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For Charles and Juliana

CHAPTER 2

INSTITUTIONAL HISTORY: THE HIGH AND LATE MIDDLE AGES

Between 1000 and 1300, Europe changed from an intellectual backwater to one of the most intellectually innovative cultures of the world. This process happened in several stages. From about the year 1000, there are numerous signs that medieval thinkers developed a new and original appreciation of nature. In the words of one important historian, twelfth- and thirteenth-century thinkers "thought of themselves as confronting an external present, intelligible, and active reality as they might confront a partner."[1] The personification of nature as a forceful and imperious goddess appeared everywhere in literature, detailed and accurate relief sculptures of local plants appeared on church exteriors, and "the natural" became a new touchstone for what was considered normal and appropriate behavior. This new awareness of nature was supported by an increasingly dynamic economy, greater social mobility, and new political, religious, and intellectual institutions. From the twelfth century onward, medieval scientists explored a vast array of scientific and related questions, ranging from the obscure ("whether light is an accidental form") to the very broad ("whether the existence of a vacuum is possible") to the seemingly bizarre ("whether aborted fetuses are resurrected").[2] Underlying this extraordinary flowering of speculative scientific thinking was the enthusiastic pursuit of the idea that nature proceeds by its own internal, rationally accessible laws, in the same way as an architect or engineer plans and executes a building (see Figure 1). The idea that nature has its own autonomous, ordered realm and does not require divine intervention for its operations is a fundamental pre-

Figure 1. God as architect of the universe. Late thirteenth century, France. This image expresses the medieval view that God created the universe in an organized and intelligent manner, endowing it with an orderly, harmonious, and rational structure. It also reflects a common description of God as a divine Craftsman. *Vienna, Österreichische Nationalbibliothek, Ms. 2554, fol.1.*

requisite for the development of science as a discipline. Although some medieval theologians objected to the enthusiasm with which natural philosophers embraced science and took issue with scientists on particular points, overall the principle that reason could explain the workings of the physical universe remained one of the basic tenets of medieval thought.

In the twelfth and thirteenth centuries, medieval science was also shaped by two key events: the recovery of classical and Arabic science and philosophy, chiefly the work of Aristotle, Ptolemy, and Galen and the Arabic commentaries on these works, and the invention of the university. These elements provided the basis for continuing achievement in all fields of science. The works of Aristotle provided a comprehensive, working body of scientific principles and knowledge; the adoption of Aristotelianism as the standard curriculum for the study of natural philosophy in the universities ensured that large numbers of students and teachers were familiar with current scientific knowledge and that science had an institutional home. These events fused with the development of scholasticism, a distinctive form of analysis which presents "pro" and "con" arguments on carefully defined questions. Scholasticism had its origins in the speculative atmosphere of the twelfth-century renaissance but soon became the basic method of intellectual argument in the universities of the twelfth and later centuries. Although scholasticism has sometimes been derided as trivializing and divorced from real-world realities, it also encouraged looking at questions from all possible sides and therefore promoted intellectual questioning. These developments made medieval science a vital and ever-evolving enterprise. At the same time, anonymous inventors and artisans both adapted old technologies, devices, and machines into more efficient and useful forms and produced new inventions. By the end of the Middle Ages, Europe had become the most technologically and scientifically advanced area of the world. In the remainder of this chapter we will follow the institutional and intellectual contexts of the development of medieval science in the crucial period from around the year 1000 to around 1300 in more detail.

REVIVAL IN THE TWELFTH CENTURY

Around the year 1000 C.E., medieval Europe entered a period of renewed security and prosperity. The attacks by Muslims, Vikings, and Hungarians which had plagued Europe during the early Middle Ages ceased and Europe began to go on the offensive, launching, for example, the First Crusade in 1096. Accompanying this new sense of confidence were the growth of cities and towns, the development of new commercial networks, the emergence of more organized governments, and a renewed creativity and vigor in art and intellectual pursuits.

New technologies were a crucial part of this revitalization of medieval culture. New agricultural techniques expanded the food supply, leading to an increase of population and consequent urbanization (see Chapter 6). These economic and social developments fueled the revival of European society, including a remarkable intellectual revival often called by historians the Renaissance of the Twelfth Century. Although we should not overlook the continuities between the early Middle Ages and the twelfth century, we should also recognize a new widening of intellectual horizons from the late eleventh century onward. Medieval writers began to explore a great range of speculative ideas about the formation of the cosmos, the fundamental elements of the physical world, and the nature of the human organism. Underlying these efforts was a vision of nature as a "harmonious, lawful, well-ordered, self-sufficient whole" whose workings could be fruitfully explored by human reason.[3] During the twelfth century, we also see a new interest in the human possibilities of mastering nature and in making technology, now called "the mechanical arts," a recognized part of philosophy. If early medieval science had depended almost entirely on the authority of past authors, by the twelfth century medieval thinkers had begun to make original contributions to a scientific understanding of the world.

Especially important for the revival of scientific thought at this time was the emergence of new educational institutions in towns and cities. Cathedral schools (called this because they were usually attached to the local cathedral) founded in the leading urban centers of Europe gradually eclipsed the old monastic schools in the tenth and eleventh centuries. The most important of these new schools were in France, in Paris, Laon, Orleans, and Chartres, but there were also cathedral schools in cities in Spain and Germany. These schools, which taught a great variety of

subjects ranging from grammar and literary studies to law and theology, attracted large numbers of students. In these schools we see the first evidence of new scientific thinking and speculation since the hey-day of the Roman Empire.

Although many students at the cathedral schools were more interested in ethics and "letters," by the beginning of the twelfth century some scholars had developed an intense, lively interest in the study of nature. These clerics celebrated the possibilities of human reason, even as they assumed that whatever they discovered would ultimately harmonize with Christian thought and belief. Adelard of Bath (c. 1080–1142), the author of a book on natural science and one on birds, for example, complained about his contemporaries, "these days you generally have the kind of listeners that demand no argument based on judgment, but trust only in the name of an ancient authority. For they do not understand that reason has been given to each single individual in order to discern between true and false with reason as the prime judge."[4] William of Conches (d. after 1154) more colorfully attacked those who condemned the pursuit of scientific knowledge: "Ignorant themselves of the forces of nature and wanting to have company in their ignorance, they don't want people to look into anything; they want us to believe like peasants and not to ask the reason behind things . . . but we say that the reason behind everything should be sought out. . . . If they learn that anyone is so inquiring, they shout out that he is a heretic, placing more reliance on their monkish garb than on their wisdom."[5] Most importantly, these thinkers articulated a vision of nature as harmonious, orderly, and designed for human use. Nature could not only be understood by men, it could also be used to benefit human life. Hugh of St. Victor (d. 1141), for example, promoted the idea that the different types of technology, which he named the "mechanical arts," like the arts and sciences, both demonstrated the brilliance of human reason and were part of the human task of salvation and the restoration of the lost Paradise of Adam and Eve.[6]

The twelfth century was also a period in which the tradition of learned religious women reached its greatest influence. Hildegard of Bingen (1098–1179), the celebrated abbess of Rupertsberg near Bingen, wrote highly original works on medicine, cosmology, and physics. Her insight into women's physiology was perhaps unique in the Middle Ages.[7] Heloise (1101–63), the student, lover, and wife of the philoso-

pher Abelard, almost certainly contributed to the development of his thought. Although she is not known to have written on scientific subjects, it is perhaps significant that she named her son Astrolabe, the name of the state-of-the-art astronomical instrument of her time.

THE INSTITUTIONALIZATION OF MEDIEVAL SCIENCE

By the late twelfth century, the cathedral schools had begun to be replaced by universities. The university, a medieval invention, was the first educational institution in history to provide a required curriculum and a systematic program of study and examinations leading to the awarding of a recognized degree and professional licenses. During the same period, scientific thought in medieval Europe was slowly transformed by the rediscovery of Greek thought and science, especially the works of Aristotle. As we have seen, Arabic scholars had sought out Greek learning and science and had translated the major works of Aristotle and other Greek scientists into Arabic during the ninth century. They also had added their own ideas to those of Aristotle, sometimes challenging Aristotle, sometimes modifying his ideas. This great body of work had a profound effect on the development of medieval science. Texts by Aristotle and his Arabic commentators became the basis for the university curriculum and hence for the scientific thought of medieval Europe until the sixteenth and seventeenth centuries.

The process of rediscovery was initially rather haphazard. Medieval scholars traveled to Spain to acquire manuscripts about which they had heard but never been able to read, often hiring Jews to translate Arabic versions of ancient Greek texts into Latin. Others learned Arabic themselves. The most famous of these translators, Gerard of Cremona (c. 1114–87), single-handedly translated over seventy works, including the basic scientific works of Aristotle and Greek and Arabic astronomical, mathematical, and medical works. Sometimes works were translated from Arabic into Spanish or Hebrew, and only then into Latin, having previously been translated from Greek to Syrian to Arabic. It is not surprising that errors and shifts in meaning crept in. Awareness of these problems fueled a second wave of translations directly from the Greek beginning in the late twelfth century and continuing to the late thirteenth century. By about 1286, the bulk of this wave of translation had been completed, although medical works continued to be translated during the first half of the fourteenth century.

The medieval university provided the institutional and intellectual setting for the integration of the work of the translators into the larger framework of medieval culture. Aristotle was crucial in this development because he provided a model for investigating the natural world through both rational inquiry and empirical observation. Although much of his approach and conclusions were eventually to prove faulty, his work provided a comprehensive, plausible, and systematic explanation of the workings of virtually all aspects of the physical world. Aristotle was considered so authoritative in natural philosophy that he was referred to simply as "the Philosopher." Yet medieval scientists did not simply blindly follow his ideas and their respect did not prevent them from challenging aspects of Aristotle's thought. As we shall see in Chapter 4, for example, modifications to Aristotle's theory of motion put forth in the late Middle Ages were part of the background to the emergence of modern physics during the Scientific Revolution.

THE STRUCTURE OF THE UNIVERSITY

The name *university* is derived from the Latin term *universitas* (corporation or whole body), which meant any group of people with a common aim or function; a university was a group of masters (trained scholars) and students (apprentice scholars) formed to organize, disseminate, and expand the boundaries of knowledge. Such corporate organizations were common in the Middle Ages and they served to protect and organize the interests of their members. The guilds of merchants or craftsmen were one example of such a corporate identity; universities were another. Being a student or a master conferred certain rights and privileges, as well as status: in some contexts, scholars were considered a new order of nobility, along with the older feudal aristocracy of lords and vassals. Scholars spoke and wrote in a privileged language, Latin, and were also distinguished by being an all-male community; women were excluded by law from both the cathedral schools and the universities, although limited educational opportunities remained for a time for women within the confines of the nunnery. At least one medieval woman is known to have put on male clothing and pretended to be a

man in order to get a university education. In the northern universities both students and masters were typically counted as clerics, a fact which explains the graduation robes still worn today.

The origins of individual universities are obscure. However, historians know that by the end of the twelfth century new associations based on learning had emerged in Paris and Oxford in France and England, respectively, and in Bologna and Padua in Italy. These first universities provided the models for virtually all later universities. The northern and southern universities differed in several ways. Paris and Oxford were governed by teachers in the liberal arts, most of whom were members of religious orders, and took the lead in the sciences, medicine, and mathematics during the thirteenth and fourteenth centuries. At Paris and Oxford, as well as the universities modeled after them, masters received support and time off from preaching and other religious duties in order to teach and pursue their own studies. Bologna and Padua, on the other hand, were run by the students and initially specialized in law and medicine, as well as the liberal arts. At these universities many of the masters were laymen and received a salary for teaching from the students as well as fees from their own practices in medicine and law. By the late Middle Ages from the late fourteenth through the sixteenth century, the northern universities had declined and the Italian universities had become the most important centers for scientific learning. By the end of the Middle Ages, there were over seventy universities in Europe and at least one in almost every major region.

The curriculum and teaching methods of the university had important effects on medieval ideas about the nature of science and scientific method. Knowledge was organized in a hierarchical fashion. Students pursuing a "bachelor of arts" degree followed a planned program covering first the seven liberal arts, then philosophy and natural philosophy (including metaphysics, physics, psychology, and biology), and finally moral philosophy (politics, economics, and ethics). This course of study was largely based on Aristotle and some other Greek texts, especially Ptolemy's *Almagest* and Euclid's *Elements of Geometry*, but gradually more contemporary textbooks were added. The emphasis on grammar, literature, and rhetoric was gradually reduced in importance over time but the study of logic continued in importance, as did that of mathematics and astronomy. Advanced degrees were offered in theology, medicine, and, in some universities, law. Medicine was especially important in the

Italian universities and had a strong practical as well as theoretical component.

Teaching depended heavily on the production of commentaries on authoritative works and disputations or debates on specific questions. This method, which came to be called scholasticism, grew out of twelfth-century attempts to organize knowledge and subject it to critical analysis. A typical discussion was initiated by the enunciation of a specific problem posed in yes or no format. A series of possible answers followed, in turn followed by a statement of the correct position, which was explained and developed in detail. Finally, there was a point-by-point refutation of the initial series of answers. This procedure allowed for a systematic exploration of the arguments both for and against the question being examined. You may recognize in this method the origins of modern ideas about the format of a balanced debate and some types of essay questions.

The development of scholasticism was intertwined with the foundation of two new preaching orders, the Order of Preachers founded by St. Dominic in 1216 and popularly known as Dominicans and the Order of Friar Minor, or Franciscans, founded by St. Francis of Assisi and given papal approval in 1208. The Franciscans and Dominicans gave priority to study and learning as prerequisites for effective preaching. Both became renowned for their learning and recruited many masters into their ranks. Many of the important scientists found in northern Europe during the High Middle Ages, including Albertus Magnus, Roger Bacon, and Robert Grosseteste, were either Franciscans or Dominicans.

The university curriculum and method of teaching produced students and scholars who were highly trained in the technical vocabulary of philosophical and scientific subjects and highly skilled in logic and the techniques of rational argument. As we shall discuss in more detail in the following section, this education encouraged an approach that was more theoretical than practical in its orientation and that depended on "book learning" more than firsthand observation or experimentation. This dependence on a priori reasoning, that is, reasoning which began with a premise assumed to be correct, perhaps hindered medieval scientists from making breakthroughs based on new observations of the natural world. However, university students and masters also learned skills and attitudes of mind which promoted careful, precise thinking and what one historian of science has called " 'the culture of poking

around,' or the irrepressible urge to probe into many things."[8] These habits of mind had a lasting impact on the history of western science and western culture generally.

SCIENTIFIC METHOD

Like the ancient Greeks, medieval scientists conceived of science as an attempt to discover the changeless reality which lay behind sense perception and the seemingly chaotic and random changes which individual physical objects, both living and nonliving, underwent during their limited life spans on earth. In a very general sense, this remains the goal of science even today. Yet, unlike modern science, which aims to accumulate progressive knowledge to be manipulated for the benefit of mankind, medieval science, as we have seen, sought primarily to illustrate eternal truths. Medieval scientific method reflected this different understanding of the scientific enterprise, as well as different theoretical premises. Medieval scientists, for example, tended to describe natural phenomena in qualitative terms and often failed to make even simple measurements, in large part because of the overwhelming influence of Aristotle. Aristotle, unlike Plato, had ignored the potential of mathematics in understanding the natural world and, as we shall see in Chapter 3, instead emphasized the idea of inherent qualities (hot, cold, wet, dry) which determined natural processes. Although some important scientists in the fourteenth century began to pay more attention to measurement and the application of mathematics to physical processes, the full understanding that nature could be best understood through the discovery of mathematical laws was not achieved until the seventeenth century.

For the most part, medieval scientists also paid comparatively little attention to systematic empirical confirmation of scientific theories and demonstrated little awareness of the concept of controlled experimentation as a way of testing scientific ideas. In the words of Edward Grant, a noted historian of medieval science, "Medieval observations were not introduced for their own sake, namely, to learn more about the world, or to resolve arguments. They were intended rather to uphold an a priori view of the world, or to serve as an example or illustration."[9] Medieval astronomers, for example, observed comets but rejected the view that they were celestial objects because this conflicted with the assumption

that the celestial realm was changeless and incorruptible. Like the ancient philosophers, medieval scientists were more concerned to explain *why* physical events happened according to underlying principles than to deduce through physical experiments *how* these events happened; instead, they often relied on "thought experiments," designed to test one logical supposition against another.

At the same time, medieval scientists did add substantially to the store of scientific knowledge available at the time and began to expand the boundaries of scientific methodology and ideas about the purpose of scientific activity. They raised myriad questions about the application of Aristotelian theory to particular issues, often refining previous answers or resolving inconsistencies. Medieval scientists made consistent efforts to observe the natural world in a precise and systematic way. Albertus Magnus, for example, discussed in the following section, reportedly made personal observations of the same eagle's nest over a period of six years while compiling information on native European birds.[10] Contemporary herbals contained hundreds of careful descriptions of local plants, their curative properties, and directions on finding and collecting them. Other natural philosophers recognized the potential and importance of mathematics, even if they failed to apply this insight in a systematic manner. In the thirteenth and early fourteenth centuries, scholars pioneered in the development of the application of mathematics to optics, especially the problem of refraction. At least one scientist, Theodoric of Freiberg (d. c. 1310), claimed to have performed experiments with prisms. In the fourteenth century, some scholars had begun to explore the notion of velocity, "impetus" (the force impressed on a moving object which caused its motion), and other questions in the field of dynamics and had attempted to formulate "a conceptual and a mathematical framework suitable for analyzing problems of motion."[11] During the twelfth and thirteenth centuries, also, many thinkers, including Hugh of St. Victor (d. 1140 or 1141), Roger Bacon (c. 1219–92), and Robert Kilwardby (d. 1279), came to include technology as an important aspect of human knowledge.

THE RELATIONSHIP OF SCIENCE AND RELIGION

Jacques Le Goff, a noted medievalist, once wrote, "nothing could become an object of conscious reflection in the Middle Ages except by

way of religion."[12] In other words, medieval thinkers saw the world through religion-colored glasses and science was no exception to this rule. Science, like philosophy, was regarded as the handmaiden of theology, and ideas about science were ultimately inseparable from ideas about God. Yet this did not mean that science was shortchanged in the Middle Ages. Although some religious figures dismissed knowledge of the natural world as irrelevant to the Christian life, more often writers used religious values to justify the pursuit of scientific and technological knowledge. Even a writer such as St. Bonaventure (1221–74), a Franciscan who expressed profound distrust of philosophy as a dangerous distraction from faith, wrote a work in which he explained how knowledge of every art and science functioned for human welfare and manifested Divine Wisdom. On the whole, it is remarkable how *little* conflict there was between religion and science in the Middle Ages.

A brief look at some of the most important natural philosophers of the High Middle Ages will illustrate some of the ways in which science and religious values interacted. Robert Grosseteste (c. 1168–1253), a master at Oxford associated with the Franciscans, was influenced by both the new philosophy of Aristotle and Neoplatonic thought. Grosseteste developed the philosophical idea of knowledge as divine illumination from the Platonic and Augustinian traditions into a natural philosophy based on a theory of light as the fundamental element of creation; for Grosseteste, the mathematical and physical study of light was the key to understanding how nature worked. His student, Roger Bacon (1214–92), a Franciscan master at Oxford, argued that all knowledge, including natural science, had been given to man "by one God, to one world, for one purpose," that is, to aid faith. Among other things, Bacon was responsible for an innovative theory of optics. Bacon wrote several lengthy manifestos to the pope in which he pleaded for the implementation of a program of scientific projects to aid in the defense of Christendom against her enemies. Especially important, Bacon argued, was the study of mathematics and "experimental science," which would yield new weapons and mechanical devices including mirrors to focus the rays of the sun on enemy armies, explosives, medicines which would marvelously prolong life, cars that would move with great rapidity without the aid of animals, and flying machines. Although Bacon ultimately subordinated science to religion (one of his sources for scientific knowledge was revelation from God), he articulated a vision of scientific progress which looks remarkably modern.

Albertus Magnus and his student Thomas Aquinas took a different route. Albertus (c. 1200–1280), a Dominican, studied at Padua and the University of Paris, as well as at a Dominican school in Cologne. A master of theology, Albertus also was thoroughly learned in the works of Aristotle and wrote commentaries on virtually all of Aristotle's works, often including the results of his own scientific work based on his own observations. Albertus consistently asserted that in the study of nature one should investigate according to the "inherent powers of nature," not according to what God could, or might, do. His detailed and original descriptions of many stones, gems, the parts of plants, agricultural methods, and many animals native to northern Europe made him "perhaps the best field botanist of the entire Middle Ages."[13] His work was systematic and exact; for example, he made detailed comparative studies of the parts of plants and, like Aristotle, opened hens' eggs at various intervals to observe the developing embryo. Albertus also included accurate and precise accounts of such contemporary technologies as iron-smelting, the building of drainage ditches, and cross-plowing to avoid erosion.

Aquinas (c. 1224–74), also a Dominican, taught theology at Paris and wrote extensively on theological questions. Like Albertus, he was committed to integrating Aristotle into a Christian framework. Although his interests were less specifically focused on science than were those of Albertus, Aquinas was an effective spokesperson for the independent value of human reason, which, although it could not attain to divine mysteries, was a truthful guide to the material world.

Albertus and Aquinas, who were trained theologians, separated the practice of science from that of theology, even as they assumed that these two avenues to truth would be ultimately compatible. Other medieval scholars also sometimes put on different "hats" for different subjects, speaking primarily from a naturalistic or moralistic perspective depending upon circumstances. For example, writers discussing medical concerns might recommend sexual activity as an aid to health, even if in other contexts they upheld the Church's disapproval of sexual pleasure. Similarly, clerics trained in universities sometimes privately pursued the sciences of alchemy and astrology, despite official Church disapproval of these subjects.

Conflicts between science and religion, however, did arise in the High Middle Ages. Certain points of the Aristotelian world-system were in direct conflict with Christianity. The Aristotelian world-system asserted the eternity of the world, which conflicted with the account of creation by God in Genesis. The Aristotelian world-system also denied the mortality of the individual human soul, which contradicted the Christian promise of personal salvation and resurrection. Another potential source of difficulty was the strain of determinism in some Arabic science and philosophy which seemed to deny free will not only to human beings but also to God. These thinkers, especially Ibn Rushd, known in the West as Averroës, argued that God Himself would be constrained by natural laws, thus denying the possibility of miracles. Some Arabic writers also seemed to be arguing that human beings were so strongly influenced by the power of the stars and heavenly bodies that the existence of free will was called into question. Most European thinkers attempted to keep a balance between the claims of science and religion. They accepted Aristotle as an authority on scientific subjects while being careful to state that where Aristotle conflicted with Christian faith, the dictates of faith should be followed. However, a few thinkers, known as the Latin Averroists, were thought to follow reason to the exclusion of Christian faith and to advocate a doctrine of "double truth," that is, that something could be true according to philosophy even if not true according to faith. The tensions between the supporters and critics of the new science led to the condemnation by the bishop of Paris in 1270 and again in 1277 of a long list of propositions supposedly held by philosophers, including the eternity of the world, the mortality of the soul, the denial of God's ability to intervene in natural processes, and the influence of the heavenly bodies on the human will and everyday events. Also condemned was the idea "that there was no first man," a denial of God's creation of Adam and Eve as described in Genesis, and "that raptures and visions are caused only by nature," a denial of mystical visions sent by God.

Historians have debated the effects of the Condemnations of 1277 on the practice of science in the late Middle Ages. Most historians agree that the condemnations had some broad effects on the intellectual climate in Europe but did little to displace Aristotelianism as the basis for scientific thought. The major effect seems to have been to end the efforts of the scholastics to forge a comprehensive synthesis of Aristotelian and

Christian thought and instead to encourage the development of philosophy and science as autonomous, limited areas of knowledge distinct from theology. Some historians of science have argued that the condemnations actually furthered the cause of science because they encouraged criticism and refinement of certain aspects of Aristotelian natural philosophy. Others have pointed to a new interest in God's absolute and omnipotent power in the following centuries. The condemnations applied only to the University of Paris, although they certainly had some influence elsewhere. Although historians know little about the immediate implementation of the condemnations, we do have evidence that earlier attempts to ban the reading of Aristotle's books on natural philosophy at Paris in 1210 and 1255 had been largely ignored. In 1325 the Condemnations were partially annulled and by 1341 we have direct evidence that the natural books of Aristotle and his commentators, including Averroës, were required reading at the University of Paris and elsewhere, to be taught "except in those cases that are contrary to the faith."

THE PRACTICE OF SCIENCE OUTSIDE THE UNIVERSITIES

The university was not the only setting for the practice of science in the Middle Ages. During the early Middle Ages, as we have seen, both monasteries and royal courts were sites for the practice of sciences with a utilitarian value, especially practical astronomy and medicine and related areas such as botany and pharmacology. Although the university far surpassed these venues in the production of theoretical science, more practically oriented scientific activity continued to take place in monastic, civic, and court settings. In addition, some sciences, especially astrology and alchemy, were largely rejected by the university community but were enthusiastically pursued by both some university-trained scientists and many unknown individuals whose names have not come down to us.

The variety in types of training and settings for practice was probably greatest in medicine. Physicians might be licensed by public political authorities, craft guilds, university faculties, or even individual rulers and might practice in urban hospitals, private homes, courts, and a variety

of other settings. Many "empirics," whose training was informal and largely based on word of mouth and trial by error, were not licensed at all. In northern Europe, many physicians were members of the clergy, although in Italy most were laymen. Surgeons, or barbers, were almost always members of the laity. Women also practiced medicine. A few, for example, Trotula of Salerno and Hildegard of Bingen, wrote learned treatises. Midwives formed a sizable group of women healers who had some degree of professional training and status. According to Nancy Siraisi, about 1.5 percent of the names of physicians known to us from northern Europe were women.[14] Many more practiced anonymously, probably intermittently, and left no trace in the written records. A significant proportion of both learned and empiric physicians were Jewish, especially in southern France, Italy, and Spain. A licensed Jewish woman physician is known to have attended the queen of Aragon for four months in 1381, and other records indicate that women practiced as physicians in fourteenth-century Paris.[15] Most physicians, even university professors, practiced privately and were hired by royal courts, noble households, town governments, or even individuals from more modest backgrounds. In rural communities, the most accessible health care was probably from the village empiric or *vetula* (old woman) who specialized in the use of local plants and herbs. Religious and academic methods of healing were frequently combined and the line between religious and academic methods and "magic" was often a fine one. For ordinary people, a visit to a "healer" might typically involve a combination of prayer, touch, herbal remedies, and charms, and even learned physicians resorted on occasion to magical remedies.

Alchemy and astrology were two sciences that for a variety of religious and philosophical reasons were largely rejected by the university establishment but flourished in other venues. Many royal and noble courts, for example, maintained not only a corps of physicians to attend the royal family, but also a number of astrologers and alchemists. Some physicians and other university-trained natural philosophers also pursued astrology and alchemy as part of their own scientific interests; medical astrology, which attempted to connect the movements of heavenly bodies with the outbreak and course of diseases, for example, was an important aspect of medical practice.

Alchemy was the theory and practice of changing base metals into gold or other precious metals and closely allied in its methods to chemistry and pharmacology; astrology was the science that analyzed the physical effects of the heavenly bodies on the earth and, secondarily, was concerned with the casting of horoscopes and the like. Although both alchemy and astrology are considered to be irrational and superstitious by twentieth- and twenty-first-century scientists, in the Middle Ages there were sound philosophical and scientific reasons for accepting both as genuine sciences. Both originated in antiquity and their practitioners could point to a long and illustrious pedigree of masters of the art. Moreover, the principles of each were consistent with Aristotelian science as understood in the Middle Ages. Finally, both offered the possibility that the natural world and scientific knowledge might be put to practical use to benefit humankind.

Alchemy was first developed in the ancient world, was adopted by the Arabs, and hence passed to Europe. Many of the alchemical treatises known to us are anonymous or falsely attributed to well-known figures. Some alchemical writing was intentionally obscure and even written in code in order that alchemical knowledge would not fall into the "wrong" hands. Other works are fairly straightforward guides to the proper tools, chemicals, and procedures to be used in the purification of various substances. Because alchemy emphasized the ability of humans to manipulate natural materials, it helped establish the idea that "art" or technology could provide results that went beyond the products of unaided nature. Many doctors were also alchemists, for the production of substances to prolong life, cure illnesses, and produce antidotes to poisons seems to have an important adjunct to alchemical practice. If we believe many of the accounts circulating in the Middle Ages, many clerics also took up alchemy. Along with records of serious practitioners, there were numerous stories of quacks and charlatans; in Chaucer's *Canterbury Tales*, for example, alchemists are represented as foul-smelling con men who use sleight-of-hand tricks to fool gullible individuals.

As in the case of alchemy, astrology ran the gamut from a serious science, closely tied to astronomy, to an activity pursued mainly for its entertainment or money-making value. Astrology as a science attempted to explain how heavenly bodies exerted physical effects on earthly bodies. It was also thought to yield important information on the proper timing for important events, including marriages, coronations, and even, occasionally, battles. Many physicians regarded astrology as a valuable adjunct to medicine as it helped determine the timing of crises in the

progress of a disease, overall conditions affecting health, and an individual's personal health risks. Astrologers therefore were a frequent presence at court, although it is difficult to always tell how seriously their predictions were taken.

THE LATE MIDDLE AGES

The continued development of scientific thinking in the late Middle Ages is more difficult to characterize than for earlier periods. The different strands in late medieval scientific thought went in many different directions and it is difficult to discern the connections among them. In addition, much of the research done on this period has been directed toward looking for connections between late medieval science and the genesis of the Scientific Revolution of the sixteenth and seventeenth centuries. While interesting and important, this emphasis has perhaps made it more difficult to see late medieval science as a whole in its own right.

One important development was a new, more mathematical approach to the study of motion. Scholars first at Merton College at Oxford University and later at the University of Paris in the fourteenth century attempted to formulate ways to quantify both motion at a constant velocity and accelerated motion. They later applied these same methods to other forms of change, including increasing intensities of heat and even changing degrees of love. Nicholas Oresme succeeded in representing velocity geometrically, using a method which has been called "a forerunner of modern graphing techniques."[16] Oresme proved what is still known as the "Merton rule" or "mean-speed theorem." This mathematical law shows that an accelerating body y travels the same distance in the same period of time as a body x moving at a constant velocity equal to the *average* speed of the accelerating body. Another mathematician in this group, John Buridan (c. 1295–c. 1358), developed a new theory of why bodies once set in motion continued to move; he supposed a natural quality of "impetus" which caused movement and depended in part upon the quantity of matter in the moving object. Oresme and Buridan also speculated about the movements of the heavenly bodies as well, both suggesting that the earth might rotate on its

axis in contradiction of the long-held belief that the earth was at rest at the center of the universe.

Another center of scientific innovation in the late Middle Ages was the University of Padua in Italy in the fifteenth century. By this time, scholars at the established universities in England and France seem to have lapsed into a conservative, tradition-bound form of Aristotelianism which became famous for its triviality, sterility, and hair-splitting; when scientists such as Copernicus and Galileo articulated the new ideas of the Scientific Revolution in the sixteenth century, academic Aristotelians were among their most vocal and hostile critics. At Padua, however, a new scientific method developed which may have influenced Galileo himself when he taught at Padua in the 1590s. Scientists at Padua began to go beyond the simple observation of nature characteristic of most of previous medieval science and develop a genuine experimental method. They argued that science should proceed by a rigorous analysis of the problem of causation and that the scientist should move from specific observations to general principles (induction) and then back to an ordered body of facts (deduction). This method remains one of the backbones of today's science.

Finally, we should note that technological development continued to accelerate in the late Middle Ages (see Chapter 6). Eyeglasses, the chimney, the mechanical clock, cannon, the handgun, and moveable type (which led to printing) were among the important inventions that appeared in this period. Improvements were also made in older devices such as windmills and watermills. During the fifteenth century, medieval scientists took an increasing interest in the practical knowledge of craftsmen and craftswomen. One especially fruitful area of interchange was between medicine, alchemy, and astrology. All three of these disciplines attempted to combine theoretical knowledge with practical results. The practice of architecture, which combined theoretical training with construction techniques requiring complex machinery, also contributed to a new interchange between theory and practice. During the late Middle Ages a number of physicians also interested in astrology and alchemy explored the possibilities of new mechanical devices, including astronomical instruments, clockwork, and war machines. A closer relationship between theoretical scientific knowledge and technology was one of the hallmarks of the Scientific Revolution of the sixteenth and sev-

enteenth centuries; the roots of this important development, however, lie in the late Middle Ages.

NOTES

1. M.-D. Chenu, *Nature, Man, and Society in the Twelfth Century: Essays in New Theological Perspectives in the Latin West*, ed. and trans. Jerome Taylor and Lester K. Little (Chicago: University of Chicago Press, 1968), p. 5.
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4. Adelard of Bath, *Conversations with His Nephew*: On the Same and the Different, Questions on Natural Science *and* On Birds, ed. and trans. Charles Burnett with the collaboration of Italo Ronca, Pedro Mantas España and Baudouin van den Abeele (Cambridge, England: Cambridge University Press, 1998), p. 103.
5. Quoted in Chenu, *Nature, Man, and Society*, p. 11.
6. Hugh of St. Victor, *The* Didascalicon *of Hugh of St. Victor: A Medieval Guide to the Arts*, trans. Jerome Taylor (New York: Columbia University Press, 1961), pp. 55–56.
7. Hildegard of Bingen, *On Natural Philosophy and Medicine: Selections from the* Cause et cure, trans. Margret Berger (Cambridge, England: D. S. Brewer, 1999).
8. Grant, *God and Reason*, p. 356.
9. Grant, *God and Reason*, p. 179.
10. David C. Lindberg, *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600* B.C. *to* A.D. *1450* (Chicago and London: University of Chicago Press, 1992), p. 230.
11. Lindberg, *Beginnings*, p. 307.
12. Jacques Le Goff, *Time, Work and Culture in the Middle Ages*, trans. Arthur Goldhammer (Chicago: University of Chicago Press, 1980), p. 109.
13. Lindberg, *Beginnings*, p. 230.
14. Nancy G. Siraisi, *Medieval and Early Renaissance Medicine: An Introduction to Knowledge and Practice* (Chicago and London: University of Chicago Press, 1990), p. 27.
15. Siraisi, *Medicine*, p. 31.
16. Lindberg, *Beginnings*, p. 298.

CHAPTER 3

ARISTOTLE, PLATO, AND THE MEDIEVAL SCIENTIFIC WORLDVIEW

While many achievements of medieval science and technology will be easily accessible to the contemporary student, some aspects of the medieval scientific world view are quite foreign. In this chapter we will examine some of the assumptions underlying medieval scientific thinking in order to better understand the conclusions medieval scientists came to when they considered specific kinds of scientific problems. The differences between medieval and modern ways of thinking about the natural world come through most dramatically in the consideration of such fundamental problems as why objects moved, the structure of the universe, and the nature of physical reality. This chapter will explore some of these basic questions to encourage an "insider's view" of medieval science in which we can begin to share the outlook and perspective of a medieval scientist.

First a note about terminology. *Natural philosophy* in this context refers to study of the natural world. Ancient and modern writers used the term *natural philosophy* to refer to the same activities we today would call "natural science."[1] A near synonym was physics. Whereas in modern science, the English term *physics* refers only to the science of the interaction of matter and energy, articulated in predominately mathematical terms, in the Middle Ages, the Latin *physica*, derived from the Greek *physis*, meant, simply, "natural science." In the Middle Ages, therefore, *physics* meant broadly an account of the fundamental principles that governed change in nature.