1867 Peirce was assigned by the Superintendent of the Survey to the Observatory for participation in its program of observations. While engaged in this work at the Observatory, he observed and measured for the first time several new lines in the spectrum of the Aurora Borealis. He was a member of a party which observed the eclipse of the sun in the United States in 1869 and made spectroscopic observations on the corona of the sun. He was a member of Benjamin Peirce's Coast Survey party for the observation of the eclipse of the sun in the Mediterranean on December 22, 1870, and made observations of the corona with polariscope. In 1871 the Harvard Observatory acquired a Zöllner astrophotometer for Peirce and with it he undertook to measure the intensity of light from selected stars. While preparing his results for publication, he was in Europe on a mission for the Survey and used the opportunity to examine the manuscripts in European libraries of Ptolemy's catalogue of stars. Peirce's report "Photometric Researches", Volume IX of the Annals of the Observatory of Harvard College (1878), includes his edition of Ptolemy's catalogue; the report also includes a comparison of the estimates of intensity of the light from certain stars by different observers which Peirce reduced to a common standard. With the aid of the data that he had obtained, Peirce made the first analytically formulated estimate of the structure of the galaxy. Peirce's observational work in photometry ended in 1875, but the experience gained in the field enabled him later to offer an hypothesis concerning the possible hyperbolic structure of space. This proposed solution to a cosmological problem, which can be of interest for a metaphysics of space, is thus a development out of Peirce's astrophysical researches into the light from the stars.

While Peirce was engaged with his photometric researches, he was instructed, November 30, 1872, by Benjamin Peirce, now Superintendent of the Coast Survey, to assume charge of the pendulum operations of the Survey. In Europe, under the auspices of *Europäische Gradmessung*, which had been founded in Berlin in 1864 through the initiative of Lieutenant General Baeyer, there were programs conducted to determine the acceleration of gravity at various points of the geodetic network.

Reversible pendulums were constructed, after a design by Bessel, and were provided with appropriate supports, by Repsold u. Söhne, Hamburg, and were used by Swiss, Russian, German, and Austrian astronomers. Peirce was authorized to order a Repsold apparatus for the Survey and on a mission to Europe took possession of it in Hamburg in May, 1875. Between then and August, 1876, when he returned home, he made observations on the oscillations of the pendulum at stations in Geneva, Paris, Berlin and at Kew Observatory. He detected an error in earlier determinations of gravity in consequence of flexure of the support, a tripod, during oscillations of the pendulum, and by measurement and theory determined the corrections to the final results of the observations. During his sojourn in Europe he presented his findings to the Special Commission on the Pendulum and to the Permanent Commission of *Europäische Gradmessung*. On return to the United States, Peirce continued his experimental work at the Stevens Institute of Technology, and subsequently conducted observations at American stations. By invitation, he submitted a paper on the influence of the flexibility of the tripod on the oscillations of the pendulum, for presentation to the General Conference of *Europäische Gradmessung* in Stuttgart in 1877, and received authorization from the Superintendent of the Survey to attend the Conference, at which his results were accepted.

Subsequently, Peirce demonstrated theoretically and experimentally the feasibility of overcoming the flexibility of the pendulum support by oscillating two similar pendulums from a common support in antiphase. He designed, had constructed, and employed a new type of invariable, reversible pendulum of cylindrical form to which he could apply Stokes' theory of resistance to the motion of a body in a viscous medium. On June 14, 1880, Peirce addressed the Academy of Sciences in Paris on the value of gravity in Paris. In 1883, Peirce again journeyed to Europe; while experimenting in an instrument-maker's shop in Paris, he discovered that the flexure of the pendulum staff during oscillations influences the results of observations for the determination of gravity, and gave a preliminary theory for the effect. Values of the acceleration of gravity at different stations are of interest in geodesy for the calculation of the ellipticity, or flattening, of the earth. Peirce contributed to this problem of geodesy by making several calculations of the ellipticity from results of observations with pendulums. Professor Theodor von Oppolzer, who supervised operations with a Repsold apparatus in Austria, presented an extensive report on apparatus for determining gravity to the General

Conference in Rome in 1883, and cited Peirce's important contributions to the field.

At the height of his activity in the fields of astronomy, gravimetry, spectroscopy, and geodesy, Peirce published in the *Popular Scientific Monthly* in 1877—1878 his famous series of papers, "Illustrations of the Logic of Science.". In his paper, "How To Make Our Ideas Clear", he stated the pragmatic criterion of meaning which is generally acknowledged to be the origin of the philosophy of Pragmatism. The rule is: "Consider what effects, which 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." Since gravity is manifested by the weight of a body, and is the object of determinations by observations on the oscillations of a pendulum, it is quite understandable that Peirce should illustrate his criterion by a discussion of the concept of force as exemplified by the weight of a body. He explains the parallelogram of forces in the manner of a teacher of physics lecturing to an elementary class.

It would appear that Peirce's pragmatic rule for the clarification of ideas was the outcome of reflection upon his experimental and theoretical work in physical science.

In the Nineteenth Century, quantitative science, which requires exact standards of weights and measures, was given a firm foundation by the establishment of the International Bureau of Weights and Measures in the Pavillion de Breutil, Sèvres, France. In accordance with his pursuit of the foundations of knowledge, Peirce concerned himself with the establishment of standards for the United States which was a responsibility of the Coast Survey. On returning home from Europe in August, 1876, he brought a line-meter which had been standardized by the Imperial Standards Commission in Berlin. Since metal bars are subject to spontaneous alterations in length, Peirce undertook to standardize a meter in terms of a wave length of light. His work on the spectrum-meter led to a theoretical and experimental explanation of "ghosts" in diffraction spectra. On a mission to Europe in 1883, Peirce compared, for the Office of Weights and Measures, a United States Standard Yard, Low-Moor Iron Yard No. 57, with the British Imperial Standards, at the Board of Trade in London. He was for a period in charge of the Office of Weights and Measures of the United States Coast and Geodetic Survey, and on January 24, 1885, he testified before a Commission of Congress on behalf of an expanded office of weights and measures for the United States.

III

While Peirce was engaged on his final reductions for his researches on gravity, he began the composition of a series of papers which appeared in *The Monist*, 1891—1893. In his paper, "The Doctrine of Necessity Examined," he set forth his doctrine of Tychism, a formulation of indeterminism in natural phenomena. One may conjecture that prolonged consideration of errors of measurement in pendulum observations prompted him to advocate this departure from the then generally accepted Mechanical conception of nature. Peirce's decision for indeterminism is especially remarkable, in view of his recognition of the possibility of indeterminism in the initial conditions of a dynamical problem, the solution of which is to be obtained from the differential equations of motion of classical analytical dynamics, a field in which he had demonstrated his expertness.

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The preceding discussion may serve to present Charles S. Peirce in terms of his actual career: as a mathematician, astronomer, physicist, and geodesist; an earnest devotee of logic, who through reflections upon the concepts and methods of his scientific activity, was led to create new doctrines for philosophy: a theory of induction based upon the concept of probability, a pragmatic criterion of meaning as a forerunner of the operational theory of physical concepts, and an indeterminism in natural phenomena which has been cited by Professor Alfred Landé in support of probabilistic foundations of quantum mechanics. (4.)

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