1 First Steps

From Alchemy to Chemistry?

In 1980, scientists at the University of California at Berkeley used a particle accelerator to change an unimaginably small sample of bismuth into gold. It cost them $10,000 to make one-billionth of a cent's worth of gold. They showed that transmutation—the conversion of one chemical element into another—is possible today, but it is clearly not a paying proposition. At the beginning of the twentieth century, transmutation was not even within the reach of scientists. And earlier, in the nineteenth century, few chemists had any interest in such a crazy idea, which they regarded as part of a discredited alchemy. Most historians have had little interest in alchemy, except to show how wrong-headed and unscientific it was. Only a few eccentrics continued to search for the philosophers' stone, the fabulous substance that would change base metals into gold. Reputable chemists could not take them seriously.

But in the seventeenth century, alchemy still mattered. The seventeenth century is widely regarded as the age of the Scientific Revolution, the crucial epoch in the rise of modern science. Finding alchemy alive and well at such a time is surprising to those who see science as something essentially modern and alchemy as prescientific and misguided. Many seventeenth-century scientists and some politicians had a very different picture of alchemy. They could reasonably look forward to success with transmutation because their scientific theories could easily find room for it, and they had high hopes of economic as well as scientific benefit. True, no one had yet succeeded in the business of multiplication—the alchemical transformation of a little gold and a lot of base metals into a lot of gold—but several major figures thought a breakthrough was in sight. Robert Boyle (1627–91) was one such figure.

Today, we would call Boyle a scientist, but that word was not invented until the nineteenth century, when it was coined to describe practitioners of the sciences. *Scientist* by the mid-nineteenth century meant a person who studied one or more aspects of the natural world using the methods of chemistry, physics, and the other sciences. In the seventeenth century, those who studied the natural world tended to have broader horizons, deliberately including in their study metaphysical and even theological questions. These investigators saw themselves as natural philosophers, as, for example did Boyle and his contemporary Isaac Newton (1642–1727). Boyle was widely regarded as the leading English chemist of the seventeenth century. He was invited to accept the presidency of the Royal Society of London but declined because he refused to swear any oaths, including the president's oath of office. He used his influence at court to legalize the alchemical production of gold, which had been forbidden in England for nearly three hundred years. In the centuries when it had been illegal, the penalty for practicing alchemy was death. The crown would confiscate the property of a convicted alchemist so that any gold he might have made alchemically would go to the king. This was to avoid flooding the market with manufactured gold and thus destabilizing the economy. That no one before the twentieth century ever made any gold, alchemically or otherwise, had little effect on alchemists and their patrons—or on legal theory. When Boyle was able to have the law against multiplication repealed, the repeal, just like the old law, stated that any gold produced in the laboratory would be deposited in the royal exchequer. Kings had a strong interest in the alchemists' success.

Boyle has been often described as the father of modern chemistry, but if he believed in alchemy as science, then his chemistry must have been very different from ours. As we shall see, it was very different. Chemistry is not something that emerged from a prechemical past, to be defined once and for all. It is, as other historians have noted, the product of its own history and is constantly undergoing changes. Those changes make any definition a limited one—limited in time, in place, and in community. Boyle's chemistry was so different from ours that the author of a recent book about it insists on calling it *chymistry,* using the seventeenth-century spelling to emphasize its special nature. John Aubrey (1626–97), who was not a natural philosopher but was a keen observer and accurate recorder, described Boyle as a great alchemist.

Alchemy too can be seen as the continuously changing product of a history. It is time to identify its main themes and main variants.

Chinese and Arabian Melting Pots

The earliest alchemy that we know anything about was practiced in China by the fourth century B.C. It was interpreted through theories arising from Taoism, which was both a religion and a philosophy. In Taoism and the alchemy derived from it, the universe was seen in terms of opposites. There was an opposition between yang, the principle that corresponded to male, hot, and light, and yin, which was female, cool, and dark. This opposition generated five elements, also understood in terms of pairs of opposites: metal and wood, fire and water, as well as a central element, earth. Here was an explanatory model that could be applied to transformations and transmutations of material substances: change the proportions of the elements, and of their underlying principles, and you change the substances. But transmutation, including the transmutation of base metals into gold, was merely a tool for Chinese alchemy, a means to an end. Chinese alchemists were above all dedicated to discovering the elixir of life, which, when imbibed, would confer immortality—or at least prolong life indefinitely. The elixir was sometimes described as potable, that is, drinkable, gold.

Chinese alchemy was thus essentially medical in its goals. The multiplication of gold was a secondary affair, but it was nevertheless of interest. For once alchemists had discovered the secret of prolonging life, their next task would be to make the conditions of life comfortable, by generating wealth. Here multiplying gold would obviously help, since gold, then as now, meant wealth for its possessor. Because living longer and becoming wealthy were highly desirable, the alchemist-physician and the alchemist-multiplier were both worth employing, in the hope that they would succeed. That meant that serious and honest alchemists could find work, but so could cheats, frauds, and quacks. It did not take long before Chinese literature recognized these twofold divisions, between physicians and multipliers, honest inquirers and frauds.

There is one other distinction that needs to be made in considering Chinese alchemy: transformation of appearance versus transmutation of essence. (This distinction will be equally important when we come to Western alchemy and chemistry.) Jewelers and goldsmiths worked with precious stones and precious metals for wealthy customers. They also produced imitations of these expensive materials, which could, for example, be worn as costume jewelry. They were concerned with appearances, not with essences. Creating the external appearance of gold, whether by covering another metal with gold leaf or by some chemical process that brought gold to the surface of a mixture, required technical skills. These skills could be used openly, so that the purchaser knew he was buying only the appearance of gold, as today we may buy a piece of gold-plated jewelry. Or they could be applied fraudulently, with the intent of deceiving the purchaser, making him think that he had purchased solid gold.

Both fraudulent and honest work in Chinese alchemy, jewelry making, and metallurgy as well as in other kinds of applied chemistry (such as pharmacy) involved practical knowledge, important for alchemy and later for chemistry. The development of furnaces, the control of heat, the making of metallic alloys, the discovery of gunpowder, and the use of solvents all feature in Chinese alchemy. Alchemy remained important in China until the rise of Buddhism, which reached China in the first century A.D.

Was Chinese alchemy important for the emergence of Western alchemy? We do not know for certain, but it may have been. Trade routes and military conquest both involve two-way dissemination of ideas and techniques, and Eastern ideas may have come directly, or filtered through India, into the Greek, Roman, and Arabic worlds. Alexander the Great of Macedon and Greece was pushing eastward in his conquests at about the same time that Chinese alchemy was taking clear shape.

Alexandria, named for Alexander the Great, was a melting pot of cultures, technologies, and people, the intersection of trade routes, and the site of the greatest library the world had ever known. After classical Greece, it became the intellectual center of the Western world, drawing on the traditions of Greece, Egypt, Babylon, Rome, and beyond. Copper smelting had been achieved in the Bronze Age and was commonplace by the time that classical Greece was enjoying its extraordinary intellectual explosion. Metallurgy developed briskly in Greece as well as in Egypt and Babylon. Perfumes, cosmetics, dyestuffs, paints, and decorative pottery all involved the technical skills of applied chemistry—the manipulation, separation, combination, and modification of different substances.

Although these crafts could be practiced without reference to any theory of why they worked, from as early as the sixth century B.C., the ancient Greeks were astonishingly prone to asking why things were the way they were. They were, in short, natural philosophers, philosophers of science, with "science" meaning knowledge of nature. An important strand of Western alchemy began when the Greeks sought to account for empirical observations derived from metallurgical, cosmetic, and other crafts and techniques by constructing philosophical explanations for them. In the sixth century B.C., before the time of Socrates, Greek philosophers had argued that all substances were derived from an original prime matter. Somewhere around 450 B.C., Empedocles sought to explain the properties of matter and its changes by saying that all substances on earth consisted of four elements—air, earth, fire, and water—in different proportions. These elements were intimately mixed, like different colors of paint stirred together, rather than jumbled, like bricks in a heap.

A century later Aristotle (384–322 B.C.), who had been a pupil of Plato and tutor to Alexander the Great, took up the idea of prime matter and Empedocles' four elements, and he added four qualities, hot, cold, wet, and dry. Qualities imposed on prime matter generated elements, which, when mixed, constituted the substances that we find in and on the earth. Earth was cold and dry; water, cold and wet; air, hot and wet; and fire was hot and dry. The pure, or philosophical, elements were never found in isolation, but always mixed with more or less of the other elements. Given this scheme, how were metals formed? Miners found them in the earth, where a natural process had imposed the qualities of metals on the original prime matter. Different metals represented different degrees of acceptance of these qualities. The process could be compared to the biological sequence of conception, pregnancy, and birth: the earth gave birth to metals, which grew in its womb.

We have considered one approach to alchemical theory in classical Greece. By Hellenistic Alexandrian times, alchemists had come to believe that they could replicate in the laboratory the process of the growth of metals and that they could also accelerate it. The goal became to strip metals of their properties, thus reducing them to prime matter, and then to impose the qualities of gold on the resulting undifferentiated mass. As alchemy took shape, the power of imposing qualities was believed to reside in what became known as the philosophers' stone. The process could be tracked by the color of the substances that the alchemist produced, with the color sequence revealing the operation's success or failure. The desired sequence went from lead to a black substance, because black represented the absence of color and was thus appropriate for prime matter. The next colors, in order, were white, yellow, and purple. Goldsmiths had long been interested in the colors of different alloys. Now their skills and experience were useful to alchemists.

Two other lines of thought are especially important for the development of Alexandrian alchemy. These are astrology, which had been established in Babylon before Greece, and Stoic philosophy. Stoic philosophy and Babylonian astrology both posited a cosmos governed by correspondences between great and small, so that what happened locally on earth reflected larger patterns in the cosmos. From this belief there emerged a detailed account of the correspondence of seven metals to the seven known planets, which in the ancient world included the sun and the moon. Gold was matched with the sun, silver with the moon, iron with Mars, mercury with the planet Mercury, copper with Venus, tin with Jupiter, and lead with Saturn. Alchemy, in the light of astrology, depended on the influences of the planets. Stoics added the notion of a world soul or spirit.

It was of course not necessary to be an astrologer in order to be an alchemist. One of the leading Alexandrian alchemists, Zosimus, who lived in the fourth century A.D., was clearly skilled in laboratory manipulations. He was a practical alchemist who knew a lot about distillation, sublimation (converting a solid directly into a vapor by heating it), filtration, the use of furnaces, and more. Zosimus and his contemporaries knew about contemporary techniques in metallurgy, dyeing, glass making, and other applied crafts. They have left us descriptions of apparatus designed and used for alchemical purposes, including a variety of stills and condensers, as well as furnaces, water baths, and sand baths (see Chapter 2). Much of the apparatus used by the Alexandrians was still in use in essentially the same form well into the Middle Ages. Many of the techniques of alchemy and later of chemistry were developed and elaborated in Alexandria at the time of the Roman Empire. But Zosimus was more than a skilled practical chemist. He also claimed to possess the key to transmutation—the philosophers' stone of later alchemists.

From *Arabian Nights* to *Canterbury Tales*

After the Islamic Arabs took Alexandria in the seventh century A.D., the center of learning shifted to Damascus and Baghdad, where renewed growth in alchemy came along with cultural resurgence under the new religion of Islam. Alchemical texts were translated from Greek into Arabic beginning in the eighth century. Under the patronage of Harun al-Rashid, who is best known today as the caliph in the tales of the *Arabian Nights,* scholars translated Hellenistic alchemical tracts into Arabic. Later scholars in Christian Europe attributed some of these translations, other original alchemical manuscripts, and numerous technical alchemical skills to Jabir ibn Hayyan, who is said to have lived from around 721 to around 815 and to have been court physician to the caliph. Unfortunately, it is probable that Jabir never existed. It was convenient, however, for later medieval scholars to attribute both writings and technical advances in alchemy to a distinguished predecessor, even an invented one. I shall write of him as if he existed, but I shall place his name in quotes as a reminder of his status, which is at best hypothetical.

"Jabir," or at least the school associated with him, made numerous contributions to laboratory practice, including refined techniques of distillation, the preparation of medicines, and the production of salts. The determination of Arabic alchemists to find the constituents of chemical substances led them to the discovery and use of strong reagents, chemically active substances used to test for the presence of a variety of other substances. They also developed theories to account for the action of those reagents. Acids, for example, could corrode a metal, a process that the alchemists interpreted as the separation of the metal into its constituents. When those constituents had been reduced to their elements, they were expected to work powerfully in producing the agents of transformation. If this were so, then analysis and subsequent synthesis could

contribute to the discovery of the philosophers' stone, sometimes known as the "elixir."

Like Aristotle, "Jabir" believed that metals grew in the earth. Aristotle had adopted Empedocles' four elements, but he interpreted the birth of metals to the combination of a wet and a dry exhalation arising from the earth under the influence of the heat of the sun. Following Aristotle, Arabic alchemists distinguished philosophical elements or principles from the substances of everyday experience. "Jabir" linked Aristotle's wet and dry exhalations with philosophical Mercury and Sulfur, which were different from and purer than the mercury and sulfur of the laboratory. By purifying everyday mercury and sulfur and appropriately adjusting their proportions, the alchemist could make gold. The making of gold and the extension of life were both important in Arabic alchemy.

Theory and practice were closely entwined for the Arabic alchemists of the eighth and ninth centuries. They asserted that every substance contained its opposite, in a hidden, or occult, way. Silver was cold and dry externally, but hot and wet internally. Gold was hot and wet externally, but cold and dry internally. In order to make gold one therefore needed to exchange the internal and external qualities of silver.

Medicine, metallurgy, and all the applied arts involving chemistry and alchemy thrived in the first centuries of Islam. So did the armies of Islam, sweeping from the Middle and Near East westward across North Africa and then northward to conquer the Iberian Peninsula (now Spain and Portugal). Spain under Islamic rule saw a flourishing of Jewish scholars and at first a tolerance for Christian scholars, alchemists among them. It was through Spain and its Arabs, gradually reconquered by Christian forces, that Greek, Alexandrian, and Arabic alchemy made their way into the Christian West.

Christian scholars translated Greek and Arabic texts into Latin. Their translations were often accompanied by a good deal of revision and modification. A thirteenth-century Italian Franciscan alchemist called himself Geber, the Latin version of "Jabir," to take advantage of "Jabir"'s august reputation. The works of Geber were indeed based on Arabic alchemy, but with significant modifications. Geber's system included a kind of corpuscularianism grafted onto the original stock, so to speak, such that inner and outer qualities could be reinterpreted in terms of inner and outer layers of minute particles, or corpuscles. Corpuscularianism is like atomism, but with one crucial difference: atoms, by definition, are indivisible, or at least they were believed to be indivisible prior to the discovery of subatomic particles in the modern age.

Geber dealt with corpuscles that could in principle be divided. His mercury could penetrate into metals and modify their inner structure, a step on the way to the transmutative production of gold.

Geber's writings also indicated that alchemical success was God-given, an attitude that reinforced the spiritual aspects of medieval alchemy. The quest for the philosophers' stone came to be seen as a metaphor for the salvation of the soul, and alchemical imagery increasingly used Christian metaphors, including references to death and rebirth. The destruction of qualities—for example, "stripping" lead of its metallic properties—corresponded to death; the alchemical production of gold was then a kind of resurrection. The oppositions that Arabic alchemists had written about (e.g., the opposition between philosophical Sulfur and philosophical Mercury) were also described in sexual terms. It is often difficult to know whether the imagery of alchemy was merely metaphorical or the correspondences implied were seen as real. Meanwhile, laboratory practice advanced. Alchemists extended their knowledge and classification of salts and produced stronger corrosive solvents, first nitric acid, then hydrochloric acid, and finally sulfuric acid.

Even before alchemy entered the Latin West, Arabic alchemists and physicians did not all agree about the possibility of transmutation. From the tenth century on there was a lively debate, with some following "Jabir"'s lead and others insisting that metals were natural species, just like animals and plants, and were not interconvertible or transmutable. The debates persisted when alchemy spread into Christian Europe. It is not surprising that in the following centuries, alchemy maintained its mixed reputation and wide embrace, encompassing both attempts at transmutation and what we would recognize as practical science (including metallurgy and, increasingly, chemical medicine).

Literary and popular satire took gleeful aim at fraudulent alchemists. A splendid portrait of such a character figures in one of Chaucer's *Canterbury Tales,* "The Canon's Yeoman's Tale." The narrator is servant to a shabby, unsuccessful, and imaginatively fraudulent alchemist. If the canon's claims were to be believed, he could use his alchemy to take the pilgrims' route to Canterbury "and pave it all with silver and with gold!" But when he hears that his servant is about to tell all, he makes a hasty departure. The servant decides that he is finished with his master and does indeed tell all. With a stained and sooty face, the result of endlessly blowing into the fire to keep it going, he explains that their goal was to learn to multiply, to turn a little gold into a lot. Failure in this enterprise never stopped them from tricking gullible and greedy patrons:

But there are lots of folks that we take in,
And borrow gold from—say a pound or two,
Or ten, or twelve, or many times that sum,
And make them think the very least we'll do
Is double the amount: make one pound two.*

Hide a little gold or silver up your sleeve, or conceal it in a hollow rod sealed with wax that melts on warming. Then introduce the gold or silver into a crucible when the victim-to-be is not looking, and tell him that the metal was produced by multiplication. Once he is persuaded that he has seen multiplication at work, he will readily come forward with his own gold or silver, for further multiplication or transmutation. Then take the money and run. By such tricks, the canon conned his victims into supporting his alchemical endeavors. But even in the case of such a cheat, it is important to recognize that he used fraud to finance earnest attempts to discover the philosophers' stone.

The yeoman's tale includes a good deal of technical information, making it clear that the range of substances available to the alchemist had expanded greatly since Alexandrian times. He tells of the importance of correct proportion by weight of substances (including the bright golden-yellow arsenical pigment called orpiment) which are ground to a powder, put into an earthen pot, and luted, that is, sealed with clay or cement to make sure that nothing, not even air, escapes. He notes the different degrees of heat used and describes processes such as amalgamation (the softening of metals by combining them with mercury, or the union of two or more metals into an alloy), calcination (applying a roasting heat to nonfusible substances), and sublimation. He runs through a list of apparatus made of earthenware and glass, much of it for distillation. He recites the names of salts, other minerals, herbs, acids, solvents, and "divers powders, ashes, dung, piss, and clay." And he recites the correspondence of the names of planets with different metals, a correspondence that popular belief in astrology had made well known by Chaucer's day.

Paracelsus: Nature as Alchemist

Alchemy saw significant advances in the range of techniques and the knowledge of mineral and plant substances from the fourteenth to the sixteenth century. There was also the addition of a kind of atomism to the basic theory and a growing emphasis on the multiplication of gold instead of medical alchemy.

*Geoffrey Chaucer, *The Canterbury Tales,* trans. David Wright (Oxford: Oxford University Press, 1985), 427–50, at 430.

These changes were not seen as revolutionary. But in the sixteenth century there came an individual who had no interest in having his works attributed to past alchemists or physicians, as he was sure he was better than all of them. His unwieldy name was Theophrastus Bombastus von Hohenheim (1493–1541), but he called himself Paracelsus as a way of claiming superiority to the great Roman physician Celsus (para-, or παρα-, is Greek for past or beyond).

He created a revolution in alchemy and in medicine, which for him were two intimately related disciplines. He had little interest in making gold by multiplication or other transmutative processes. For him, alchemy was most valuable, perhaps only valuable, when it was used in the service of medicine. He rejected the mercury-sulfur theory that Arab alchemists had grafted onto Aristotle's wet and dry exhalations. This theory of two elements (a dyad) was inadequate for Paracelsus. He saw sicknesses as distinct and specific, arguing that distinct and specific medicines were needed to cure them. This was in complete revolt against the reigning medical theories of his time. These theories, following the Greek physician Galen, posited four humors akin to Aristotle's four elements and saw sickness as the result of humoral imbalance, thus medicine operated mainly by adjusting the imbalance through bleeding, purging, and similar debilitating treatments. The treatments, like the overall perception of illness, were systemic and general, not specific and local. Paracelsus aimed to overthrow traditional medicine along with traditional alchemy. He was a revolutionary and an iconoclast.

If alchemy was a servant for Paracelsus, it was also a glorious and powerful one. He saw the transformation of the invisible into the visible as essentially alchemical, and so regarded the processes of living nature as alchemical. The growth of animals and plants, the ripening of fruit and vegetables, the processes of fermentation in making beer and wine, the digestion of food, indeed all natural processes involving transmutation, growth, and development were alchemical. Nature was an alchemist; and God, who ruled Nature, was the supreme alchemist.

Medieval alchemists had generally adhered to a dyad theory, in which Sulfur and Mercury were the principles of all metals and change was produced by the interaction of these two principles. Substances rich in Sulfur were more combustible, while those rich in Mercury were less so. Paracelsus took this dyad theory and added a third principle of Salt to it. His three principles—the *tria prima,* or three first things—were able to explain the alchemical transformations of all bodies. This material trinity matched the Holy Trinity in heaven as well as the three principles of which we are made: vital spirit, soul, and body. Important in this scheme are correspondences between the great world, the *macrocosm,* and the little world, or *microcosm,* of our bodies, between heaven and earth, and between alchemical processes in the laboratory and physiological processes in the human body. The overall theory, like its predecessors in alchemy, was of exceeding generality. But when it came to medicine, Paracelsus got down to particulars.

He looked for specific causes and symptoms of distinct diseases. He worked in mining regions of German-speaking lands, and one of his achievements was to identify both a lung disease of miners (silicosis) and its cause in miners. Where treatment involved medicine, alchemy was essential for Paracelsus. It was the science of the preparation of medicines.

Paracelsus was the founder of medical chemistry, known as *iatrochemistry,* to which we shall return in Chapter 3. After him came a Flemish alchemical physician, or iatrochemist, Jan Baptista van Helmont (1579–1644). Van Helmont combined Paracelsus's organic, or biological, model with the corpuscularianism of Geber. He used Genesis, the first book of the bible, as a guide to his matter theory. There was no element of fire in Genesis, so he rejected it as an element. The bible tells of water *above* the firmament, which for him meant that heaven and water were made prior to earth. He concluded that there were two original elements, air and water. Water was the primordial substance, within which sulfur and mercury somehow form distinct but inseparable parts. The mercury and sulfur could be rearranged, and so could mask or change the appearance of water. This process of masking was at the heart of Van Helmont's most famous experiment, in which he potted a willow sapling with some earth and weighed it. He watered it regularly over a period, weighed it again, and then deduced that the increase in weight and the growth of the sapling had to come from water, since it had not come from the soil and water was the only substance that had been added.

Looking Both Ways: Isaac Newton

When Robert Boyle began his work, alchemy was alive and well. It was widely although far from universally used in medicine. The search for the philosophers' stone was still taken seriously by leading natural philosophers, and many kings and princes were keen to have their own alchemists. Corpuscularianism was also alive and well, and Boyle was able to combine the latest brand of corpuscularianism with alchemy, to powerful effect. He did not accept Paracelsus's element theory, nor was he keen on Van Helmont's; and he was not much impressed by the way in which seventeenth-century iatrochemists had added phlegm and earth to Paracelsus's *tria prima.* But he did believe that transmutation was possible and that the alchemical production of gold by multiplication was a reasonable prospect. He was willing to put his money where his mouth was and to pay for knowledge as well as to seek it in the laboratory.

Boyle was also a close colleague of another natural philosopher, who would come to have even greater distinction than he, Isaac Newton (1642–1727). Newton's crowning achievement was the elucidation of the law of gravitation and its application to celestial and terrestrial phenomena. He was a professor of mathematics at Cambridge University. He was also for many years president of the Royal Society of London and, more briefly, a member of Parliament and Master of the Mint. He was, in short, the very model of a modern major scientist and statesman of science. Until recently, historians have accepted that strict model and been reluctant to recognize that he was also a serious student and practitioner of alchemy. It is arguable that alchemy was as important to him as mathematical physics and astronomy. Newton and the age in which he lived were clearly more complex than the old historical model perceived.

Newton was engaged in alchemy for more than forty years. These years spanned the writing of his two great books, *The Principia: Mathematical Principles of Natural Philosophy* (first edition 1687), and *Opticks* (first edition 1704). He studied the literature of alchemy and was profoundly absorbed in its experimental practice, so much so that he has been well described as a "philosopher by fire." Newton, both in his accounts of universal gravitation and in his pursuit of alchemical transformation and transmutation, talks about God and discusses active principles, the tools of divine activity in the world. The God-grounded unity of truth meant for Newton that all avenues to truth, including alchemical wisdom and experiment, were mutually reinforcing.

He was a corpuscular philosopher. Early on, Newton became convinced that matter came from a single root, such that there was a unity of matter. That made transmutation possible in principle. As he wrote in the first edition of his *Principia,* "Every body can be transformed into a body of any other kind and successively take on all the intermediate degrees of qualities."* The question was how to effect such transformations. He looked to a universal vegetative principle, a material spirit and source of activity that would generate gold from a metallic seed or semen. He sought the substance that would best embody that principle, which, when combined with the action of fire, would first reduce a substance to chaos, like the prime matter of the Greeks, and would then move on to generation.

As a corpuscular philosopher, Newton was able to echo Geber, with inner and outer qualities of matter, and to explain transmutation as the result of

*Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy,* trans. I. Bernard Cohen and Anne Whitman (Berkeley and Los Angeles: University of California Press, 1999), 795.

changes in the inner arrangement of matter and of qualities. Mere changes in arrangement corresponded to mechanical chemistry, while a living vegetative spirit, the alchemical carrier of divine activity in the world, produced more profound changes. Newton's God was an active God, forever working in nature, and was in part an alchemist. This spiritual dimension of alchemy encouraged Newton to be cautious and even secretive when it came to transmutation. With his laboratory in Cambridge where he spent so many hours in the experimental pursuit of alchemical wisdom, Newton looked back to the great alchemists of the past as his guides.

Alchemy began in antiquity, as a practical and a theoretical or philosophical pursuit. Combining theory and practice, it has to be taken seriously as science. Its fundamental theories were wrong, but that does not rule it out as science. Most old science turns out to have been wrong, including much of Newton's work on optics. Einstein's relativity has overtaken Newton's mechanics. But Newton's science was still good science, providing a framework and a tool for the acquisition and organization of knowledge. Much of our science today will, sooner or later, be old science, and future scientists will reject much of it.

Alchemists, over a period of hundreds of years, devised apparatus and instruments as well as techniques for using them that remained valuable even after alchemical theories had been discredited. They constantly extended the range of known chemical substances and developed criteria for identifying and classifying those substances. They developed and refined notions of purity (as we shall see, the question of the purity or impurity of reactants has a major role to play in the history of chemistry). Not least among the achievements of alchemists was their success in establishing their science upon a succession of theoretical foundations. It was possible, at least until the end of the seventeenth century, to integrate alchemy with major trends in the growth of contemporary science, such as medical chemistry and mechanical and corpuscular philosophy. It is worth noting both continuity and discontinuity in the history of alchemy. As we have seen, here was a science that underwent more than one revolution of its own before the Scientific Revolution of the seventeenth century. As will be clear from the example of Robert Boyle, the leading English practitioner of alchemy, chymistry, and chemistry during the Scientific Revolution, it is simply not possible to make a sharp separation between alchemy and chemistry in the seventeenth century.