Encyclopedia of Science and Religion

Philosophy of Science, History of

In tracing the history of the philosophy of science, it should be noted that philosophy and science were not clearly distinguished from each other until the early eighteenth century; furthermore, the philosophy of science, as a distinct subdiscipline, did not emerge until the nineteenth century. Nonetheless, almost from the beginning of philosophy, there were thinkers who reflected on the methods, aims, and epistemological status of inquiry into nature. In this respect, Aristotle (384–322 B.C.E.) is generally regarded as the first philosopher of science.

Ancient and medieval periods

Aristotle's views on the philosophy of science are primarily found in his *Posterior Analytics.* For Aristotle, genuine scientific knowledge has the status of necessary truth. This necessity comes from the fact that scientific explanations are to be demonstrations—that is, logical deductions from premises that are necessarily true. He argued that these premises must function as "first principles," which are primitive (they cannot themselves be demonstrated), known immediately, and known better than the conclusions. Each science, whether it be zoology or physics, has its own first principles. Aristotle thought that we come to know these first principles inductively through experience; that is, we can intuit or perceive the essences of things in our observations of nature.

In the Middle Ages, reflections on the scientific method were primarily focused on elaborations and criticisms of the views laid out in Aristotle's *Posterior Analytics* (which was reintroduced to Western scholars in the twelfth century). In the thirteenth and fourteenth centuries many scholars began to call into question Aristotle's assertion that scientific knowledge is demonstrative—that it, has the status of necessary truth. For many theologians, this assertion seemed to be in conflict with the doctrine of God's omnipotence and with revelation as the preeminent source of knowledge. The growing tension between Aristotelian natural philosophy and church doctrine led the Bishop of Paris, Etienne Tempier, in 1277 to issue a condemnation of 219 propositions. Among these were propositions relating to Aristotle's views that the world is eternal and that a vacuum is impossible. Both Pierre Duhem and the contemporary historian of science Edward Grant has argued that the condemnation of 1277 was an important stone in paving the way, not only for the scientific revolution, but for new philosophical views about the methods and epistemological status of science.

Early modern period

In 1620 Francis Bacon (1561–1626) published his *Novum Organum,* or *New Organon,* in which he laid out a new philosophy and methodology of science that he hoped would replace Aristotle's *Organon* (the name given to the collection of Aristotle's six books on logic and scientific method: *Categories, De Interpretatione, Prior Analytics, Posterior Analytics, Topics,* and *Sophistical Refutations*). Whereas Aristotle emphasizes deductions from necessary first principles, Bacon emphasizes induction as the central scientific method. Bacon was not, however, a naïve inductivist: He notes that impressions from the senses can be deceptive and that it is a bad induction to infer the principles of science through simple enumeration (*Novum Organum,* Book I, Aphorism 69). Bacon famously compares the proper scientist to a bee:

> Those who have handled the sciences have been either Empiricists or Rationalists. Empiricists, like ants, merely collect things and use them. The Rationalists, like spiders, spin webs out of themselves. The middle way is that of the bee, which gathers its materials from the flowers . . . but then transforms and digests it by a power of its own. (*Novum Organum,* Book I, Aphorism 95)

Bacon is often referred to as the father of experimental science. Instead of simply observing nature, Bacon advocates the use of experiments, which are skillfully thought out and framed for the purpose of inquiry. An important and controversial legacy of Bacon's philosophy of science is his notion of a crucial experiment or "instance of the fingerpost" (described in Aphorism 36 of Book II), which is designed to unambiguously decide in favor of one hypothesis or theory and refute another.

Although René Descartes (1596–1650), like Bacon, saw himself as providing a new epistemological foundation for science, in many respects his views on science were a return to the Aristotelian ideal of science as a set of deductions from necessary first principles. According to Descartes, these first principles are known not through observations, but by the "light of nature" that is given to us by God. Towards the end of his life, however, Descartes seemed to concede that this deductive ideal is unattainable.

Descartes's contemporary, Galileo Galilei (1564–1642), blended a Baconian emphasis on experimentation with a Cartesian emphasis on the importance of geometry for physics. In *The Assayer* he famously claims:

> Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometrical figures. (p. 238)

One of Galileo's most important contributions to the methodology of science is his use of idealization. As Ernan McMullin (1985) notes, Galileo uses not only mathematical idealization, but also a sort of causal idealization, whereby one considers nature not in its full causal complexity but in an idealized situation in which all but the causal line of interest have been eliminated. Whether the conclusions drawn from these "artificial" scenarios apply to nature in its full complexity as well was an issue of debate between Galileo and the Aristotelian natural philosophers.

Scientific Revolution

In the generation following Descartes, Christian Huygens (1629–1695) argues that the method of science differs distinctly from that of geometry and that the conclusions of science are, at best, highly probable. In the preface to his *Treatise on Light,* he argues for the hypothetico-deductive method in science. According to this method one first puts forward a hypothesis and then deduces from it certain observational predictions. If those predictions are born out then the hypothesis is rendered more probable.

Isaac Newton (1642–1727), by contrast, famously declared that hypotheses have no proper place in science—a declaration that was not entirely consistent with his practice. In the General Scholium to his *Principia* he writes, "I frame no hypotheses; . . . and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy" (p. 443). Instead, Newton advocates the method of analysis and synthesis, which he describes in Query 31 at the end of his *Opticks.* According to this method one begins with "analysis," which consists of making observations and experiments and then inductively drawing conclusions from them. Once one has these inductive generalizations in hand, the method of "synthesis" consists in using them in turn to explain the phenomena. Although Newton's name is often associated with the godless mechanistic worldview, Newton himself believed that blind necessity could not account for the diversity in the world (General Scholium). He furthermore believed that the uniform motions of the planets required the intervening maintenance of God. In Query 31 of the *Opticks* he writes:

> For it became him who created them [all material things] to set them in order. And if he did so, it is unphilosophical to seek for any other Origin of the World, or to pretend that it might arise out of Chaos by the mere Laws of nature. . . . [B]lind Fate could never make all the Planets move one and the same way in Orbs concentrick [sic]. (p. 402)

By the end of the eighteenth century an important shift had taken place, namely figures such as Huygens and Newton realized that the empirical sciences could at best yield probable knowledge; the ideal of scientific knowledge as certain knowledge came to be largely abandoned.

Early nineteenth century

In the early nineteenth century three important books were published on the philosophy of science: John Herschel's *A Preliminary Discourse on the Study of Natural Philosophy* (1830), William Whewell's *The Philosophy of the Inductive Sciences, Founded Upon Their History* (1840), and John Stuart Mill's *System of Logic* (1841). In Part I of his *Discourse* Herschel defends the study of natural philosophy (science) against the charge that it leads one to "doubt the immortality of the soul, and to scoff at revealed religion," arguing instead that it leads to the betterment of one's moral character and undermines atheism (section 5). In Part II of the *Discourse* he lays out three methods by which one can come to discover scientific laws: first, by inductive reasoning; second, "by forming at once a bold hypothesis . . . and trying the truth of it by following out its consequences and comparing them with facts" (section 210); and third, by a process that combines both. With regard to the second (hypothetico-deductive) method, Herschel notes "when a theory will bear the test of such extensive comparison, it matters little how it has been original framed" (section 220). Passages such as this have led the contemporary philosopher of science John Losee to attribute to Herschel the invention of the distinction between what Hans Reichenbach (1891–1953) would later call the "context of discovery" and the "context of justification."

Whewell (1794–1866) was the first philosopher of science to take the historical turn, arguing that the philosophy of science ought to reflect—and be a product of—a close historical examination of the practice of science. Despite this important insight, Whewell's own philosophy of science was probably to a greater extent shaped by the philosophies of Bacon and Immanuel Kant (1724–1804), than the history of science. Like Herschel, Whewell recognizes the important role that hypotheses play in science, though he thinks that these hypotheses are to be grounded inductively. Whewell sees his work as a renovation of the inductive method laid out in Bacon's *Novum Organum.* The most striking renovation was Whewell's (Kantian) claim that the mind supplies from within itself certain "fundamental ideas" that shape, and are a necessary precondition for, experience and the empirical knowledge on which the sciences are based. Whewell represents a surprising return to the claim that science aims for, and can obtain, the status of necessary truth. The contemporary philosopher of science, Laura Snyder, has cogently argued that these two aspects of Whewell's philosophy of science (fundamental ideas and empirical science as necessary truths) can be properly understood only in the context of his natural theology. Snyder explains:

> we are able to have knowledge of the world because the Fundamental Ideas which are used to organize our sciences resemble the Ideas used by God in his
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> creation of the physical world. . . . [T]he Divine origin of both our Ideas and our world is what enables Whewell to claim that axioms knowable a priori from the meanings of

> our Ideas are informative about the empirical world, and necessarily true of it. (p. 796)

In 1833 Whewell contributed his "Astronomy and General Physics Considered with Reference to Natural Theology" to the well-known Bridgewater Treatises.

John Stuart Mill (1806–1873) debated Whewell on the nature of induction in science. In Book II, chapter 5 of his *System of Logic* Mill rejects Whewell's claim that science can obtain the status of necessary truths. Mill writes:

> I may have seen snow a hundred times and may have seen that it was white, but this cannot give me entire assurance even that all snow is white, much less that snow *must* be white. However many instances we may have observed of the truth of a proposition, there is nothing to assure us that the next case shall not be an exception to the rule . . . experience cannot offer the smallest ground for the necessity of a proposition. (pp. 155–156)

Here it is clear that Mill is squarely in the empiricist tradition of David Hume (1711–1776) and is construing induction narrowly as induction by simple enumeration. Mill's best known contribution to the philosophy of science is his four methods of experimental inquiry (typically referred to as "Mill's Methods" though, as Losee and others have noted, they can be found in the works of earlier medieval natural philosophers) described in chapter 8 of Book III of *System of Logic.* They can be summarized as follows:

- Method of Agreement: If two or more instances of the phenomenon have only one circumstance in common, the circumstance in which the instances agree is the cause of the phenomenon.
- Method of Difference: If an instance when the phenomenon under investigation occurs and an instance in which it does not occur have every circumstance in common save one, then that circumstance by which they differ is the cause (or an indispensable part of the cause) of the phenomenon.
- Method of Residues: Subtract from any phenomenon those parts that are known to be the effect of certain antecedent causes; the remaining part of the phenomenon (the residue) is the result of the remaining antecedents.
- Method of Concomitant Variations: Whatever phenomenon varies when another phenomenon varies is either a cause, or an effect of that phenomenon or is causally related to it some way (e.g., both the product of a common cause).

Late nineteenth and early twentieth centuries

New challenges to the English inductivist tradition came from the French physicist and historian of science Pierre Duhem (1861–1916). Duhem argues that physics is subject to certain methodological limitations that do not affect other sciences. In his book *The Aim and Structure of Physical Theory* (1914) Duhem provides a devastating critique of Baconian crucial experiments. According to Duhem, an experiment in physics is not simply an observation, but rather, is an interpretation involving a theoretical framework. Furthermore, no matter how well one constructs one's experiment, it is never a single hypothesis that faces an experimental test. Instead, it is a whole interlocking group of hypotheses, background assumptions, and theories. This thesis has come to be known as *holism.* According to Duhem, it is this holism that renders crucial experiments impossible. More generally, Duhem is critical of Newton's description of the method of physics as a firm and straight forward "deduction" from facts and observations.

In the appendix to *The Aim and Structure,* entitled "Physics of a Believer," Duhem draws out the implications that he sees his philosophy of science as having for those who argue that there is a conflict between physics and religion. He writes, "metaphysical and religious doctrines are judgments touching on objective reality, whereas the principles of physical theory are propositions relative to certain mathematical signs stripped of all objective existence. Since they do not have any common term, these two sorts of judgments can neither contradict nor agree with each other" (p. 285). Nonetheless, Duhem argues that it is important for the theologian or "metaphysician" to have detailed knowledge of physical theory in order not to make illegitimate use of it in speculations.

This separation of physics from metaphysics that Duhem describes is characteristic of the positivist movement founded by Auguste Comte (1798–1857) and developed by the Austrian physicist and philosopher Ernst Mach (1838–1916). Mach's philosophy can be characterized as a form of sensationalism, according to which the world consists not of things, but sensations. In other words, an object, such as an apple, is nothing but a composite of various elements of sensations: red, round, crunchy, and sweet; and talk about apples is really just an economical way of talking about collections of sensations. Indeed, all scientific theories, for Mach, are just economical ways of talking about sensations. Mach's elements of sensation are neither subjective, nor purely mental: Sensations can also be considered physical in so far as they depend in various ways on each other. Although this view may be reminiscent of Bishop George Berkeley's (1685–1753) idealism (the view that there are no material substances—only ideas and the minds that contain them), Mach explicitly distinguishes his view from both Berkeley and Kant: "Berkeley regards the 'elements' [of sensation] as conditioned by an unknown cause external to them (God); accordingly Kant, in order to appear as a sober realist, invents the 'thing-in-itself'; whereas, on the view which I advocate, a dependence of the 'elements' on one another is theoretically and practically all that is required" (pp. 361–362). Mach sees sensationalism as providing a framework in which to unify the newly emerging psychological sciences with the physical sciences. Both progress and unification require eliminating all concepts in physics that do not correspond directly to sensations (i.e., eliminating all metaphysical concepts). On these grounds, Mach famously denied atomism, which he took to be an unnecessary metaphysical assumption. Mach's philosophy—in particular, his rejection of metaphysics and concern for the unity of science—greatly influenced the founders of the Vienna Circle.

Henri Poincaré (1854–1912) was a French physicist, mathematician, and philosopher. In the preface to his *Science and Hypothesis* (1902) he distinguishes three kinds of hypotheses in science: "some are verifiable, and when once confirmed by experiment become truths of great fertility; . . . others may be useful to us in fixing our ideas; and finally, . . . others are hypotheses only in appearance, and reduce to definitions or to conventions in disguise" (p. xxii). It is his defense of this third kind of "hypothesis" that makes Poincaré's philosophy of science a form of conventionalism. While he does not think that all of science is a matter of convention, he does take the geometry of space and certain principles of mechanics to be simply stipulated, rather than discovered. By saying that something is conventional, Poincaré does not mean that it is arbitrary—there are certain constraints and consequences that come with fixing a convention. For example, although neither logic nor experience forces us to accept Euclidean geometry, rather than non-Euclidean geometry, as the correct description of our space (i.e., it is a free choice), choosing to adopt one geometry rather than another will require us to adjust our physical theories in certain ways (e.g., will require introducing new forces). Despite his conventionalism, Poincaré adopts a realist stance toward science. He writes, "we daily see what science is doing for us. This could not be unless it taught us something about reality; the aim of science is not things themselves . . . but the relations between things" (p. xxiv). This has led some contemporary philosophers to attribute to Poincaré the first expression of a view known as structural realism. Poincaré concludes the preface to his book by noting, "No doubt at the outset theories seem unsound, and the history of science shows us how ephemeral they are; but they do not entirely perish, and of each of them some traces still remain. It is these traces which we must try to discover, because in them and in them alone is the true reality" (p. xxvi). While Poincaré's remarks may or may not be true of the history of science, they do seem to be true of the history of philosophy of science.

See also PHILOSOPHY OF SCIENCE; SCIENCE AND RELIGION, HISTORY OF FIELD

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ALISA BOKULICH


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