Robert Boyle | Encyclopedia.com

Complete Dictionary of Scientific Biography COPYRIGHT 2008 Charles Scribner's Sons
118-150 minutes

Boyle, Robert

(*b*. Lismore, Ireland, 25 January 1627; *d*. London, England, 30 December 1691)

natural philosophy, physics, chemistry.

The son of Richard Boyle, first earl of Cork and a great Elizabethan adventurer, and his second wife, Katherine Fenton, Robert Boyle was born to considerable affluence and was related, by blood or marriage, to all the great Anglo-Irish families of his day. He was the youngest son in a family of fourteen children. At the age of eight, after private tuition at home, he was sent for several years to Eton, which the sons of gentlemen were just beginning to attend, and then, at the age of twelve, to the Continent with his next older brother, Francis, later Lord Shannon. There a citizen of Geneva tutored him privately in the polite arts, the conventional subjects of a liberal education, and practical mathematics; then, or in the course of his subsequent travels, he was introduced to the new science, including Galileo's *Dialogue on the Two Chief World Systems*, which he read in Florence in 1642.

The outbreak of the Anglo-Irish wars, as well as the Civil War in England, led to his return home. Although his father was a Royalist, Boyle was persuaded by his elder sister, Katherine, Lady Ranelagh, a strong Parliamentarian (as befitted a friend of John Milton), to look favorably on the Parliamentary side. Lady Ranelagh also introduced him to Samuel Hartlib, who seems to have turned his interests to medicine and such practical matters as agriculture. Medicine led him to chemistry, at first for the preparation of drugs; but he soon became not only a skillful chemical experimenter but also an original chemical thinker. He read the chemists who wrote in English, French, or Latin, as well as the most important writers on other sciences. His early interest in astronomy persisted for a time but, under the combined influence of Bacon and Descartes, he soon turned to wider problems. Soon his point of view, except for his belief that chemistry was an important *physical* science (not merely a practical art or a mystic science), coincided with that of the leaders of the English scientific movement (such as John Wilkins, John Wallis, and Seth Ward), whom he joined at Oxford about 1656.

After the Restoration, Boyle was frequently in London, finally settling there in 1668. He was one of the founders of the Royal Society and throughout his life was its most notable and influential fellow. He was active in Irish affairs, was (from 1661) governor of the Society for the Propagation of the Gospel in New England, and had some connection with the Court. His lodgings (in his sister's house) were always open to visitors, and his laboratory became a center for research. In spite of frequent ill health he was continuously active in scientific endeavors, and with the aid of assistants (many of whom later became famous scientists) he experimented until his final illness. He was a prolific author, writing on science, philosophy, and theology.

Although Boyle's first scientific interest was chemistry, his first published scientific book, the one that established his fame, was on pneumatics: *New Experiments Physico-Mechanicall, Touching the Spring of the Air and its Effects* (1660). Three years earlier he had learned of Guericke's invention of an air pump and, immediately perceiving the scientific potentialities of the instrument, set his laboratory assistants to work designing one that had a glass receiver and was so constructed that objects could be easily inserted. Robert Hooke's successful design permitted Boyle to devise and carry out a brilliant series of experiments upon the physical nature of air: he proved that the phenomena of Torricelli's experiment were indeed caused by the air, that sound was impossible in a vacuum, that air was truly necessary for life and flame, and that air was permanently elastic. In an appendix to the second edition of *New Experiments* (1662), he developed this last discovery into a quantitative relationship (that volume varies inversely with pressure), rightly called Boyle's law; here he also endeavored to refute several critics (including Hobbes and the English Jesuit Francis Linus) who tried to defend and uphold the old. Scholastic view that there was no such thing as a vacuum and that some mysterious force, rather than atmospheric pressure, was responsible for the phenomena associated with suction pumps and syphoning.

At intervals throughout his life, Boyle published further accounts of the experiments *in vacuo* that he never tired of devising and that he alone, among the scientists of his day, was capable of devising without cessation. Perhaps the most influential of these experiments were those showing that many fruits and vegetables contain air (actually carbon dioxide), which they give off during fermentation—the eighteenth-century chemist's "fixed air." Although Boyle's reputation in experimental physics rests on his pneumatic experiments, he also worked in the related field of hydrostatics. His *Hydrostatical Paradoxes* (1666) is both a penetrating critique of Pascal's work on hydrostatics, full of acute observations upon Pascal's experimental method, and a presentation of a series of important and ingenious experiments upon fluid pressure.

The air pump experiments showed Boyle to be a confirmed opponent of Aristotelian and Scholastic physics, as well as an able and original experimental physicist. His scientific associates knew him better as a profound believer in the need to establish an empirically based, mechanistic theory of matter and in the possibility of establishing a scientific, rational, theoretical chemistry by means of just such a theory of matter. In 1660 he had already partially prepared a series of treatises upon both subjects, and he occupied himself for the rest of his life with experiments and arguments furthering these beliefs. His first published declaration of his positions appeared in 1661 in *Certain Physiological Essays*, a work whose arguments were somewhat obscurely supported by the now better known *Sceptical Chymist*, which was published later in the same year; both had circulated among scientists in earlier, manuscript versions.

Certain Physiological Essays made plain Boyle's decided support for the particulate theories of matter then slowly displacing the Aristotelian view of the joint role of matter and form. Boyle was long remembered as "the restorer of the mechanical philosophy's in England, and he regarded his corpuscularian philosophy as an original and useful theory of matter. He had been familiar with Epicurean atomism since boyhood, when he read Diogenes Laertius' *Lives of the Philosophers;* he now read the extant writings of his contemporaries, like Gassendi's brief *Epicuri philosophiae Syntagma* (1649) and Walter Charleton's *Physiologia Epicuro-Gassendo-Charletoniana* (1654). He was, however, too devout to be a true Epicurean and too aware of the developments of contemporary science—to which he was, moreover, contributing fully—to accept any attempt to apply literal Epicureanism to the current scientific scene. Like all his contemporaries, he was familiar with Democritean atomism as confuted by Aristotle, but it had the same disadvantages as Epicureanism.

What really influenced him first were Bacon's suggestive outlines of the possibilities of an empirically based particulate theory of matter (principally in *Novum organum*, 1620), and Descartes's ambitious outline of a completely mechanistic and logical particulate view of the universe (in *Principia philosophiae*, 1644). From Bacon, he learned to regard heat as a mode of motion of the least particles of matter; he also learned to believe that experiment could lead one to demonstrate, and possibly to prove, the existence of such particles, and that it could further aid in the deduction of how the shape and motion of the particles could provide an explanation of the observed properties of bodies.

Similarly, Boyle took many specific explanations of the properties of matter from Descartes—for example, the view that solidity and fluidity depend upon the amount of relative motion of the constituent particles, the particles of solids being relatively quiescent—although he rejected Descartes's detailed structure of particles, particularly the omnipresent Cartesian ether, for which he could find no experimental justification. He was also enormously influenced by the commanding scope of Descartes's great system of the world, built logically from a few definitions of matter and laws of motion.

Boyle was an eclectic; what mattered most to him was destroying all Aristotelian forms and qualities—semantic explanations at best, such as the "form of heat" or "the dormitive virtue of opium"—and substituting for them rational, mechanical explanations in terms of what he called "those two grand and most catholic principles, matter and motion".

"Mechanical", to Boyle and his contemporaries, was always in opposition to both "Aristotelian" and "mystical", mechanical explanations were rational and also, inasmuch as they dealt with particles of matter and their motion, consonant with the newly formulated laws of mechanics. It was, Boyle insisted, no derogation of God's majesty to compare His creative power to that of a watchmaker, the creator of the most elaborate mechanism known to the seventeenth century. Boyle's first aim in *Certain Physiological Essays;* in the more elaborate *Origine of Formes and Qualities (According to the Corpuscular Philosophy)*, published in 1666; in the detailed and specific *Experiments, Notes &c. About the Mechanical Origine or Production of Divers Particular Qualities*, published in 1675; and in numerous other minor treatises was to refute the older Scholastic or Aristotelian view and establish the mechanical one in its place. His second aim was to show that this was best done by the use of experiment, and he devoted great care and ingenuity to devising (and conducting) experiments that should demonstrate the nonexistence of the supposed "substantial forms" and "real qualities" and the positive existence of particles whose size, shape, and motion could easily and rationally account for the observed behavior and properties of matter. The many experiments with which his works are filled made them useful even to those who did not accept his conclusions, and such experiments as those demonstrating the mechanical production of heat and magnetism can still command admiration. Since Boyle rejected both the atoms of the Epicureans and the complex hierarchy of particles of Descartes, preferring the neutral word "corpuscle", his discussions were, as he hoped, acceptable and convincing to all mechanical philosophers, whatever theory of matter they chose to espouse.

No one except a dedicated Aristotelian could fail to find Boyle's arguments powerful and convincing; the only question was whether the immense labor of the experimental approach was worthwhile or not. Such rationalists as Huygens and Leibniz were inclined to doubt the value of demonstrating by experiment what they (and all "rational" thinkers) knew to be true by logical resonating. In 1662 and 1663 Boyle conducted (through Henry Oldenburg, who often acted as his editor and literary agent) a long dispute with Spinoza on the question of whether experiment could provide *proof:* to Spinoza, only logical thought could provide the conviction that Descartes had taught the philosophical world to regard as proof, while experiment could only confirm or (possibly) refute; to Boyle, experiment was an essential ingredient of proof, and logical argument merely meant the employment of a priori hypotheses. This was an important difference in scientific method in the seventeenth century; although Boyle at first had few disciples, his eventual influence in this respect was very great—one of his firmest followers was Isaac Newton, a careful and impressionable student of Boyle's works.

Boyle's recognition of the complexities of the experimental approach was very rare in his day. Few before him had realized that empiricism required technique and the working out of methodical procedure. One reason for the now tedious length of most of his treatises was his desire to describe his expriments faithfully and in such a way that others could follow. He also was always careful to describe experiments that did not succeed, a procedure he defended in two of *Certain Physiological Essays* as essential to progress in experimental philosophy. Nonempiricists might very reasonably find all this tiresomely prolix, but heuristically it was important and influential. Through his writing on his experiments, Boyle helped establish the experimental method in many branches of physics and chemistry.

Successful though Boyle's empirically based corpuscular philosophy was, it was not without its weaknesses and failures. He was always reluctant to antagonize those with fixed convictions, and therefore was often inclined to avoid committing himself to a definite and limiting view. Thus, he never satisfactorily described his own explanation of the cause of air's elasticity, although he wrote about the problem on many occasions; indeed, he went so far in his first book on the air pump as to cite the analogy, originated by the anatomist Jean Pecquet, between air particles and coils of raw wool, an analogy that he almost certainly did not accept as an explanation. Yet readers of only this book cannot know of his later doubts, hesitations, and tentative suggestions for a more satisfactory explanation. (In fact, he seems to have held that the elasticity was caused by a combination of the shape of the particles and their motion.)

Again, although he made it very clear that he regarded the cause of heat as nothing more than the vibratory motion of particles, he never clearly defined cold as mere absence of motion, even in the special treatise he wrote on the subject, *New Experiments and Observations Touching Cold* (1665), which has very valuable discussions of thermometry and of freezing mixtures. He also spoke ambiguously on the nature of light and fire; and his conviction that all properties must ultimately reside in the properties of particles gave him curiously mixed results when, in his *Experiments and Considerations Touching Colours* (1664) he tried to understand what made matter appear colored. Whiteness and blackness (the nearly total reflection and nearly total absorption of light, respectively) he understood thoroughly and illustrated brilliantly with what came to be considered classic experiments, such as noting the effects of white and black cloths laid on snow on a sunny day. He also observed the colors on soap bubbles and thin glass surfaces ("Newton's rings"). But he did not understand the relation of light and color, nor did he try to explain this relation or the prismatic colors in terms of modification of light; rather, he thought of light as having a physical constancy and color as being the result of an action by the material particles of bodies. In fairness, however, it must be noted that Boyle appreciated the treatment accorded light by Hooke in his *Micrographia* (1665) and by Newton in his papers on light and colors (1672, 1675), and recognized their superiority to him in optics.

It was not surprising that Boyle regarded extraordinary effects such as optical phenomena as the result of the configuration of particles, for he was, after all, a chemist as well as a physicist; and chemistry had been the first science he thoroughly mastered. He was a practiced and devoted technical chemist in his twenties, whereas he came to experimental physics (in the form of pneumatics) only at the age of thirty. It is true that many of his ideas on the nature and structure of matter were formulated before he began work on the air pump, but it becomes apparent, if one studies his work chronologically, that his first approaches to this subject were chemical. Indeed, his first specific publication on the corpuscular theory of matter, *Certain Physiological Essays*, also contains his first published account of chemical experiments. This is the complexly titled third essay: "Some Specimens of an Attempt to Make Chymical Experiment Usefull to Illustrate the Notions of the Corpuscular Philosophy", with the subtitle "A Physico-chemical Essay, Containing an Experiment Touching the Differing Parts and Redintegration of Salt-Petre"; the body of the essay was subsequently referred to by Boyle as "The Essay on Nitre". This, as he indicated, was an attempt to use a purely *chemical* experiment (the conversion of niter—KNO_3—to its seemingly component parts by means of a glowing lump of charcoal and its subsequent reconstitution from the fixed and volatile parts) to demonstrate the strong probability of the existence of particles that could persist through physical and chemical changes. Boyle recognized this as a novel approach, and also saw it as an attempt to show chemists that the physicist's approach, the employment of the mechanical philosophy, might be useful to chemistry; for he considered that it contributed much to an understanding of the reaction involved if one thought in terms of particles (whether simple or complex). He expressly stated in the preliminary discussion that he hoped "to beget a good understanding 'twixt the chymists and the natural philosophers", a lifelong desire only partially achieved.

It is difficult to realize how confused and confusing chemical reactions appeared before chemists thought in corpuscular terms. Chemistry in Boyle's day still applied a sort of Aristotelian plenum: the only possibility of breaking down such a substance as niter was to resolve it into its component elements. Seventeenth-century elements, like the Greek elements but unlike nineteenth-century elements, were not merely the simplest bodies into which chemical substances could be analyzed or resolved; they were also the necessary ingredients of all bodies, the substances into which all bodies were analyzable. Thus, if salt was taken to be an element, then salt was present in all bodies and would appear as a product of rigorous analysis. Boyle not only thought that corpuscles were the only things universally present in all bodies; but he also suspected that none of the n accepted elements—whether the earth, air, fire, and water of the Aristotelians; the salt, sulfur, and mercury of the Paracelsans; the phlegm, oil, spirit, acid, and alkali of later chemists—was truly elementary, as the term was then understood. He tried to explain all this in the *Sceptical Chymist*, a curiously literary piece of polemic that is much misunderstood in modern times. Here, in spite of what is commonly said, Boyle did *not* give a modern definition of an element, but (specifically and intentionally) a clear definition of an element as it was understood in his day. The work is cast in a decidedly turgid dialogue form, perhaps in imitation of Galileo, perhaps merely as a relic of Boyle's youthful literary proclivities; its chief value in its day, aside from its main message, was the wealth of chemical experiment that, like the "Essay on Nitre" showed the chemist how to employ corpuscular terms in chemical explanation and also presented new chemical facts. For, prolific experimenter that he was, Boyle almost always found new chemical combinations and reactions, as well as a few new chemical substances; the best-known of these is hydrogen, which he prepared from steel filings and strong mineral acid, but there were also various copper and mercury compounds. Unlike other chemists of his day, he never stressed the novelty of such preparations, for it was the reactions and their interpretation that interested him.

Convinced as he was that the term *element*, as used in his day, was an erroneous and misleading concept, Boyle never approached the modern definition, which emerged during the eighteenth century as the influence of his teaching helped to weaken the older view. He seems not to have felt the need of any elements other than corpuscles; in this he was perhaps, as some of his contemporaries complained, too much a physicist and too little a chemist in his mode of thought. But this skepticism did not prevent him from recognizing at least some classes of substances by a method and in a fashion far more useful to chemistry than the old notion of element had been. Characteristically, he arrived at this classification empirically and as an outgrowth of a combination of physical and chemical investigations.

The color changes observed in the course of chemical reactions had always interested Boyle, especially since he thought they showed how evanescent and unreal Aristotelian forms really were; in the *Sceptical Chymist* he described many reactions involving color changes. He went further in *Experiments and Considerations Touching Colours*, for here he not only described various ways of producing color changes, such as the conversion of a blue vegetable solution to red or green, but he also emphatically indicated a *use* for these color changes: chemical classification and identification. It had long been known that some acids turned the blue syrup of violets red; Boyle claimed to be the first to realize that all acids did so and that those substances that did not do so were not acids—a bold but useful distinction. Similarly, he claimed to be the first to note that alkalies—all alkalies—turned syrup of violets green. This left him with three classes of salts: acid, alkali, and those that were neither. He reinforced this empirically derived classification by observing that the blue opalescence of the yellow solution of *lignum nephriticum* (a South American wood with supposed medical virtues and of considerable optical interest) was destroyed when the solution was acidified and could be restored by the addition of alkali; he also used this reaction to determine the relative strength of acidic and alkaline solutions.

These tests also allowed Boyle to determine the purity of chemicals bought from apothecary shops. He discovered a further useful color change when he demonstrated (what he claimed to have deduced) that different alkalies give differently colored precipitates with mercury sublimate (mercuric chloride); “vegetable alkalis” (potassium carbonate and possibly sodium carbonate) give an orange precipitate (a form of mercuric oxide), while “animal alkalis” (ammonia compounds) give a white precipitate (ammonium-mercury chloride). Since limewater was already known to turn cloudy when a solution of niter was added, Boyle now had the ability to distinguish among all the common alkalies.

The importance of these tests, upon which Boyle placed absolute reliance, was very great, for in the late seventeenth century there was still great confusion over the identity, not to mention the composition, of various simple substances. He found it necessary on the one hand to insist that all salts were not common salt, but on the other that salt of tartar, hartshorn, and vegetable alkali were all one salt—a point not always appreciated by his contemporaries. Many chemists of his day insisted upon sweeping generalizations like that of the acid-alkali hypothesis (which claimed that all substances were either acids or alkalies, and all reactions therefore were neutralizations), or carelessly confused end products with starting materials.

Boyle was unique in realizing the continual need for meticulous care in examining purity, testing composition, and searching for chemical differences and similarities. How methodical he could be is amply demonstrated in his two investigations into the nature of phosphorus, *The Aerial Noctiluca* (1680) and *New Experiments and Observations Made Upon the Icy Noctiluca* (1682), in the course of which he discovered the chief chemical and physical properties of phosphorus and phosphoric acid, and in *Short Memoirs for the Natural Experimental History of Mineral Waters* (1685), an admirable set of analytical directions. Few other chemists of his day seem to have been sufficiently patient to elaborate an analytical procedure, although it became commonplace in the next century.

To his work on acids and alkalies Boyle added a host of other specific tests: for copper by the blue color of its solutions; for silver by its ability to form silver chloride, with its characteristic blackening over time; for sulfur and various mineral acids by their characteristic reactions. Some of these were new, others had been known for years or even centuries. These tests enabled him to discuss the composition of substances in what can only be called positivistic terms—that is, in terms of empirically determined components rather than in terms of metaphysical, a priori “elements.” This was perhaps Boyle’s greatest contribution to chemistry, for while few chemists followed him in altogether dispensing with elements, most chemist saw the utility of distinguishing in analysis between empirically verifiable components and a priori elements. When this occurred generally, the way lay open for the immense strides to be made in analytical chemistry in the eighteenth century. And although it was quite possible to practice this sort of chemistry without paying more than lip service to the corpuscular philosophy (a physicist’s theory, after all), there is no doubt that Boyle was helped by his adherence to the corpuscular philosophy, and perhaps would never have formulated his new chemical method without his habit of thinking in corpuscular terms. And it is not without significance that this more physical way of approaching chemistry was introduced into France by William Homberg, who worked for some time in Boyle’s laboratory.

In his lifetime Boyle was honored not only as an original chemist and physicist, a great exponent of English experimental philosophy, and a pillar of the Royal Society, but also as a prolific writer on natural theology, the point where religion and science met. He was a truly devout man and scrupulous to the point of having a tender conscience where oaths were concerned, as he explained in declining to serve as president of the Royal Society in 1680—presumably because he thought he might be subject to the provisions of the Test Act, as a public officer. Yet he was not dogmatic, and he was a devoted scientific investigator. Fortunately, he experienced no conflicts of conscience; for him a God who could create a mechanical universe—who could create matter in motion, obeying certain laws out of which the universe as we know it could come into being in an orderly fashion—was far more to be admired and worshiped than a God who created a universe without scientific law.

Boyle's God stands in the same relation to the watchmaker as the watchmaker might to an untutored savage who thinks a watch is a living creature because its hands move. Boyle never tired of writing on this subject, finding his thoughts becoming more devout the more he studied the wonders of nature. Not all his numerous books on religious subjects were an offshoot of his scientific endeavors, but many were, and it was these that were influential. At his death Boyle left a sum of money to found the Boyle lectures (really sermons), intended for the confutation of atheism; and his contemporaries immediately concluded that he meant the arguments against atheism to be drawn from the scientific advances of his day. Hence the first and most famous series of Boyle lectures, by Robert Bentley, was filled with arguments and illustrations drawn from Bentley's discussions with Newton. Subsequent Boyle lectures (by Clarke, Whiston, Woodward, Derham, and others) followed this pattern to produce what is thought of as a characteristically eighteenth-century form of "natural" religion, much less formal and theological than anything usual in Boyle's day.

In this, as in so much else, Boyle set the tone and inspired the methods of thought widely accepted by the next two generations. In large part this was so because eighteenth-century Newtonians found that Boyle's opinions, discoveries, and scientific method usefully supplemented those of Newton. Modern historians see this as a sign of Boyle's very real influence upon Newton; Newtonians saw it as a proof that the "new science" was a product of the English methods proclaimed in the charter of the Royal Society.

BIBLIOGRAPHY

The standard edition of Boyle's works is Thomas Birch, ed., *The Works of the Honourable Robert Boyle*, 5 vols. (London, 1744), 2nd ed., 6 vols. (London, 1772); available in a facs. repr. Separate works are *The Sceptical Chymist* (London–New York, 1911, and later eds.) and *Experiments and Considerations Touching Colours* (repr. New York, 1964). John Fulton, *A Bibliography of the Honourable Robert Boyle*, 2nd ed. (Oxford, 1961), is a complete bibliography of works by Boyle and of secondary sources to 1960. M. B. Hall, ed., *Robert Boyle on Natural Philosophy* (Bloomington, Ind., 1965), contains an introductory discussion of his work and long illustrative excerpts from his writings. Boyle's manuscripts are preserved chiefly in the archives of the Royal Society. Many letters to Boyle are published in Birch's edition cited above; his letters to Oldenburg are published in A. R. and M. B. Hall, eds., *The Correspondence of Henry Oldenburg* (Madison, Wis., 1965–).

Marie Boas Hall

Boyle, Robert

(*b*. Lismore, Ireland, 25 January 1627; *d*. London, England, 30 December 1691),

natural philosophy, physics, chemistry. For the original article on Boyle see *DSB*, vol. 2.

The landscape of the history of science has changed dramatically in the years since the original *DSB* was published, and Boyle has been at the center of a seismic shift resulting from a new emphasis on intellectual traditions formerly written off as marginal and on broader social and cultural factors once dismissed as irrelevant to the growth of scientific ideas. Marie Boas Hall's article is succinct and at times brilliant; it was a model account of Boyle according to the terms of reference that prevailed when it was written. Much of its content still stands and need not be recapitulated here, including its account of Boyle's pneumatics, his appetite for the experimental vindication of the mechanical philosophy against the prevailing Aristotelian orthodoxy, and his empirical investigations of colors, salts, and the like. At the same time, the article needs to be significantly supplemented on aspects of Boyle's ideas and milieu that it neglected, and the result is to give a markedly different overall picture of Boyle.

Sources. In Boyle's case, revaluation is also required because the materials on which studies of him are based have radically changed since 1970. Boyle's massive archive at the Royal Society was cataloged for the first time in the 1980s and has since been fully exploited, with the result that a number of studies and editions have appeared based on hitherto unknown material in it. In addition, a new edition of Boyle's *Works*, published in 1999–2000, has replaced the eighteenth-century edition by Thomas Birch on which Hall was dependent. This offers a more accurate text of Boyle's published writings, with a full apparatus lacking from Birch's edition that describes the history of the composition and publication of each book, including the Latin translations that Boyle had made to ensure that his ideas reached an international audience. In addition, it makes available for the first time a number of previously unpublished texts by Boyle, some of the most important of these dating from his early life and hence illustrating the formative period of his career as a writer. These early writings have received intensive scrutiny, resulting in an awareness of a period of Boyle's life when he saw his role as that of a moralist and attempted to write in the style of the French romances by which he was strongly influenced. Only in about 1650, it appears, did he turn to science, and even when he did so his earlier moralistic concerns and literary aspirations left a significant legacy.

The new edition of Boyle's *Works* is accompanied by a complete edition of his *Correspondence*, superseding the selection of letters included by Birch in his edition, and this too gives a somewhat different view of Boyle from that available hitherto, not least because of its inclusion of many letters on alchemical and other topics that Birch omitted; other letters reveal the teeming underworld of minor virtuosi with whom Boyle interacted, giving more of a sense of the texture of the science of the day than was evident from Birch's rather partial selection. Indeed, it turns out that even more such material once survived but has been lost, in at least some cases because of the disdain of Birch and his collaborator, Henry Miles, whose idealized view of Boyle has influenced evaluations of him ever since.

Alchemy and Speculative Science. Undoubtedly the most dramatic element in the revaluation of Boyle by comparison with the image of him presented in the original *DSB* concerns his interest in alchemy. This goes back to the earliest phase of Boyle's scientific activity in the early 1650s, when he was mentored by the American alchemist George Starkey, who introduced him to the ideas of the Flemish iatrochemist Joan Baptista van Helmont, a figure whose crucial influence on Boyle and his contemporaries is now clear, although ignored in more traditional histories of science. In Boyle's case, Starkey seems to have introduced Boyle to Helmontian practices of quantification and compositional analysis as key elements in his chemical method, while he also showed him how to make the Helmontian drug *Ens veneris* and a philosophical mercury.

The latter remained of absorbing interest to Boyle throughout his career, during which it is clear that he engaged in alchemical activities of quite an arcane kind and sought contact with other practicing alchemists to a much greater extent than had hitherto been acknowledged. In fact, far from the antipathy to "mystical" writers implied by Hall in her article, Boyle had a great respect for adepts whose penetration of the secrets of nature he hoped to emulate; it was only for "vulgar chymists" of the textbook tradition that he showed disdain in his *Sceptical Chymist* (1661). Though Boyle's alchemical interests mainly have to be reconstructed from manuscript sources, he brought out two publications on such topics in the late 1670s, his article in *Philosophical Transactions* on the incalescence of mercury and his tract on the "degradation" of gold published in 1678.

Other published writings also show an interest in aspects of "chymistry" that might at one time have seemed inappropriate in a figure such as Boyle, including his *Producibleness of Chymical Principles* of 1680, and Hall's own insight that Boyle was a chemist before he was a physicist can now be taken much further, in that it seems likely that he considered that corpuscles were endowed with chemical, as against strictly mechanical, principles, and that the texture of bodies might vary regardless of the shape and size of the corpuscles that they comprised. Also revealing are some of the shorter treatises that Boyle published in the early 1670s, in which he divulged speculative ideas that had often been merely the subject of asides in the more substantial and better-known works of the 1660s on which Hall's account mainly focused. Thus Boyle considered the possibility that the universe might contain "cosmical qualities" that transcended purely mechanistic laws, or that there were "seminal principles" in the plant, animal, and mineral kingdoms.

Other notions that were to prove influential included his view of the potency of "effluvia" emanating from the earth that affected health and other aspects of human life; his interest in the life-giving properties of salts; and his speculations on such topics as the nature of the seabed and the temperature of the subterranean regions. Such writings were often based on information he learned from travelers and others, of which he kept extensive notes in his "workdiaries," compendia in which such data rubbed shoulders with experimental findings; these also included accounts of "supernatural" phenomena, on which he

explicitly solicited information in order to vindicate the reality of divine or other spiritual interventions in the world. Such activities, as much as his alchemical concerns, reveal the need for a nuanced view of Boyle and an awareness of the extent to which his adherence to the mechanical philosophy was tempered by a wish to do justice to the complexities that the world might contain.

Natural History and Utility. Nevertheless, Boyle was himself at pains to distinguish between the more speculative elements in his corpus and the foundation of natural historical data, which, following Francis Bacon, he saw at once as crucial to the growth of science and as his own chief legacy to posterity. Indeed, Boyle's Baconian methodology is a further aspect of his science that requires greater emphasis than Hall gave it. (Her main claim for Bacon's influence on Boyle related to the supposed significance of Bacon's particulate matter theory; her assertion of Bacon's influence on Boyle in this respect was in fact almost certainly exaggerated.) A sophisticated form of Baconianism seems to have come to the fore slightly later in Boyle's career than might have been expected, in the 1660s rather than the 1650s, but once Boyle had awoken to the full potential of Bacon's prescriptions he showed the zeal of a convert in adopting and seeking to exemplify this methodology. Up to a point this is encapsulated in his appeal to "matters of fact" in controversy, his wish to separate issues susceptible to empirical proof on which people could agree from those which were matters of hypothesis. But he also took to heart the Baconian method of organizing data by "heads" or "titles," and he devised a sophisticated "design" for the pursuit of natural history in which he laid out an agenda for collecting data and the procedures that needed to be implemented so that researchers were aware of but not "prepossessed" by theories as they investigated nature. In addition, the Baconian ethos encouraged Boyle to explore a variety of novel forms of publication as a means of divulging his findings, if necessary in provisional form, including journal articles and volumes made up of disparate "tracts." Indeed, such strategies go far toward explaining the apparently chaotic nature of a number of Boyle's books which scholars have often found puzzling.

A further aspect of Boyle's science that is strangely absent from the original *DSB* article is his concern for the application of science, as exemplified in his *The Usefulness of Natural Philosophy*, largely written in the late 1650s and published in 1663 and 1671 (with supplementary material included in the *Works* in 2000). Boyle's aspiration to utility worked at various levels. One, divulged in part 1 of the work, was the significance of science in religious terms, as a source for understanding a theistic cosmos. But equally important was the utility of natural knowledge to human life, the subject matter of part 2, which aimed to show that practical inventions and technical improvements were grounded in more theoretical developments which were worth encouraging for just this reason. This was exemplified by a plethora of instances of the spin-offs of scientific investigation for practical affairs, ranging from diving bells to improved methods for fertilizing land. In connection with this, Boyle also stressed the value for scientists of taking an interest in the activities of practitioners of trades and other "mechanical disciplines."

The largest single section of *Usefulness* dealt with medicine, in which Boyle argued for the value of natural philosophy in understanding and improving human health. This was a major preoccupation for Boyle throughout his career, and it was a field where he was particularly anxious to vindicate the practical benefits of an improved understanding of nature. Though he abandoned the outright assault on orthodox medical practice that he planned and partially wrote by way of developing the more cautious remarks that he included in *Usefulness*, in his later years he brought out a number of treatises devoted to the significance of what might be called the medical sciences, including his *Memoirs for the Natural History of Human Blood* (1684) and his *Medicina Hydrostatica* (1690). He also collected and tested medical recipes with a view to making the best of them more widely available, a project that he started to implement in his later years, although inhibited by an anxiety that the publication of such material might be beneath his dignity as a natural philosopher.

Religious and Other Contexts. Boyle shared his ambition to make science useful with other contemporaries, notably the circle of Samuel Hartlib in the 1650s and the Royal Society after the Restoration, and this aim of achieving a wider social role for the study of the natural world is undoubtedly a significant theme in the history of science in the period, even if opinions differ as to the effectiveness of many of the projects that resulted: a case in point is the scheme for desalinizing water with which Boyle and various colleagues were involved in the 1680s, which seems to have met with rather mixed success. However, the claims that have been made for Boyle's involvement in broader, political objectives in his pursuit of science— not least in connection with his controversy with Thomas Hobbes— have been less convincing. These claims have focused on the perceived need to control subversion in the aftermath of the English civil war and to overcome the fragmentation of intellectual authority associated with that by capitalizing on the consensual nature of experimental activity, especially as represented by the Royal Society.

In fact, though certainly active in such debates, Boyle turns out to have been a less establishmentarian figure than such views have often implied, and the reason for this is his strong religious commitment, the dominant force in his entire life. Indeed, it could be argued that without a proper understanding of this it is impossible to do justice either to Boyle's intellectual ambitions and achievements or to his life as a whole. Boyle's personal piety was strong to the extent of being tortured; this gave him an obsessiveness that is in evidence in many facets of his life, not least his intense experimental practice. (Hall could not have been more wrong in asserting that "fortunately, he experienced no conflicts of conscience," even if she was here thinking of a potential science-religion tension from which Boyle was certainly immune, rather than the acute scruples on moral and other issues from which it is known that he suffered.) Boyle's own deep piety also gave him considerable respect for others whom he considered comparable recipients of religious insight, even if they were opposed to the powers that be. His commitment to his Christian duty also made him sympathetic to the plight of the poor to an extent that set him at odds with the Restoration establishment, and his enthusiasm for missionary work did not always go down well with the colonial interests of the day.

More publicly, it seems clear that Boyle's ongoing controversy with Hobbes owed less to political motives than to religious ones, in that he explicitly stated in his *Examen* of Hobbes (1662) that it was because of the pernicious effect of Hobbes's principles on religion and morality that he felt obliged to oppose his views in natural philosophy. Earlier, it appears that Boyle initially came to espouse experiment not least because he believed that such knowledge would offset what he saw as the damaging religious implications of the prevailing Aristotelianism of the day. Moreover, he was unswerving in his conviction that a proper understanding of the natural world could make a crucial contribution to the comprehension and worship of God, a topic to which he devoted various treatises in his later years. He even devoted an entire book to a discussion of the final causes of natural things, arguing that it was appropriate for the naturalist to speculate about these, even if it was not his task to be primarily concerned with them. This is the background to the foundation of the Boyle Lectures through one of the provisions of his will, as described by Hall in her article.

Yet Boyle was not a complacent rationalist like some of his eighteenth-century successors. His deep sense of the limitations of human reason in comparison with the power and inscrutability of God led to a stress on the need for intellectual humility that goes beyond a simple avoidance of dogmatism. Indeed, he was convinced that there were "things beyond reason" both in natural philosophy and in divinity, and the true profundity of his views on such matters is now better understood. Just as in theology he believed that things might seem contradictory or incomprehensible to inferior humans but not to God, so in his natural philosophy his empiricism was accompanied by a stress on the extent to which God could have created the world differently had he wished, and to which even the laws of nature were contingent by virtue of being expressive of the divine will. Hence, the "new" Boyle that has emerged is not exclusive of the figure presented in the original *DSB* but is a more complex and in many ways a more interesting one—more at home in his seventeenth-century context and perhaps more sympathetic to the twenty-first.

SUPPLEMENTARY BIBLIOGRAPHY

WORKS BY BOYLE

The Early Essays and Ethics of Robert Boyle. Edited by John T. Harwood. Carbondale and Edwardsville: Southern Illinois University Press, 1991.

The Works of Robert Boyle. 14 vols. Edited by Michael Hunter and Edward B. Davis. London: Pickering & Chatto, 1999–2000.

The Correspondence of Robert Boyle. 6 vols. Edited by Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe. London: Pickering & Chatto, 2001.

The Workdiaries of Robert Boyle. Available from http://www.livesandletters.ac.uk/wd.

OTHER SOURCES

Anstey, Peter R. *The Philosophy of Robert Boyle*. London and New York: Routledge, 2000.

———. "Boyle on Seminal Principles." *Studies in History andPhilosophy of Biological and Biomedical Sciences* 33 (2002): 597–630.

Chalmers, Alan. "The Lack of Excellency of Boyle's Mechanical Philosophy." *Studies in the History and Philosophy of Science*24 (1993): 541–564.

Clericuzio, Antonio. "A Redefinition of Boyle's Chemistry and Corpuscular Philosophy." *Annals of Science* 47 (1990): 561–589.

Frank, Robert G., Jr. *Harvey and the Oxford Physiologists:Scientific Ideas and Social Interaction*. Berkeley and Los Angeles: University of California Press, 1980.

Hunter, Michael, ed. *Robert Boyle Reconsidered*. Cambridge, U.K.: Cambridge University Press, 1994.

———.*Robert Boyle, 1627–91: Scrupulosity and Science*. Woodbridge, U.K.: Boydell Press, 2000.

———. “Robert Boyle and the Early Royal Society: A Reciprocal Exchange in the Making of Baconian Science.” *British Journal for the History of Science*40 (2007): 1–23.

Hunter, Michael, et al. *The Boyle Papers: Understanding theManuscripts of Robert Boyle*. Aldershot, U.K.: Ashgate, 2007. Includes a revised version of the catalog of the Boyle archive referred to above.

Jacob, James R. *Robert Boyle and the English Revolution: A Study in Social and Intellectual Change*. New York: Burtt Franklin, 1977.

Kaplan, Barbara Beigun. *Divulging of Useful Truths in Physick:The Medical Agenda of Robert Boyle*. Baltimore, MD: Johns Hopkins University Press, 1993.

Knight, Harriet. “Organising Natural Knowledge in the Seventeenth Century: The Works of Robert Boyle.” PhD diss., University of London, 2003.

Newman, William R., and Lawrence M. Principe. *Alchemy Tried in the Fire: Starkey, Boyle, and the Fate of Helmontian Chymistry*. Chicago: University of Chicago Press, 2002. Principe, Lawrence M. “Virtuous Romance and Romantic Virtuoso: The Shaping of Robert Boyle’s Literary Style.” *Journal of the History of Ideas* 56 (1995): 377–397.

———.*The Aspiring Adept: Robert Boyle and His AlchemicalQuest*. Princeton, NJ: Princeton University Press, 1998.

Sargent, Rose-Mary. *The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment*. Chicago: University of Chicago Press, 1995.

Shapin, Steven. *A Social History of Truth: Civility and Science in Seventeenth-Century England*. Chicago: University of Chicago Press, 1994.

Shapin, Steven, and Simon Schaffer. *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*. Princeton, NJ: Princeton University Press, 1985.

Webster, Charles. *The Great Instauration: Science, Medicine, and Reform 1626–1660*. London: Duckworth, 1975; reissued with new introduction, Oxford and New York: Peter Lang, 2002.

Wojcik, Jan W. *Robert Boyle and the Limits of Reason*. Cambridge, U.K.: Cambridge University Press, 1997.

Michael Hunter

Boyle, Robert

International Dictionary of Films and Filmmakers

Art Director. **Nationality:** American. **Born:** Los Angeles, California, 1910. **Education:** Attended the University of Southern California, Los Angeles, B. Arch. 1933. **Family:** Married. **Career:** Worked for several architectural firms, and acting extra; 1933—sketch artist and draftsman, Paramount, then worked for Universal, RKO, and Universal again. **Agent:** The Gersh Agency Inc., 232 North Canon Drive, Beverly Hills, CA 90210, U.S.A.

Films as Art Director or Production Designer:

1942

Saboteur (Hitchcock)

1943

Flesh and Fantasy (Duvivier); *Shadow of a Doubt* (Hitchcock); *Good Morning, Judge* (Yarbrough); *South of Tahiti* (*White Savage*) (Lubin)

1946

Nocturne (Marin)

1947

They Won't Believe Me (Pichel); *Ride the Pink Horse* (Montgomery)

1948

Another Part of the Forest (Gordon); *An Act of Murder* (*Live Today for Tomorrow*) (Gordon); *For the Love of Mary* (de Cordova)

1949

The Gal Who Took the West (*The Western Story*) (de Cordova); *Abandoned* (Newman)

1950

Buccaneer's Girl (de Cordova); *Louisa* (Hall); *The Milkman* (Barton); *Sierra* (Grenen); *Mystery Submarine* (Sirk)

1951

Iron Man (Pevney); *Mark of the Renegade* (Fregonese); *The Lady Pays Off* (Sirk); *Weekend with Father* (Sirk)

1952

Bronco Buster (Boetticher); *Lost in Alaska* (Yarbrough); *Yankee Buccaneer* (de Cordova); *Back at the Front* (G. Sherman)

1953

Girls in the Night (Arnold); *The Beast from 20,000 Fathoms* (Lourié); *Gunsmoke* (Juran); *Abbott and Costello Go to Mars* (Lamont); *Ma and Pa Kettle on Vacation* (Lamont); *It Came from Outer Space* (Arnold); *East of Sumatra* (Boetticher)

1954

Ma and Pa Kettle at Home (Lamont); *Johnny Dark* (G. Sherman); *Ride Clear of Diablo* (Hibbs)

1955

Chief Crazy Horse (G. Sherman); *Kiss of Fire* (Newman); *The Private War of Major Benson* (Hopper); *Lady Godiva* (Lubin); *Running Wild* (La Cava)

1956

Never Say Goodbye (Hopper); *A Day of Fury* (Jones); *Congo Crossing* (Pevney)

1957

The Night Runner (Biberman); *The Brothers Rico* (Karlson); *Operation Mad Ball* (Quine)

1958

Buchanan Rides Alone (Boetticher); *Wild Heritage* (Haas)

1959

The Crimson Kimono (Fuller); ***North by Northwest*** (Hitchcock)

1962

Cape Fear (Lee Thompson) (co)

1963

The Birds (Hitchcock); *The Thrill of It All* (Jewison) (co)

1964

Marnie (Hitchcock)

1965

Do Not Disturb (Levy) (co); *The Reward* (Bourguignon) (co)

1966

The Russians Are Coming, the Russians Are Coming (Jewison)

1967

Fitzwilly (Delbert Mann); *In Cold Blood* (R. Brooks); *How to Succeed in Business without Really Trying* (Swift)

1968

The Thomas Crown Affair (Jewison)

1969

Gaily, Gaily (*Chicago, Chicago*) (Jewison)

1970

The Landlord (Ashby)

1971

Fiddler on the Roof (Jewison)

1972

Portnoy's Complaint (Lehman)

1974

Mame (Saks)

1975

Bite the Bullet (R. Brooks)

1976

Leadbelly (Parks)

1978

Winter Kills (Richert)

1980

Private Benjamin (Zieff)

1983

Staying Alive (Stallone)

1986

Jumpin' Jack Flash (P. Marshall)

1987

Dragnet (T. Mankiewicz)

1988

Troop Beverly Hills (Kanew)

1991

To Meteoro vima tou pelargou (*The Suspended Step of the Stork*) (Angelopoulos)

Publications

By BOYLE: articles—

Film Comment (New York), May/June 1978.

Cahiers du Cinéma (Paris), June 1982.

On BOYLE: article—

Films and Filming (London), March/April 1970.

* * *

During his 46 years as an independent Hollywood art director, Robert Boyle worked on a variety of films, applying his technique and the tricks of the art director's trade to make realistic looking sets and locations. He created images that would not only enhance the story but also cement it to time and place. From Hitchcock's *Saboteur* to *Troop Beverly Hills*, Boyle worked on such films as *The Russians Are Coming, the Russians Are Coming*; *The Thomas Crown Affair*; and the original *Cape Fear*. But along with these impressive films, Boyle also served as art director on such films as *Abbott and Costello Go to Mars* and *It Came from Outer Space*, as well as a few Ma and Pa Kettle films. Westerns such as *Bronco Buster* and such costume films as *Buccaneer's Girl* were also part of Boyle's oeuvre.

Boyle began his career in the thirties when film sets started to move away from the style that was more suitable to the theater, from which they had been borrowed. Film studios began to maintain large art departments and art department heads were appointed to be responsible for the ultimate style of the studio. At Paramount, where Boyle was associated with Wiard Ihnen, the art department head was Hans Drier, a German architect. Drier brought a flair for the modern to Paramount, having been influenced by Bauhaus artists and the Swiss architect, Le Corbusier. It was said that Drier's Paramount was able to make sets look more like the real thing.

Although trained as an architect, Boyle started out as a sketch artist and assistant designer. He was, however, able to use his architectural skills to design the realistic sets that were in demand by the studios during the thirties. Developing his skills at this time made Boyle a believer in film sets and the total control the art director could exercise over them. He also found that it was easier to design a location than to find one. After reading a script, Boyle would put into reality the images he conceived from the story. On the film set, Boyle would be able to use all the tricks of his trade to design and build a believable set.

As films changed and location filming became more popular, Boyle adapted as well. He used his tricks to make the location shots more controllable. Using mattes to improve the mood and floodlights to correct existing conditions—or adding bits and pieces to the location—Boyle used anything to try to create the preconceived image he got from the script. Although he worked on memorable films by other great directors, it is his work with Hitchcock for which Boyle is best known. He first worked as an art director on Hitchcock's *Saboteur* in 1942, then worked on four more Hitchcock films—*Shadow of a Doubt*, *North by Northwest*, *Marnie*, and *The Birds*, receiving an Oscar nomination for his work on *North by Northwest*.

Hitchcock wanted to use actual locations for *North by Northwest*, including Grand Central Station and Mount Rushmore. Since filming at Mount Rushmore was limited, the sequence was filmed on a stage using rear projections to create the illusion that it was filmed on location. For Grand Central Station, Boyle used a maximum of light to create a proper set. Boyle said he flooded the station with so much light he wondered if Paramount could pay the bill. He also showed his adaptability with location shooting by using an ideal site for the crop-duster assault on Cary Grant. The image is one of a lone figure in the dusty field with no cover in sight desperately trying to flee the airplane. The contrast between the impeccably dressed Grant, the dust from the fields, and the emptiness of the landscape combine to create a memorable scene.

The most startling and perhaps the most technically complex film Boyle has worked on is *The Birds*. Boyle drew his inspiration from Edvard Munch's painting "The Cry" for his overall look. For the technical challenge, he turned to the Disney studios for their special effects technology. Using mattes, and a borrowed special effect prism from Disney, he was able to exercise total control of the imagery and to make convincing illusions. One of the more famous scenes is the bird's-eye view of the fire in the town of Bodega Bay. Boyle had to create the entire scene using mattes; even the apparently moving smoke was part of the mattes. The only actual "real" objects were the gas, the phone booth, the car and, of course, the fire. The filming of the fire was done in the studio parking lot, and the town was added in matte by matte to create the final image. Boyle said they could not film the fire on location because the town in the movie was actually a composite of several towns. Boyle created Bodega Bay by using bits and pieces from one town or another, another example of his ability to take control and create his vision of the story while on location.

Marnie was to be his last film with Hitchcock, and Boyle went on to work with Norman Jewison for several films. He was nominated for an Academy Award for his work on *Gaily, Gaily*—a lavish production set in Chicago in 1910 in which he successfully incorporated historic landmarks and period scenes in and around Chicago. *Fiddler on the Roof*, Jewison's film version of the theater production, was shot on location in Yugoslavia. The film called for real houses, real animals and real landscapes. Boyle again was nominated for an Academy Award for his work on this film, the look of which was described as gritty and realistic.

Boyle continued to show his adaptability and versatility well into the 1980s working on such films as *Private Benjamin*, *Staying Alive* (Stallone's sequel to *Saturday Night Fever*), *Jumpin' Jack Flash*, and finishing his career with the film version of *Dragnet* in 1987 and *Troop Beverly Hills* in 1988.

—Renee Ward

Robert Boyle

Encyclopedia of World Biography

The British chemist, physicist, and natural philosopher Robert Boyle (1627-1691) was a leading advocate of "corpuscular philosophy." He made important contributions to chemistry, pneumatics, and the theory of matter.

The seventh son and fourteenth child of the 1st Earl of Cork, Robert Boyle was born on Jan. 25, 1627, at Lismore Castle in County Cork, Ireland. His father was one of the richest and most powerful men in Ireland, and throughout his life Boyle enjoyed, in addition to his native talents, the advantages of position, family, and wealth. At the age of eight he was sent to school at Eton and then in 1638 to Geneva, Switzerland, where he was privately tutored for the next two years. Upon the death of his father, Boyle returned in 1644 to England, where after some initial delay he settled at the manor of Stalbridge in Dorsetshire, which he had inherited from his father.

Boyle devoted much time to study and writing, and although he wrote extensively on ethical and religious topics, he became increasingly interested in natural philosophy. He interested himself in nearly all aspects of physics, chemistry, medicine, and natural history, although it was chemistry that "bewitched" him and primarily occupied his time.

In 1652 Boyle left Stalbridge for Ireland, where 10 years of civil war had seriously disordered the family estates. During his stay he continued to pursue his scientific interests. In 1654 he settled in Oxford, then the scientific center of England. He there associated himself with a group interested in the "new learning." This group, including many of the leading scientific figures of the day, quickly recognized Boyle's exceptional abilities, and he became a regular participant in their activities, pursuing particularly his interest in chemistry.

Pneumatic Investigations

Soon after his arrival in Oxford, Boyle's researches took on an additional dimension. Having learned in 1657 of the vacuum pump recently invented by Otto von Guericke, Boyle immediately set Robert Hooke, his brillant assistant (and later an eminent scientist in his own right), the task of devising an improved version. Utilizing this improved pump Boyle immediately began a long series of investigations designed to test properties of the air and to clearly establish its physical nature. Boyle's first account of these "pneumatic" investigations was entitled *New Experiments, Physico-Mechanical, Touching the Spring of the Air and Its Effects* (1660). He continued his study of air and vacuum throughout the rest of his life, and although his experiments with the "Boyleian vacuum" (as it came to be known) were repeated by many, no one in the 17th century surpassed Boyle's ingenuity or technique.

Boyle made extensive studies of the elasticity of the air and of its necessity for various physical phenomena, such as combustion, the propagation of sound, and the survival of animals. He verified Galileo's conclusions about the behavior of falling bodies by studying the rate at which a light body fell, both in air and in a vacuum. By placing a Torricellian barometer in the receptacle of his pump, he also verified that it was indeed air pressure which supported the column of mercury. When his conclusions about the relationship between the pressure of the air and the weight of the mercury it would support were challenged, he produced a series of experiments demonstrating that for a given quantity of air the volume is inversely proportional to the pressure, a relationship now known as Boyle's law.

Corpuscular Philosophy

The Sceptical Chymist (1661), although one of Boyle's more theoretical works and suffering from his usual lack of organization, well illustrates his contention that all scientific investigation must be firmly based on experiment. Directing his attack at what he conceived as the erroneous foundations of contemporary chemical theory, he brought forth extensive experimental evidence to refute the prevailing Aristotelian and Paracelsian concepts of a small number of basic elements or principles to which all compounds could be reduced by chemical analysis. He demonstrated that common chemical substances when decomposed by heat not only failed to yield the requisite number of elements or principles, but that the number was a function of the techniques employed. Accordingly, he denied that elements or principles (as thus defined) had any real existence and sought to replace these older concepts of chemical change with what he termed the "corpuscular philosophy."

Although he emphasized the necessity of basing scientific research on experiment, Boyle was not a simple empiricist. Behind his more specific and detailed work was a general theory of the structure of matter; and his continued advocacy of the mechanical philosophy—that is, explanation in terms of matter and motion—was one of his most significant contributions. According to Boyle's corpuscular philosophy, God had originally formed matter in tiny particles of varying sizes and shapes. These particles tended to combine in groups or clusters which, because of their compactness, had a reasonably continuous existence and were the basic units of chemical and physical processes. Any change in the shape, size, or motion of these basic clusters altered the properties of the substance involved, although chemical reactions were generally conceived as involving primarily the association and dissociation of various clusters.

Boyle also made significant contributions to experimental chemistry. He made extensive studies of the calcination of metals, of combustion, and of the properties of acids and bases. He emphasized the application of physical techniques to chemical investigation and developed the use of chemical indicators which showed characteristic color changes in the presence of certain types of substances. His pioneering study of phosphorus, during which he discovered nearly all the properties known for the next two centuries, well illustrates the effectiveness of his experimental techniques.

Science and Religion

An influential public figure, Boyle was often at court and was among those who in 1662 used their influence to obtain a charter for the Royal Society. He was a charter member of the society, as well as one of its initial council members, and provided the society with two of its most influential early officials: Henry Oldenburg, who had been tutor to Boyle's nephew, was appointed the society's first secretary, and Robert Hooke became its first curator.

In 1668 Boyle moved to London. As a leading figure of English science and a member of a prominent family, he was offered numerous honors, including a peerage and a bishopric, all of which he declined, insisting that he preferred to remain a simple gentleman. In 1680 he even refused the presidency of the Royal Society on the grounds that his conscience was, as he said, "tender" about subscribing to the necessary oaths.

Throughout his life Boyle maintained a deep and pervasive religious commitment. As an active supporter of missionary work, he was appointed by the King the governor of the Corporation for Propagating the Gospel in New England. He was particularly concerned, however, with demonstrating that science and religion were not only reconcilable but in fact integrally related, and in his effort to promote this belief he produced numerous essays and tracts on religion and natural theology. He died on Dec. 30, 1691, and in addition to leaving much of his estate for the furtherance of various Christian endeavors, he provided in his will for the establishment of an annual series of sermons, in his words, "for proving the Christian Religion against notorious Infidels." These sermons, known as the Boyle Lectures, became by tradition one of the primary platforms for promoting the belief that in the study of nature could be found much of the evidence for religion.

Further Reading

Boyle's better-known writings are collected in Thomas Birch, ed., *The Works of the Honourable Robert Boyle* (5 vols., 1744; new ed., 6 vols., 1772), together with an account of his life which is the principal source of all subsequent biographies. Although not entirely satisfactory, the standard biography is Louis Trenchard More, *The Life and Works of the Honorable Robert Boyle* (1944). A briefer account, with extensive selections from his more important works, is Marie Boas Hall, *Robert Boyle on Natural Philosophy* (1965), while the significance of Boyle's chemical studies is discussed at length in her *Robert Boyle and Seventeenth-Century Chemistry* (1958). A case study of his work in pneumatics is contained in James Bryant Conant, ed., *Harvard Case Histories in Experimental Science* (2 vols., 1957). □

Boyle, Robert (1627–1691)

Europe, 1450 to 1789: Encyclopedia of the Early Modern World

BOYLE, ROBERT (1627–1691), natural philosopher and lay theologian. Boyle was born in Ireland, the youngest son of Richard Boyle (1566–1643), earl of Cork, and was raised as an aristocrat. After attending Eton, Robert Boyle embarked on a grand tour. When his travels were cut short as a result of the economic upheavals caused by the Irish Rebellion, he made his way back to England, where he found his sister, Katherine Ranelagh, living in London. After a brief stay with her (during which he became acquainted with the Puritan reformers of the Dury Circle), Boyle moved in 1645 to "Stalbridge," the estate in Dorset he had inherited from his father. There he wrote a number of ethical treatises and other moralistic pieces before becoming more interested in experimental philosophy. In 1649 he set up a laboratory at Stalbridge and began systematic studies in chemistry (and alchemy).

In 1655 or 1656 Boyle moved to Oxford, where he became a part of the experimental natural philosophy group. There he published some of his more important works in natural philosophy, including *New Experiments Physico-Mechanical Touching the Spring of Air and Its Effects* (1660), *The Sceptical Chymist* (1661), and *The Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666). In 1668 Boyle moved back to London, where he became one of the founding members of the Royal Society of London. He established a laboratory in his sister's home and lived with her for the remainder of his life. Boyle continued his experiments and publications in natural philosophy and in addition published a number of works that were either primarily theological in nature or works in which it is impossible to separate his theological concerns from his work in natural philosophy. Among these are *The Excellency of Theology Compar'd with Natural Philosophy* (1674), *A Free Enquiry into the Vulgarly Receiv'd Notion of Nature* (1686), *A Discourse of Things above Reason* (1681), *A Disquisition about the Final Causes of Natural Things* (1688), and *The Christian Virtuoso* (1690).

As a natural philosopher, Boyle is best remembered for Boyle's Law, for advocating a corpuscularian matter theory, and for being extremely influential in the development of an empirical and experimental method. He had a marked aversion to speculative metaphysics, and in *Notion of Nature* argued against attributing any ontological status to either the Aristotelian notion of "nature" (as in "Nature abhors a vacuum") or to the "hylarchic principle" (or "plastick nature") of the Cambridge Platonists. Boyle argued that entities such as these are not needed to explain the phenomena and ought not be admitted into a theory of nature on the grounds of Ockham's razor (the principle that entities ought not to be multiplied beyond necessity).

Boyle is still honored in introductory chemistry texts as the "father of modern chemistry," the natural philosopher who successfully separated chemistry from its alchemical antecedents. This claim, however, is based on the fact that the work in which he is supposed to have done this, *The Sceptical Chymist,* was misinterpreted until the late twentieth century. Rather than being an attack on alchemy, the work is instead an attack only on certain practitioners and textbook writers—most specifically those who divorced alchemy from any theoretical underpinning. Indeed Boyle was quite involved in alchemical pursuits throughout his life, both in attempts to transmute base metals into gold and in the investigation of alchemical processes for medicinal purposes.

During his lifetime and after his death Boyle was honored as much for his piety as for his work as an experimental philosopher. Boyle considered the investigation of the world God created as a way of worshiping God, seeing the created world as a temple and the investigator of that world as a priest. He was painfully aware of the growing suspicion that the revival of Epicureanism (in the form of the corpuscular philosophy) might lead to a materialist worldview and an accompanying atheism, and he published work after work in which he attempted to show that the astute natural philosopher would become a more devout Christian rather than being led to question God's existence or providence. He advocated a natural theology that was typical of the time, showing that reason alone could prove God's existence and the immateriality of the soul.

Boyle was quite clear, however, that this natural philosophy was only the first step toward belief and that its main purpose was to serve as a bridge to revelation. As Boyle expressed it, knowing that God exists and having come to admire his workmanship, one naturally wants to learn more about the deity, and fortunately God has provided that knowledge via revelation. Boyle wrote extensively in an attempt to privilege the mysteries of Christianity from rational scrutiny, arguing that just as there are aspects of nature that human beings cannot (yet) understand, so too are there mysteries revealed in Scripture that human beings cannot (yet) understand. Indeed Boyle went so far as to argue that, where revelation is concerned, it is sometimes necessary for human reason to affirm apparently contradictory truths, such as God's prescience and human beings' free will (emphasizing that God, in his infinite wisdom, understands how such apparent contradictions are in fact consistent).

The unity of Boyle's thought is revealed in his voluntarism (his emphasis on God's will and power rather than on God's goodness and reason). In Boyle's view God was free to create any world whatsoever. The only way to discover the nature of God's creation is to investigate it, and (because the world was created commensurate to God's infinite understanding rather than to finite human understanding), there will always be aspects of this world that humans are unable to comprehend. The same thing is true of the mysteries of Christianity. God has reserved a full understanding of both nature and theology for the afterlife, thereby providing an incentive for godly living and belief.

See also **Alchemy** ; **Chemistry** ; **Nature** ; **Scientific Method** ; **Scientific Revolution.**

BIBLIOGRAPHY

Primary Sources

Boyle, Robert. *The Correspondence of Robert Boyle*. 6 vols. Edited by Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe. London, 2001.

——. *The Early Essays and Ethics of Robert Boyle*. Edited by John T. Harwood. Carbondale and Edwardsville, Ill., 1991.

——. *Robert Boyle: By Himself and His Friends: With a Fragment of William Wotton's Lost "Life of Boyle."* Edited by Michael Hunter. London, 1994.

——. *The Works of Robert Boyle*. 14 vols. Edited by Michael Hunter and Edward B. Davis. London and Brookfield, Vt., 1999–2000.

Secondary Sources

Anstey, Peter R. *The Philosophy of Robert Boyle*. London and New York, 2000.

Clericuzio, Antonio. *Elements, Principles, and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century*. Dordrecht, 2000.

Hunter, Michael. *Robert Boyle (1627–91): Scrupulosity and Science*. Woodbridge, U.K., 2000.

Hunter, Michael, ed. *Robert Boyle Reconsidered*. Cambridge, U.K., 1994.

Principe, Lawrence M. *The Aspiring Adept: Robert Boyle and His Alchemical Quest*. Princeton, 1998.

"Robert Boyle (1627–91)." Robert Boyle Project, University of London. Directed by Michael Hunter. Available: www.bbk.ac.uk/Boyle/index.html.

Sargent, Rose-Mary. *The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment*. Chicago, 1995.

Shapin, Steven. *A Social History of Truth: Civility and Science in Seventeenth-Century England*. Chicago, 1994.

Shapin, Steven, and Simon Schaffer. *Leviathan and the Air- Pump: Hobbes, Boyle, and the Experimental Life*. Princeton, 1985.

Wojcik, Jan W. *Robert Boyle and the Limits of Reason*. Cambridge, U.K., 1997.

Jan W. Wojcik

Boyle, Robert

Chemistry: Foundations and Applications

BRITISH PHYSICIST AND CHEMIST
1627–1691

Robert Boyle was born in 1627, the youngest son of a large upper-class English family with significant landholdings in Ireland and ties to both sides of the English Civil War (1642–1651). Boyle's literary and religious interests

turned to **natural philosophy** as early as 1647. Boyle was active within the Baconian group called "the Invisible College," which would later become the **Royal Society** , chartered by King Charles II after the Restoration.

Among Boyle's earliest scientific work were studies involving the air pump. At the time, Robert Hooke was Boyle's laboratory assistant. Starting with the German physicist Otto von Guericke's description of an air pump, Hooke improved on its design, reducing its size and increasing its performance while making it easier to use. Utilizing this improved air pump, Boyle devised experiments to explore the properties of air. He examined the behavior of sound, heat, light, electricity, magnetism, chemical reactions (such as a flame), and living systems (such as small animals or plants) in a vacuum. He also considered the behavior of the air itself under extension or compression. The result of this study was the relationship now known as Boyle's law, which states that the pressure and volume of a confined air (gas) are inversely related. Mathematically, this is expressed as pressure times volume equals a constant

$PV = \text{constant}$

In 1661 Boyle published the first edition of *The Sceptical Chymist*. A second, expanded edition was published in 1680. It has earned him the title "the father of chemistry" among some British historians. Many point to this as the work in which Boyle examined numerous alchemical procedures and ultimately rejected the classically derived notion of the four elements (earth, air, fire, and water); also dismissed the Paracelsian notion of three essences: salt, sulfur, and mercury; and articulated a relatively modern working definition of atoms. Modern scholarship has questioned some of the details of this interpretation of Boyle's work, but his importance cannot be denied.

Boyle was among the first chemists not primarily trained in medicine and medicinal chemistry, in mining and **metallurgy** , or interested in those applications. He was also among the first to recognize chemistry as an intrinsically important subject for natural philosophy. In pursuing such a line of thought, he had to convince natural philosophers that chemistry was something other than the disreputable **alchemy** it was known as and chemists that the experimental principles of natural philosophy might offer them a valuable area of practice.

Boyle refocused the study of chemistry in two important ways. First, he shifted attention away from questions surrounding the source and history of a material to its identity and purity. Second, he redirected the interest in desired byproducts to an examination of the chemical reaction itself. In doing this, Boyle promoted the use of chemical identity tests and a control arm in an experiment. Among the measures of identity and purity were color, specific gravity, crystal shape, flame tests, solubility, precipitates, and reaction to standardized **reagents** . In these ways, Boyle helped frame the important questions for succeeding chemists until the seminal work of Antoine-Laurent Lavoisier.

see also Alchemy.

David A. Bassett

Bibliography

Boas, Marie (1958). *Robert Boyle and Seventeenth-Century Chemistry*. Cambridge, UK: Cambridge University Press.

Boyle, Robert (1772). *The Works of the Honorable Robert Boyle*. 6 vols. Reprinted, Bristol, U.K.: Thoemmes Press, 1999.

Boyle, Robert

The Columbia Encyclopedia, 6th ed.

Robert Boyle, 1627–91, Anglo-Irish physicist and chemist. The seventh son of the 1st earl of Cork, he was educated at Eton and on the Continent and conducted most of his researches at his own laboratories at Oxford (1654–68) and London (1668–91). He invented a vacuum pump and used it in the discovery (1662) of what is now known as Boyle's law (see gas laws). Boyle is often referred to as the father of modern chemistry; he separated chemistry from alchemy and gave the first precise definitions of a chemical element, a chemical reaction, and chemical analysis. He also made studies of the calcination of metals, combustion, acids and bases, the nature of colors, and the propagation of sound. Although he was especially noted for his experimental work, Boyle also contributed to physical theory, supporting an early form of the atomic theory of matter, which he called the corpuscular philosophy, and using it to explain many of his experimental results. His extensive writings contributed greatly to the dominance of the mechanistic theory following Newton's work. Boyle was one of the group at Oxford that later became the Royal Society, but he refused the presidency of the society in 1680, as well as many other honors.

See his works, ed. by T. Birch (6 vol., 1772; repr. 1965–66); biographies by R. E. W. Maddison (1969) and M. Hunter (2009); study by M. B. Hall (1958, repr. 1968).

Boyle, Robert

The Oxford Companion to British History

Boyle, Robert (1627–91). Famous for his work on air pressure, Boyle was the youngest son of the 1st earl of Cork. After Eton, he went on a grand tour in 1639–44, and during the 1650s belonged to the ‘invisible college’, so called because they never all met together at once, associated with John Wilkins at Wadham College, Oxford. Crucial in the scientific revolution in England, this was a nucleus for the Royal Society, in which, though very important, Boyle would never take office. With Robert Hooke in Oxford he made and experimented with an air pump, and hit upon the law of gas pressure, discovering a new variable. A godly man who brought prestige to natural philosophy, he was a great advocate for a version of the atomic, or *corpuscular*, theory of matter: having been impressed by the Strasbourg clock, he sought mechanical explanations of all phenomena.

David Knight

Boyle, Robert

World Encyclopedia

Boyle, Robert (1627–91) British chemist, b. Ireland, often regarded as the father of modern chemistry. Boyle conducted research into air, vacuum, metals, combustion, and sound. His Sceptical Chymist (1661) proposed an early atomic theory of matter. He made an efficient vacuum pump, which he used to establish (1662) Boyle's law. Boyle formulated the first chemical definitions of an element and a reaction.

Boyle, Robert

Encyclopedia of Irish History and Culture

Robert Boyle (1627–1691), the most eminent natural philosopher in England in the seventeenth century before Isaac Newton, was born in Lismore Castle the seventh son of the first earl of Cork by his second wife, Catherine Fenton. His academic abilities were recognized early, and he was schooled at Eton, privately, and on a Grand Tour with his brother Francis. Settling in Geneva (1638), he was introduced to the natural philosophy of Galileo. He also went through a profound religious experience that shaped his life and science.

These travels ended when rebellion broke out in Ireland in 1641 and the party returned to London. A younger son, Boyle avoided public life and immersed himself in medicine and chemistry, to which he was introduced by Samuel Hartlib, the eminent acquaintance of his sister Catherine (Lady Ranelagh). Boyle could reconcile medicine and chemistry with his religious conscience because of their imagined social utility. He moved to Oxford in 1654 and joined a politically diverse group in experimentally investigating the new philosophy. Boyle believed that experiment revealed the structure of nature and that theorizing was a separate activity. Even as he compared the numerical results of his experiments on the "spring of air" (pressure) with the predictions of theory, others deduced from them what is now known as Boyle's Law. Although he was dependent on the design and laboratory skills of men such as Robert Hooke, Boyle became a skilled chemist and an important contributor to chemical theory. He refuted Scholastic arguments against the existence of a vacuum and against the particulate nature of matter. Some of his explanations were Cartesian, yet he rejected many others because he could find no experimental evidence for them.

His scrupulosity as a Christian gentleman also marked his science and included painstaking descriptions of his methods, instrumentation, and results. He delineated for the fledgling scientific community (especially for members of the new scientific institution the Royal Society, of which he was a founding member) the proper conduct of natural philosophers and the methods of natural philosophy. The precarious position of the Royal Society in the early Restoration period was alleviated by Boyle's presence in London after 1668.

Boyle's elevated social position made him a symbol and representative of the new science and he spent much time entertaining important visitors to London for scientific activity. Boyle never married and seems to have suffered ill health for most of his life. In his will he established a series of public lectures (named after him) that were used by his contemporaries to refute atheism through use of the new science. Of all Irish-born scientists, he is the most distinguished.

SEE ALSO Dublin Philosophical Society; Petty, Sir William; Restoration Ireland

Bibliography

Harwood, John T., ed. *The Early Essays and Ethics of Robert Boyle*. 1991.

Hunter, Michael. *Robert Boyle (1627–1691): Scrupulosity in Science*. 2000.

Maddison, R. E. W. *The Life of the Honourable Robert Boyle*. 1969.

Shapin, Steven. *A Social History of Truth: Civility and Science in Seventeenth-Century England*. 1994.

Elizabeth Garber

Boyle, Robert

Encyclopedia of Science, Technology, and Ethics

Born at Lismore Castle in Munster, Ireland, on January 25, 1627, Robert Boyle (1627–1691) was an experimentalist who made fundamental contributions to chemistry, hydrostatics, philosophy of science, and the relationship between science and religion, including morality and natural theology. Before he penned his first work on natural philosophy, the deeply pious Boyle wrote several essays and treatises on religious themes, and his early interests in morality, theology, and casuistry remained undiminished throughout his life. In some of his most important mature works he linked his religious interests explicitly with his scientific pursuits, but implicit connections are often just beneath the surface in many of his writings.

The intensity of Boyle's interest in moral philosophy is readily seen in his earliest treatise, the *Aretology*, an unpublished work on ethics, vocation, and self-knowledge. This work reflects influences from Aristotle and the Christian humanist tradition, especially the German theologian Johann Alsted (1588–1638), whose enormous *Encyclopedia* (1630) served Boyle as a quarry to mine. Boyle's first published essay was dedicated to Samuel Hartlib (1600–1662), a Prussian-born disciple of the Czech educational reformer Johann Comenius (1592–1670). Its theme—that physicians should disavow secrecy and openly disseminate recipes for effective medicines, as an act of Christian charity—would be repeated numerous times in other works. An ethical impulse to improve the human condition through the application of chemistry to medicine motivated Boyle, as much as anything else, to become a scientist. A further motivation came from his conviction that nature was the third divine book in the human library—scripture and conscience were the others. The study of nature was divinely mandated, and the knowledge it produced would point unambiguously to the creator.

The Bible and the Christian Experiment

No influence was more important, however, than the Bible. Although he was not a Puritan himself, Boyle sought before all else to be biblical in everything he did, like the Puritan divines he counted among his friends. His devotion to the Bible, which he read daily in Hebrew and Greek, was nothing short of profound. At the urging of biblical scholar James Ussher (1581–1656), Boyle wrote *Some Considerations Touching the Style of the Holy Scriptures* (1661), in which he rejected the claims of courtly "wits" that biblical language was too poorly chosen for a divinely authored book. He also rejected courtly mores, which promoted the sinful vices of vanity, promiscuity, and greed, rather than the biblical virtues of humility, chastity, and charity.

Boyle sought to bring such virtues not only to his private life as an anonymous giver of alms, but also to his public life as the leading English natural philosopher of his generation. His stated policy was "to speak of Persons with Civility, though of Things with Freedom," instead of "railing at a man's Person, or wrangling about his Words," for "such a quarrelsome and injurious way of writing does very much mis-become both a Philosopher and a Christian" (Hunter and Davis 1999–2000, Vol. 2, p. 26). In an age known for the strongly negative tone of its scientific controversies, Boyle was remarkable for his consistent avoidance of derision. In his last major theological work, *The Christian Virtuoso* (1690–1691 and 1744), he reflected on other ways in which Christianity mirrored the moral attitude and experience of the scientist (the *virtuoso*). Living the Christian life, he argued, is like "trying an experiment" that leads to personal peace and happiness, in this world as well as in the world to come. Just as "personal experience" could show the evil consequences of "a vicious course of life," so the same experience could "assure him of the practical possibility of performing the duties and functions of a Christian." Likewise, "heedful observations" would "satisfy a man of the vanity of the world, and the transitoriness of ... sinful engagements, and of the emptiness of those things, for which men refuse the ways of piety and virtue" (Hunter and Davis 1999–2000, Vol. 12, pp. 431–432). The Christian virtuoso, Boyle claimed, would put truth over personal gain; cultivate humility, generosity, and trustworthiness; promote open communication over secrecy (as far as possible, given his vital interest in alchemy); and show devotion to scientific work as a kind of religious vocation. In short, it is no accident that Boyle considered himself a "priest" in the "temple" of nature.

The Mechanical Philosophy and Natural Theology

Although Boyle often spoke of nature as a temple, his favorite metaphor was much more impersonal. The world was "a great piece of Clock-work" (Hunter and Davis 1999–2000, Vol. 8, p. 75), containing numerous smaller engines—the bodies of animals, sometimes likened to "watches," and of humans—with God the clockmaker. By the mid-seventeenth century, artisans could build and repair a great variety of clockwork mechanisms that were capable of following the motion of the heavens and imitating the motions of animals and humans. This encouraged natural philosophers to think that the universe and its parts could best be explained in terms of matter and motion, giving rise to what Boyle himself first called the *mechanical philosophy*. Although he saw the possibility that some would have the great clockwork run on its own, without divine involvement or supervision, Boyle nevertheless found the new mechanical science theologically superior to the prevailing Aristotelian concept of nature. His subtle book on the doctrine of creation, *A Free Enquiry Into the Vulgarly Received Notion of Nature* (1686), argued that the *vulgar* (i.e., commonplace) view was idolatrous for the way in which it personified nature—for example, *nature abhors a vacuum*, or *nature does nothing in vain*—effectively placing an intelligent, purposive agent, "much like a kind of 'Goddess'" (Hunter and Davis 1999–2000, Vol. 10, p. 456) between the creator and the creation. It was far more appropriate, Boyle believed, to explain phenomena in terms of impersonal, "mechanical" properties and powers created by a personal God. In this way the sovereignty of God would be underscored—and people would be more likely to worship their creator, the real source of intelligence and purpose in nature.

For Boyle, as for many of his contemporaries, science had a central religious function: to make plain the signature of God in creation. Echoing his own lifelong struggle with religious doubt, Boyle saw the design argument, especially but not exclusively in its biological form, as a powerful foil against unbelief. He did not seek merely to confute philosophical atheism, which he realized was rare in his day, but fully to persuade people of the existence of the divine creator and legislator, that they might thereby live piously in the full sight of God. Changed lives and hearts, not just changed minds, were his goal. Here again, the Christian virtuoso had much to contribute. It is "very probable," Boyle noted, "that the world was *made*, to manifest the existence, and display the attributes of God; who, on this supposition, may be said to have made the world for the same purpose, for which the pious philosopher studies it" (Davis and Hunter 1999–2000, Vol. 12, p. 483). In keeping with this attitude, Boyle left funds in his will to establish a lectureship for "proveing the Christian Religion against notorious Infidels [and] Atheists," including even Jews and Muslims, although lecturers were expressly forbidden from discussing "any Controversies that are among Christians themselves" (Madison 1969, p. 274). Ultimately, however, Boyle believed that the best evidence for the truth of Christianity came not from the testimony of nature, but from the testimony of those who had witnessed the miracles of Jesus and his disciples. Through the eyes of the biblical authors one could have a trustworthy vicarious experience, sufficient to establish the authenticity of the gospels as a divine revelation. Although a systematic treatment of this topic remained unfinished at his death, Boyle's published works contain much information about his views on miracles, including their consistency with the mechanical philosophy.

However, the mechanical philosophy, especially as it was articulated by the French philosopher René Descartes (1596–1650), also had a darker side. Animals were typically seen as little or nothing more than complex machines, with full rationality and sensitivity reserved only for humans, angels, and God. When coupled with a nearly universal desire to improve the human condition by advancing the knowledge of anatomy and physiology, the temptation to engage in animal experimentation was often too great to resist. Boyle, who sought as much as anyone to enhance what he called "the Empire of Man over Other Creatures" (Hunter and Davis 1999–2000, Vol. 3, p. 193), carried out numerous diverse experiments involving both vertebrate and invertebrate live animals—dogs, cats, birds, butterflies, worms, and many others. Yet he did so with considerable sympathy and even regret; on several occasions, he even released animals that had survived one experiment precisely in order to spare them further suffering. Unlike Descartes Boyle was not convinced that animals lack sensation, and he considered gratuitous cruelty to animals blasphemous, since all creatures belonged to God. At the same time he believed that God intended the creatures to serve humankind, thus sanctioning a certain amount of animal experimentation.

Boyle's Legacy

Boyle's influence on subsequent thinking about science, religion, and morality has been larger than many writers realize, much larger (for example) than that of Isaac Newton (1642–1727)—who actually published very little of importance about religion, although he devoted many years to the study of theology and church history. The Anglo-American tradition of natural theology derives substantially from Boyle's extensive treatment of the subject, and his outstanding example of a pious scientist writing about the Bible and morality has been much imitated.

EDWARD B. DAVIS

SEE ALSO *Christian Perspecitves*; *Scientific Revolution*.

BIBLIOGRAPHY

Davis, Edward B., and Michael Hunter, eds. (1996). *Robert Boyle: A Free Enquiry into the Vulgarly Received Notion of Nature*. Cambridge: Cambridge University Press.

Harwood, John T., ed. (1991). *The Early Essays and Ethics of Robert Boyle*. Carbondale: Southern Illinois University Press.

Hunter, Michael. (1993). "Casuistry in Action: Robert Boyle's Confessional Interviews with Gilbert Burnet and Edward Stillingfleet, 1691." *The Journal of Ecclesiastical History* 44(1): 80–98.

Hunter, Michael, and Edward B. Davis, eds. (1999–2000). *The Works of Robert Boyle*, 14 vols. London: Pickering & Chatto.

Madison, R. E. W. (1969).*The Life of the Honourable Robert Boyle* London: Taylor & Francis.

Oster, Malcolm. (1989). "The 'Beame of Diuinity': Animal Suffering in the Early Thought of Robert Boyle." *British Journal for the History of Science* 22: 151–180.

Shapin, Steven. (1994).*A Social History of Truth: Civility and Science in Seventeenth-Century England*. Chicago: University of Chicago Press.

Boyle, Robert (1627–1691)

Encyclopedia of Philosophy

Robert Boyle, the English natural philosopher, was the fourteenth child of Richard Boyle, the first earl of Cork, who by judicious marriages and land purchases had made himself the most influential man in Ireland and the richest in England. The political and financial fortunes of the earl of Cork fluctuated considerably during his son's lifetime, but ultimately Robert Boyle inherited a considerable income, which greatly facilitated his scientific researches.

In October 1635, Boyle entered Eton, which with Sir Henry Wotton as provost was a notable center of culture and learning. As a result of a change of teachers, Boyle left Eton in 1638 to be privately tutored. In 1639 he went to Geneva, where he studied mathematics; his devotion to religion, so he tells us in his fragment of an autobiography, *An Account of Philaretus during His*

Minority, dates from this same period. A visit to Florence in 1641–1642 introduced him to Galileo Galilei's ideas and confirmed him in his hostility to Roman Catholicism. His return to England was delayed by a crisis in his father's affairs. When Boyle was free to return to England in 1644, his father was dead and he had inherited the manor of Stalbridge in Dorsetshire.

Boyle stayed at first in London with his favorite sister, Lady Ranelagh, whose house was a center of intellectual life. There he met Samuel Hartlib (d. 1670?), an enthusiastic educator and intellectual middleman, through whom Boyle was brought in touch with the burgeoning scientific activities of London. In Boyle's correspondence with Hartlib there are several references to their membership in an "Invisible College"; this has generally been identified by biographers with the Gresham's College group out of which the Royal Society was to develop. The "Invisible College" Boyle referred to, however, would seem rather to have been an independent group centering on Hartlib and having an interest in social and educational reform as well as in science.

From 1645 until 1652 Boyle lived in retirement at Stalbridge, remote from the political upheavals of the times. He was still essentially a dilettante, interesting himself—but not too seriously—in chemistry, writing theological tracts of a highly moral character, and composing what was perhaps the first religious novel, *Seraphic Love* (1648). In 1652–1653 he visited his Irish estates; unable to obtain materials for chemical experiments, he studied anatomy under William Petty. The interest in biological processes thus engendered remained with him. In bad health from early manhood, he was particularly interested in the application of chemical methods to the cure of disease and was a diligent collector of prescriptions.

The Commonwealth had appointed a number of London scientists to posts at Oxford; in 1654 Boyle accepted an invitation from John Wilkins to make his home there. Now his serious career as a scientist began. He built a laboratory and employed a number of research assistants, in particular Robert Hooke (1635–1703), later to be curator of experiments at the Royal Society. With Hooke's help, Boyle constructed a greatly improved air pump, experiments with which provided the groundwork for Boyle's first and most important scientific work: *New Experiments Physico-Mechanical touching the Spring of the Air and Its Effects* (1660). Following up the work of Galileo and Evangelista Torricelli, Boyle demonstrated that air has both weight and elasticity and that the phenomena that had traditionally been ascribed to an anthropomorphically conceived "horror of a vacuum" were, in fact, a product of the air's elasticity.

His conclusions created an immediate stir but were not universally accepted. Boyle was criticized on philosophical grounds by Thomas Hobbes, Henry More, and the Jesuit Franciscus Linus (1595–1675), to all of whom he replied in detail. In the course of his reply to Linus, Boyle formulated what is known as Boyle's law. (On the Continent it is called Mariotte's law, Mariotte having confirmed it in 1676.) In the years that followed, Boyle took part in the meetings of the embryonic Royal Society at Oxford, conducted and published a great many experiments, corresponded voluminously with most of the leading thinkers of Europe, studied Oriental languages, actively supported the distribution of the Bible in foreign parts—becoming for that purpose a governor of the Corporation for the Spread of the Gospel to New England and a director of the East India Company—and wrote a considerable number of scientific, philosophic, and theological treatises. After the Restoration most of his scientific friends returned to London; Boyle left Oxford for London in 1668 and lived in Lady Ranelagh's household until her death. He died a week later.

Science and Philosophy

Boyle was profoundly influenced by Francis Bacon's conception of science; much of his published work consists of what Bacon called "histories"—systematic accounts of such qualities as color, firmness, and coldness as they appear under a variety of circumstances. His *Spring of the Air* was the first scientific paper of the modern type. He encouraged scientists to write relatively brief experimental "essays" rather than general treatises. His *Animadversions upon Mr. Hobbes' Problemata de Vacuo* (published in Boyle's *Tracts*, 1674) emphasized the fruitlessness of a priori philosophical reasoning—what Boyle called "book philosophy"—about issues that could be settled only by experiment.

But it is wrong to suppose that Boyle was an opponent of theorizing. He discusses the place of theory in science in his proemial essay to *Certain Physiological Essays and other Tracts* (1661). Scientists, he says, should "set themselves diligently to make experiments and collect observations, without being over forward to establish principles and axioms." Theories ought never to be taken as final; they should be thought of as "the best we have but capable of improvement." Nevertheless, it is the scientist's task to develop theories that are as clear, as simple, and as comprehensive as possible—a point that particularly emerges in Boyle's essay "About the Grounds of the Mechanical Hypothesis" (published in *The Excellency of Theology*, 1674).

Indeed, it was Boyle's main object "to beget a good understanding between the chemists and the mechanical philosophers, who have hitherto been too little acquainted with each other's learning." The corpuscular theory, which Pierre Gassendi had revived, suffered, Boyle thought, in the eyes of practical chemical experimentalists because so little had been done to test it. Theorists had been accustomed to illustrate their theories rather than to test them. On the other side, the work of the chemists had been ignored by physical theorists, largely because it had been associated with theories of a totally inadequate kind.

Doctrine of Matter

Boyle's *The Sceptical Chemist* (1661) is mainly concerned with demonstrating the unsatisfactory character of the standard chemical theories. It is written in the form of a dialogue in which the main speaker, Carneades, attacks not only the traditional theory of elements but also the alchemical theories that had been proposed by Paracelsus and Jan van Helmont. None of these theories, Boyle argued, can be reconciled with experiment, unless they are interpreted in so vague and symbolic a manner as to make them scientifically worthless. As an alternative, he set up the corpuscular theory. It is sometimes said that he also so redefined "elements" as to prepare the way for the modern doctrine of elements; but that is a mistaken interpretation. Indeed, what his chemistry lacked was precisely this modern conception of elements. That is why he was still able to believe in the possibility of alchemical transmutations. In 1689 he secured the repeal of Henry IV's statute against "multiplying gold."

In a sense, however, Boyle's work was too advanced theoretically. Not enough was known about chemical substances to enable the corpuscular theory to be effectively applied in chemistry. Although, in trying to bring together physics and chemistry and chemistry and biology, Boyle anticipated the long-range development of science, the program that he laid down for chemistry was one that for the moment no one knew how to fulfill; the immediate effect may well have been to hold back the development of chemistry. Boyle conceded, it is true, that explanations referring to perceptible properties rather than to the behavior of corpuscles are, at a certain level, perfectly satisfactory; but the general effect of his work was to discourage explanations of the only sort that chemists were actually in a position to offer. His own writings abound in interesting theoretical suggestions—in his *General History of the Air* (1692), for example, he anticipated the kinetic theory of gases—but for a very long time they had to remain no more than suggestions. Although Boyle's actual contributions to science are very few in number, the range of his anticipations is remarkable. He had set out to make chemistry respectable; he had succeeded, many chemists thought, only at the cost of turning it into physics.

Primary and Secondary Qualities

Boyle exerted an important influence on philosophy by lending the authority of a practicing scientist to the corpuscular theory of matter and the associated doctrine of primary and secondary qualities. In *The Experimental History of Colours* (1663), Boyle sets out to demonstrate that color is a "secondary quality" (his own terminology). Objects give rise to sensations of color, he tries to show, not because they are themselves colored but because the structure of their corpuscles modifies light in a special way. The word *color* is most properly applied, he argues, to the modified light that "strikes upon the organ of sight and so causes that sensation we call colour"; if we say that bodies themselves are colored, this can mean no more than that, by virtue of "a certain disposition of the superficial particles," they are capable of refracting or reflecting light.

This thesis is generalized in *The Origin of Forms and Qualities according to the Corpuscular Philosophy* (1666), in which the theory of qualities, which John Locke was to rely upon in his *Essay concerning Human Understanding*, is set forth in detail and contrasted with the Scholastic doctrine of substantial forms. The qualities of a material object, Boyle argues, consist of "the size, shape and motion or rest of its component particles, together with that texture of the whole which results from their being so contrived as they are." These primary qualities of objects, operating upon the "peculiar texture" of a sensory organ, "occasion ideas in us."

Science and Religion

The corpuscular philosophy had generally been associated with atheism. Boyle sets out to show that "by being addicted to experimental philosophy a man is rather assisted than indisposed to be a good Christian" (*The Christian Virtuoso*, 1690). His views about the relation between God and Nature, however, are by no means clear. In "An Hydrostatical Discourse Occasioned by Some Objections of Dr. Henry More," included in *Tracts* (1672), Boyle strongly opposes More's view that mechanical principles cannot explain the phenomena of pressure or any other physical phenomena. We do not need, he says, to have recourse to More's "incorporeal creatures"; mechanism is enough. Yet, at the same time, in *Forms and Qualities* he argues against René Descartes that we cannot account for the behavior of living organisms by supposing that they consist of particles on which God bestowed motion. We have to suppose, Boyle says, that the Creator not only set the world moving but also introduced into it "seminal seeds" that are responsible for the growth and propagation of animal organisms.

Again, in *A Disquisition about the Final Causes of Natural Things* (1688), he expresses his disagreement with those who would reject final causes completely, although he also argues that the scientist, in his day-to-day work, need pay no attention to anything except the size, shape, texture, and motion of particles. At times, indeed, as in *The Excellency of Theology, or the Pre-eminence of the Study of Divinity above That of Natural Philosophy*, Boyle's anxiety about the contemporary tendency to abandon theology in favor of scientific inquiries leads him into a skepticism about science. If theology has its obscurities, he argues, they are as nothing to the obscurities inherent in the scientific account of continuity or of the relation between mind and body. Revelation can tell us far more about the place of man in nature than can science. But the example of Boyle the scientist was more influential than the precepts of Boyle the theologian. His last gesture in favor of Christianity was to leave in his will a sum sufficient to endow lectures for the defense of Christianity against its opponents; his intellectual legacy, however, was the mechanical interpretation of the world that deism took as its starting point.

See also Atheism; Bacon, Francis; Carneades; Colors; Deism; Descartes, René; Galileo Galilei; Gassendi, Pierre; Hobbes, Thomas; Locke, John; Matter; More, Henry; Paracelsus; Physicotheology; Primary and Secondary Qualities; Scientific Method; Scientific Theories.

Bibliography

For a bibliography of Boyle's voluminous works, see John Farquhar Fulton, *A Bibliography of the Honourable Robert Boyle*, rev. 2nd ed. (Oxford: Clarendon Press, 1961). The only complete collected edition of Boyle's *Works*, edited by Thomas Birch, and with a still useful life by Birch that incorporates Boyle's *Account of Philaretus*, was published in London in five volumes in 1744 and in six volumes in 1772. *The Sceptical Chemist* is in the Everyman Library (London, 1911), and *The Weight and Spring of the Air* is in Vol. I of *Harvard Case Histories in Experimental Science* (Cambridge, MA: Harvard University Press, 1957), an anthology edited by James B. Conant.

For works on Boyle, see Edwin A. Burtt, *The Metaphysical Foundations of Modern Physical Science* (London: K. Paul, Trench, Trubner, 1925; rev. ed., 1932), Ch. 6, "Gilbert and Boyle"; Louis T. More, *The Life and Works of the Hon. Robert Boyle* (New York and London: Oxford University Press, 1944); Mitchell S. Fisher, *Robert Boyle, Devout Naturalist* (Philadelphia: Oshiver Studio Press, 1945); Marie Boas, *Robert Boyle and Seventeenth Century Chemistry* (Cambridge, U.K.: Cambridge University Press, 1958)—an excellent book; Richard S. Westfall, "Unpublished Boyle Papers relating to Scientific Method," in *Annals of Science* 12 (1) (March 1956): 63–73, and 12 (2) (June 1956): 103–117.

John Passmore (1967)