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Science in the Middle Ages

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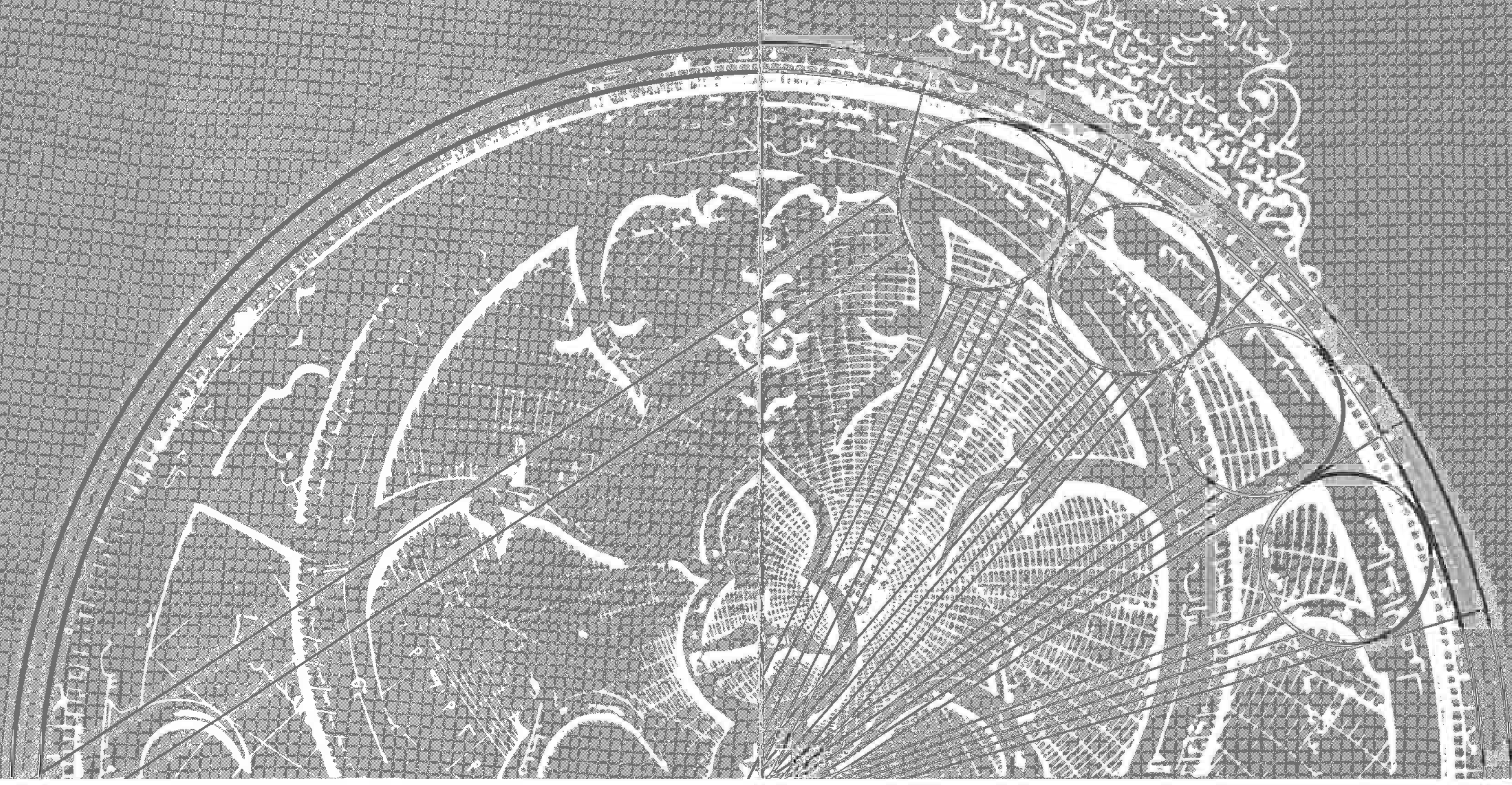

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Preface

The first serious large-scale exploration of the history of medieval science was that of the French physicist, philosopher, and historian Pierre Duhem (1861–1916). While searching for precursors of Leonardo da Vinci, Duhem discovered a wealth of manuscript and printed material which persuaded him that medieval scholasticism had by no means suffocated empirical scientific endeavor, as had theretofore been supposed. Quite the contrary: it now appeared to Duhem that the very foundations of modern science had been laid during the fourteenth century. He summarized his findings in the following words:

> A more exact knowledge of the doctrines taught in the . . . schools of the Middle Ages . . . teaches us that in the fourteenth century the masters of Paris, having rebelled against the authority of Aristotle, constructed a dynamics entirely different from that of the Stagirite; that the essential elements of the [mechanical] principles [commonly] thought to have received mathematical expression and experimental confirmation from Galileo and Descartes were already contained in this [fourteenth-century] dynamics; that at the beginning of the fifteenth century these Parisian doctrines were spread into Italy, where they encountered a vigorous resistance from the Averroists, jealous guardians of the Aristotelian tradition and the great Commentator [Averroes]; that they were adopted in the course of the sixteenth century by the majority of mathematicians; and finally that Galileo, in his youth, read several of the treatises where these theories . . . were presented.

(1894): 157–72; Roswitha Ankenbrand, *Das Pelzbuch des Gottfried von Franken* (Heidelberg, 1970), published dissertation; [Charlemagne,] *Capitulare de villis*, in *Monumenta Germaniae Historica, Legum sectio II: Capitularia Regum Francorum*, ed. Boretius, 1: 82–91; *The Book of Husbandry by Master Fitzherbert*, ed. W. Skeat (London, 1882); Dorothea Oschinsky, ed., *Walter of Henley and other Treatises . . .* (Oxford, 1971); Palladius, *On Husbondrie*, ed. B. Lodge (London, 1883); Peter of Crescenzi, *Opera di agricoltura* (Venice, 1553); Walafridus Strabus, *Hortulus*, trans. Raef Payne, commentary by Wilfrid Blunt (Pittsburgh, 1966).

84. Published lapidaries include Marbod of Rennes, *Lapidarius*, in Migne, *Patrologia Latina*, vol. 171 (Paris, 1854), cols. 1737–70; Giulio Bertoni, "Il lapidario francese estense," *Zeitschrift für romanische Philologie* 32 (1908): 686–97; Paul Meyer, "Les plus anciens lapidaires français," *Romania* 38 (1909): 44–70, 254–85, 481–552; Joan Evans and Mary Serjeantson, *English Mediaeval Lapidaries* (London, 1960); Friedrich Wilhelm, *Denkmäler deutscher Prosa des 11. und 12. Jahrhunderts* (Munich, 1914) ("Das Prüler Steinbuch de XII. lapidibus," pp. 37–39). For useful discussions of lapidaries, see John Riddle, "Lithotherapy in the Middle Ages," *Pharmacy in History* 12 (1970): 39–50; R. Besser, "Über Remy Belleaus Steingedicht," *Zeitschrift für neufranzösische Sprache und Literatur*, 8 (1886): 185–250.

85. For example, Valentin Rose, "Aristoteles De lapidibus und Arnoldus Saxo," *Zeitschrift für deutsches Alterthum* 18 (1875): 321–455.

86. Although outdated, the editor's introduction to Guillaume's *Bestiaire Divin* is one of the few attempts to deal with bestiaries, herbals, and lapidaries; see C. Hippeau, *Le Bestiaire Divin*, pp. 3–72. See also F. H. Garrison, "Herbals and Bestiaries," *Bulletin of the New York Academy of Medicine* 7 (1931): 891–904; and Christian Hünemörder, "Botanisches und Zoologisches bei Alanus ab Insulis," in *Festgabe für Kurt Lindner* (Berlin, 1971), pp. 125–31.

87. Albertus Magnus, *Book of Minerals*, trans. Dorothy Wyckoff (Oxford, 1967).

88. Willy Braekman, *Medische en technische Middelnederlandse Recepten* (Ghent, 1975); H. G. T. Frencken, *t'Bouck va Wondre, 1513* (Roermond, 1934); Piero Giacosa, "Un ricettario del secolo XI esistente nell'Archivio Capitolare d'Ivrea," *Atti della Reale Accademia di Torino*, ser. 2, 37 (1886): 643–63; Hjalmar Hedfors, *Compositiones ad tingenda musiva* (Uppsala, 1932); D. V. Thompson, "The De clarea of the So-Called Anonymous Bernensis," *Technical Studies in the Field of Fine Arts* 1 (1932): 8–19, 69–81; Hans Vermeer, "Technischnaturwissenschaftliche Rezepte," *Sudhoffs Archiv* 45 (1961): 110–26.

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James A. Weisheipl, O.P.

The Nature, Scope, and Classification of the Sciences

The modern word *science* has come to mean different things to different people, particularly in modern times. In order to arrive at a precise meaning it is important to understand how it was used in Greek antiquity and in the Middle Ages before the Scientific Revolution of the seventeenth century. A brief historical survey will show how the ancients used the word *science*, how scientific knowledge differed from other kinds of knowledge, and how various kinds of science can be classified and studied. Provisionally, *science* can be taken to mean a given area of study, worthy of human investigation and knowledge. It is clear from the very start that there are many areas of human learning, all deserving of investigation for the betterment of mankind, as well as for the betterment of the individual. In order to understand the history of science we must see how the word was used in Greek antiquity and how it came to be understood in the Latin West.

Science in Greek Antiquity

By the beginning of the classical period, Greek education consisted first in a study of the "liberal arts," meaning by that music, gymnastics, poetry, grammar, rhetoric, and dialectics (the art of reasoning and disputing).[1] These were thought necessary for the well-rounded Greek mind in civilized society. They were called "arts" (*tekne*), as distinct from philosophy, because in each case something was produced or constructed at least mentally. They were taught as productive skills, or practical techniques, necessary for the cultivated life of the free man, the citizen in a free society. In early Greek thought "philosophy" (which literally means "the love of wisdom") was taken to mean a kind of true, objective, unsophisticated knowledge, vastly different from the liberal arts. This wisdom (*sophia*) was the attempt of the human mind to explain in a rational way some of the natural processes in nature, the peculiar properties of number, or the moral values of conduct. These were recognizably different areas of human knowledge worthy of the learned man. Such speculative knowledge, whether it be of natural processes (physics), numbers (mathematics), or moral values (ethics) was called "scientific" (*episteme*), or objectively demonstrable knowledge, to describe a human study essentially different from the arts, whether those arts be "liberal" or "technical." The implication that philosophical (or "scientific") studies should be pursued only after the liberal arts had been mastered was endemic to the Greek concept of scientific knowledge.[2] Thus there were at least three important areas of objective truth worthy of pursuit by the mature man after he had acquired the arts, namely, physics, mathematics, and moral values. But these parts of philosophy or "scientific" knowledge could not be studied without the necessary art of logic, which was a liberal art, the art of right reasoning.

The earliest Greek philosophers before Socrates were intensely interested in discovering the ultimate source or root of all physical things observable in nature.[3] For Thales of Miletos, one of the seven "wise men of Greece," the ultimate principle of all natural beings was some kind of moisture or water. For Anaximander it was some "limitlessness" distinct from the obvious four elements: earth, water, fire and air. For Anaximines, it was some kind of life-giving air or breath (spirit); and for Xenophanes, it was the tension between earth and water which produced a kind of Super One, from whom all things come. All of these early philosophers tried to find a physical explanation in some given thing that could be identified as one. But it was Heraclitus, an irritable Ionian from the city of Ephesus, who provoked the response that was to dominate the formation of "scientific" explanations in Greek thought. For him, "all things are in flux," as fire that must ever be driven on by its own contraries. "All things come into being by conflict of opposites, and the sum of all things flows like a stream." In other words, there is no stability anywhere in the universe, and all true wisdom lies in the recognition of constant change. Heraclitus had no sympathy for the flourishing school of Pythagoreans, with their abstract and immobile numbers and figures; nor had he sympathy for the poet-educator Hesiod.

Heraclitus's absolute denial of stability in nature seems to have brought an immediate response from Parmenides of Elea about the

year 500 B.C. In a relatively long poem, preserved by Simplicius and later writers, Parmenides distinguished between two types of human knowledge: the way of popular opinion and the way of objective and absolute truth. The way of popular opinion followed by most people is no more than the deception offered by the senses. Among these deceptions are the plurality of things in the universe and the continual mutability of things in nature. The truth of the matter, according to Parmenides, was that "all is one and absolutely motionless." That is to say, he denied the multiplicity and mutability apparent to the senses. The basic principle of Parmenides' philosophy was that only "being" can exist; whatever is "not being" cannot exist.[4] By "being" Parmenides clearly meant a physically existing body; every sort of vacuity would be "nothing" and, hence, incapable of existence.[5] From this principle it logically follows that change and plurality are impossible. In every change something "new" supposedly comes into existence. Whence comes this new thing? It cannot come from nothing, for nothing can come from nothing (*ex nihilo, nihil fit*); it cannot come from being, for then it would already have been (*quod est non fit*). Similarly, all plurality implies separation and distinction, so that one is somehow different from the other at least in place; but this would require the existence of a "nothing" to distinguish them, and a "nothingness" cannot exist. Therefore, the way of truth and reason requires us to say that all is one and immutable, even though the senses tell us otherwise. If all is one and changeless, then the search pursued by the ancient physicists is futile. There is nothing to be accounted for. The logical dilemma of Parmenides revolutionized Greek thought in the sense that henceforth some rational account had to be given to explain the possibility of both change and plurality.

The "most systematic and consistent theory," Aristotle tells us, was advanced by the atomists Leucippus and Democritus.[6] In order to justify the obvious multiplicity and mobility in the world, Leucippus of Miletos (fl. 430 B.C.) made one change in the Eleatic principle of Parmenides and his followers: he insisted on the reality of "non-being," or "nothingness," which could be conceived as the void. Leucippus maintained that "*what is* is no more real than that *which is not*," and that "both are alike causes of the things that come into being."[7] In other words, by postulating the real existence of Being and Nothingness, one could account for plurality and movement in the world. In the last analysis, however, the Greek atomists could not explain how atoms themselves could be generated or corrupted, that is, changed; these atoms had to be immutable, as Parmenides had argued. Apparent generation and corruption of "substantial unities" could be explained by the rearrangement of atomic particles, and local movement of those particles in the void could justify sense experience that at least local motion is possible, even though substantial change in the atoms themselves, that is, their generation and corruption, is untenable. Consequently, the world of sense experience, the "way of opinion," tells us that there are substantial entities which are generated and corrupted. But reason, "the way of truth," knows that there are only immutable atoms in a real void.

Again the bifurcation of knowledge remained: the way of opinion and popular belief on the one hand, and scientific knowledge of the truth (the void and the local motion of atoms) on the other. The assumption is that evidence of the senses does not deserve the title of true science, but only of "opinion," for it is a world of ever-changing shadows, as Heraclitus and Plato noted.

Plato's philosophy of nature owes much to Heraclitus, Pythagoras, and Parmenides. Like Heraclitus, Plato viewed the sensible world as ever-changing and not susceptible to scientific inquiry. Like Pythagoras, Plato postulated the separate existence (that is, separate from material things) of geometrical figures and numbers, which never change and can be studied. And like Parmenides, Plato held that only the immutable is real and eternal; these immutable and eternal Forms or Ideas exist apart from the world of change, and true "wisdom" consists in contemplating them until one logically reaches the highest Idea of the One and the Good, namely the supreme God.

The grades of knowledge, for Plato, correspond directly to the grades of being: the more abstract the knowledge, the more immaterial and perfect the being. This view is partially represented by the well-known allegory of the line (*Republic* 6. 509D–511E). The gradation of being and speculative knowledge can be represented as is shown in chart 1.

In other words, Plato considered the study of nature to be no more than "a likely story" to explain how things might have come about, as described in his *Timaeus*. Since the world of sense experience is ever-changing, as Heraclitus had said, the study of nature does not merit the name of "science." Higher than the world of sense experience and physics is the domain of mathematics, including geometry, arithmetic, astronomy, and harmonics. These were the areas studied by the Pythagoreans. Since the world of mathematics is made up of immutable, eternal truths, it deserves the name and character of "science." For Plato, the world of mathematical reality consists of subsistent numbers and figures, existing apart from the world of sen-

Visible world	1. The shadows of physical bodies, such as shadows cast by objects in light; to these correspond imaginative *conjectures* in interpreting the shadows as to what the real object might be. 2. The physical, sensible, and visible objects, which in reality are but "shadows" and reflections of a subsisting Idea beyond the physical, for example, animals, plants, and inanimate bodies. To this grade corresponds *belief*; this is the domain of PHYSICS, or the study of nature, to which all of his predecessors had been devoted.	Opinion (*doxa*)
Intelligible world	3. Intelligible objects to which the mind must turn as to the model of physical objects; but to study these intelligible Forms, the mind must utilize certain "hypotheses" in order to reach a true conclusion. Corresponding to this grade is discursive reason, which is the domain of MATHEMATICS, or disciplinary science (geometry, astronomy, arithmetic, and harmonics). 4. Intelligible objects apprehended without the aid of any sensible object, the mind passing only from one Idea to another Idea. Corresponding to this grade of true and pure being is pure contemplation, or understanding (*noesis*) and perfect "science" which is DIALECTICS (later called "first philosophy" or metaphysics); this perfect science uses hypotheses not as first principles, but as points of departure into a world which is above hypotheses in order to rise beyond them to the first, unique principle of the whole.	Science (*episteme*)

Chart 1

sation, intermediate between the world of pure "Ideas" and the world of material objects perceived by sensation. But even higher than the world of mathematicals is the domain of subsistent forms and ideas, separate from all matter. Among the ideas that are immaterial and subsistent in their own right are the ideas of pure man, fire, water, hair, mud, and dirt, existing apart from the physical, changing world.[8] The contemplation of these forms is "wisdom"; and the contemplation of the highest form, namely the Good-in-itself, is "theology." Plato, of course, made no distinction between dialectics, the highest wisdom, and moral philosophy, since for Socrates and Plato, knowledge of the transcendental good necessarily produces virtuous actions. Only after Aristotle was moral philosophy generally distinguished from the speculative sciences, because for Aristotle mere knowledge of virtue does not necessarily produce virtuous actions.

It is clear that Plato's tripartite division of speculative knowledge is a hierarchical one: physics at the bottom, mathematics (geometry, astronomy, arithmetic, harmonics) in the middle, and dialectics (which was later called first philosophy or metaphysics) at the top. The main point is that for Plato, mathematical being is more fully real than physical, sensible being; it is conducive to opening the doors of "dialectics," which is about all separated forms or ideas, the highest of which is the One and Good-in-itself (God). The crux of Platonic philosophy is that things exist in reality in the same way as they are conceived by the mind. Since mathematical being is conceived without sensible matter, so they must exist without sensible matter.

A problem arises, however, concerning the forms of material things, such as tables, humanity, animality, and the like; these are conceived in a universal manner by the mind without individual matter. But the very nature and definition of these forms involve "sensible" matter. For this reason Aristotle argued that they cannot subsist in themselves without matter; the nature of man involves flesh, blood, and bones—not *this* blood and *these* bones—but flesh, blood, and bones that require sensible matter even in their definition. It was precisely over the existence of separate forms for each species that Aristotle broke with Plato. The only "separated substances" that Aristotle would admit to exist were those demonstrated in natural philosophy as movers of the heavens.

For Aristotle, the tripartite division given by Plato does not correspond to a hierarchy of scientific knowledge or to a hierarchy of being. Instead of Plato's hierarchical grades of abstraction, Aristotle showed that mathematics alone is really "abstract"; the mathematical sciences are more removed from reality than physics, and, hence, must be judged by natural philosophy, not the other way around. For this reason, mathematics can be taught to young men as a preliminary to the sciences of being: physics, ethics, and metaphysics or "first philosophy." Moreover, whereas Plato had denied the scientific status of physics, Aristotle spent most of his effort rehabilitating the "science of nature," which he described in general terms in the *Physics*, and continuing his researches into all of its branches including biology and psychology. Further, Aristotle gave a new foundation to "first philosophy." Rejecting subsistent immaterial ideas, Aristotle established his metaphysics on the proved existence of "separated substances" (such as the celestial movers), which are the cause of motion and sensible being studied in physics. Finally, he distinguished the practical science of ethics or "moral philosophy" from the contemplation of the supreme Good attained in metaphysics. Thus, for the first time a difference is recognized between speculative sciences and practical sciences.

Aristotle clearly distinguished three types of academic discipline: the "arts," the practical sciences of moral philosophy, and the three branches of speculative philosophy (physics, mathematics, and metaphysics). However, in the order of training or acquiring learning, Aristotle would have youths trained first in the liberal arts (gymnastics, grammar, statuary, music, logic, rhetoric, and poetry) and then in the "disciplinary" sciences of mathematics (arithmetic and geometry) before beginning the extensive science of nature, to which could be added "the more physical parts of mathematics," namely, optics, harmonics, and astronomy. Only after a considerable part of natural science had been mastered, especially psychology, should one study the moral sciences, to play his role in the political life of the city and to prepare himself for the supreme science of metaphysics, the most important part of which is called theology. Thus, for Aristotle, the acquisition of learning and wisdom is a lifelong process, where true wisdom or metaphysics is not expected of a man until he is fifty years old and where a life of virtue is expected to be practiced in a social and political context.

With these qualifications in mind, we can construct a division of the sciences drawn from the incidental statements scattered throughout Aristotle's *Metaphysics* and *Nicomachean Ethics* (see chart 2).

There are two important points to be noted regarding Aristotle's classification of the speculative sciences: (1) despite its superior position in the schema, mathematics is not to be considered a higher or nobler science than physics, "the science of nature," but only as a preparation for natural science and metaphysics, even though it is truly "abstract"; (2) the sciences which Aristotle calls "the more physical parts of mathematics," namely, optics, astronomy, harmonics, and mechanics, occupy a unique position in the schema of the sciences, for they are *intermediate* between pure mathematics and physics and later became known as *scientiae mediae*, or intermediate sciences; these intermediate sciences use mathematical principles and formulas to study certain areas susceptible of mathematical consideration, such as celestial motions, radiant lines (optics), tonal ratios (harmonics), and mechanical problems of every kind, and every other kind of knowledge involving the application of mathematics to nature.

It was Aristotle who most clearly presented the precise nature of truly "scientific" knowledge. This he did in his many writings on logic, particularly his two books on demonstrative knowledge, the *Posterior Analytics*. The most perfect kind of demonstration is a proof through the proper, immediate, and commensurate *cause* of an

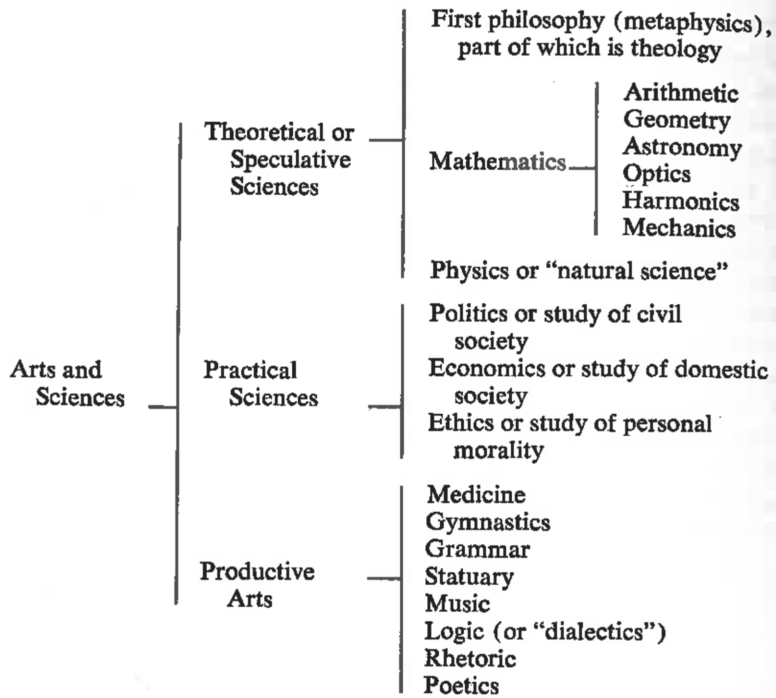

Chart 2

effect or fact; this is called *propter quid* demonstration. It is a knowledge and proof of a fact through a true cause or reason for the fact. These are hard to discover. In the absence of such perfect demonstration, the scientist can still "demonstrate" the fact of a thing or proposition through a proof known as *quia*, either through some remote cause of an effect (*per causam remotam*) or through a proper effect (*a posteriori*). These are different kinds of logical demonstrations which beget true "scientific" or epistemic knowledge. Of course, no human science is made up solely of *propter quid* demonstrations. Such demonstrations are often hard to come by or even impossible, and a human science must often be content with *quia* demonstrations, statements of fact, conjectures, workable hypotheses, and even the considered opinions of other learned men. Thus, each "science" is a huge area of learning that consists of proofs or "demonstrations" of what is clearly and certainly known to be the case. But investigation of these areas often involves possible theories, hypotheses, opinions, clarification, and simple classification.

The Early Middle Ages

Soon after Aristotle, several important philosophical schools emerged quite independently of Plato and Aristotle. The most important of these for the Roman world was the Greek philosophy of the Stoics, who placed the highest goal in life in their stoic ethics. They divided philosophy into three branches or areas of study: (1) logic, (2) physics, which included whatever bits of metaphysics they would admit, and (3) ethics, as the highest "science" of human life. While Stoic philosophy played an important role in molding the Roman mind and way of life, it played an insignificant role in the development of medieval science, despite the fact that St. Augustine adopted the Stoic division of philosophy, thinking it to be Plato's.[9]

Rome inherited a long-standing tradition in educating youths in the arts, particularly in grammar and rhetoric. Grammar was taught not only at the elementary level, but also at an advanced level. Eminent grammarians flourished in Roman society; they laid the foundations of the Latin language. But more important than the grammarians were the rhetoricians, because rhetoric was considered indispensable for the cultivated Roman who wished to fulfill his role in the life of Roman society. Under the Empire, Roman education copied much that was Greek, but with some interesting differences. The study and practice of Roman Law, even at Byzantium in the East, was in the Latin language. Philosophy and medicine, on the other hand, never became integral parts of Roman education, not even at its highest levels; these had to be studied in the Greek language. Even before the reign of Augustus Caesar, boys of the Roman aristocracy learned the liberal arts in both Latin and Greek. Cicero was an outstanding example of the educated Roman who knew Greek philosophy and played a significant part in the conduct of Roman society.

The earliest Latin classification and exposition of the liberal arts seems to have been incorporated in the now lost work of Terence Varro (116–27 B.C.) entitled *Disciplinarum libri IX*. Varro's compendium of the disciplinary or "encyclical" studies embraced successively: (1) grammar (fragments of which are still extant), (2) logic, or "dialectics," (3) rhetoric, (4) geometry, (5) arithmetic, (6) astronomy, (7) music, (8) medicine, and (9) architecture. In later classifications of the "arts," architecture and medicine were considered parts of the mechanical or "servile" arts. The remaining parts of Varro's classification are the well-known trivium (grammar, dialectics, and rhetoric) and quadrivium (geometry, arithmetic, astronomy, and music). Early in 387, St. Augustine started to write an encyclopedia of the seven "liberal arts" and philosophy in his *Disciplinarum libri*, but only the grammar, six books on music, and the beginning of "the other five disciplines, namely dialectics, rhetoric, geometry, arithmetic, and philosophy" seem to have been actually completed by him.[10]

The "Dark Ages" that followed the fall of the Roman Empire and Latin civilization left little for posterity except the seven liberal arts and "theology," which was basically the study of the Bible. More than anyone else, Manlius Severinus Boethius deserves to be remembered for the elementary textbooks he provided for later centuries that groped their way to a new civilization we know as "medieval." The new civilization was gothic, but its roots were Roman. Boethius (ca. 475–524) has been called "the last Roman and the first Scholastic,"[11] because he preserved the ideal of the classical Roman tradition when the Roman world was crumbling all about him; and he established the foundations of medieval Latin scholasticism both in theology and in philosophy. Boethius translated many of Aristotle's logical works into Latin, providing the only real link between Aristotle and the Dark Ages. Boethius himself was a convinced Platonist, but he realized the importance of Aristotle and wished to translate and "harmonize" all the works of Plato and Aristotle.[12] The Roman world had an abundance of works on Latin grammar and rhetoric in the writings of Donatus, Priscian, Cicero, and others. But it provided nothing for logic, philosophy, and the quadrivium (a term first used by Boethius to signify the four mathematical sciences). Boethius, therefore, composed elementary adaptations from the Greek for music, arithmetic, and geometry. It would seem that Boethius also translated Ptolemy's "astronomy" and Archimedes' "mechanics," but nothing is known of these translations or summaries today.[13] The summaries and translations of Boethius plus the Roman works that survived the barbarian invasions constituted the foundation of a liberal education for the next six hundred years in Western Europe. To these must be added the important study of the Bible throughout these centuries.

Although Boethius discussed the nature and division of "philosophy" in his two commentaries on Porphyry's *Isagoge*, the *locus classicus* for the division commonly accepted in medieval schools is found in his short theological treatise *De trinitate*. For Boethius, "philosophy," which is the love of wisdom, is divided into speculative and practical. Practical philosophy is divided into (1) ethics of the individual, (2) ethics of the family, and (3) politics, which is the highest science in the practical order. Speculative sciences are also divided into three kinds or "branches": (1) physics, which deals with material bodies in motion, both in reality and in our consideration of them; (2) mathematics, which leaves out of consideration the aforesaid material bodies in motion, but considers only their changeless, measurable and numerable aspects; and (3) metaphysics or "natural theology," which leaves aside material bodies in motion and concentrates on truly changeless and immaterial things, such as "being" and the Divine Substance, which is without matter and motion. Boethius introduces his treatise *De trinitate* with the division of philosophy to show that the subject matter of his treatise is without matter and without motion, in other words, a treatise of pure theology. This Boethian division of philosophy is the old tripartite division given by Plato and Aristotle, but with one important difference. For Boethius, the "object" of each science is a "form" of some kind, namely, a form in matter and motion (physics), a form without matter and motion in consideration by the mind but not in reality (mathematics), and a form without matter and motion in reality and in our consideration (theology). According to Boethius, the forms "abstracted" seem to constitute a hierarchy ascending from physics, through mathematics, to metaphysics and God. The schema and description shown in chart 3 represents the way he was read during the later Middle Ages:

- Philosophy
  - Speculative
    - Physics—material bodies in motion both in reality and in mental definition
    - Mathematics—changing material bodies, considered apart from their matter and motion; subdivided into arithmetic, geometry, music, and astronomy
    - Theology—changeless, immaterial things both in reality and in mental consideration
  - Practical
    - Ethics of the individual (monastics)
    - Ethics of the family (domestics)
    - Ethics of society (politics)

Chart 3

Marcus Aurelius Cassiodorus, a junior contemporary of Boethius, wrote a highly influential *Institutiones* for his monks at Vivarium about the year 544–45. This is a manual of divine and secular literature, divided into two books. The first book is a compendium of sacred scripture, exegesis, hagiography, and religious discipline. The second book is a summary of the seven liberal arts: grammar, rhetoric, dialectics (logic), arithmetic, music, geometry, and astronomy. At the beginning of his summary of dialectics, Cassiodorus discusses the definition and division of "philosophy," a procedure which was frequently followed throughout the Middle Ages. His division of philosophy is identical with that of Boethius, but for each part Cassiodorus gives a brief definition, indicating its nature and scope within the classification. *Natural* philosophy discusses the nature of each material thing which is produced naturally; *doctrinal* philosophy (mathematics) is the science which considers abstract quantity, that is, quantity which has been mentally "separated" from matter and from other accidents; and *divine* philosophy, which considers the ineffable nature of God and spiritual creatures. The rest of the second book discusses the seven liberal arts. This second book of the *Institutiones* was often copied separately and expanded in later centuries.

Early in the seventh century, Isidore of Seville composed an encyclopedic work called the *Etymologiae* in twenty books, which served as a common reference work throughout the Middle Ages. He gives a summary of the seven liberal arts in the first three books: 1, grammar; 2, rhetoric and dialectics; 3, arithmetic, geometry, music, and astronomy. Following Cassiodorus, Isidore discusses the definition and division of "philosophy" at the beginning of his compendium of dialectics, but he gives two schemes for subdividing "philosophy." The first is the familiar Stoic division, which St. Augustine attributed to Plato, namely, logic, physics, and ethics. To this Stoic division he gratuitously added his own subdivision (see chart 4).

Side by side with the Stoic division and his own subdivision of philosophy, Isidore simply repeated the familiar tripartite division of speculative philosophy into physics, mathematics, and metaphysics (theology) and of practical philosophy into ethics of the individual, ethics of the family, and politics. The point is that at this time nobody knew what to make of "philosophy" or "science" strictly so called.

During the early Middle Ages, that is, up to the introduction of the Aristotelian corpus into the Latin West in the twelfth century, Schoolmen preserved the division of Boethius even though they had little or no idea of what was meant by physics, metaphysics (natural

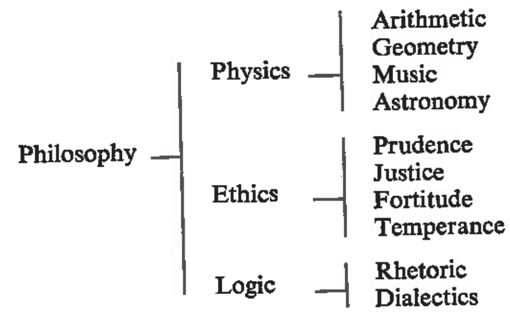

Chart 4

theology), or ethics. Some, following Isidore, thought that physics meant the quadrivium; some, like Cassiodorus following Boethius, thought that metaphysics meant Christian theology based on the Bible; some, like Isidore, thought that ethics meant the four cardinal virtues. It is a tribute to medieval scholarship that the medieval schoolmen continued to promulgate Boethius's division of philosophy without having the Aristotelian books that would have given meaning and content to the schema of classification. Throughout the early Middle Ages, scholars—such as Alcuin of York, Rabanus Maurus, Scotus Eriugena, and the entire school of Chartres—gave one or the other of the two classical divisions of "philosophy," and sometimes combined the two.[14] In practice, no damage was done, even though no advance was made in philosophy. Education simply comprised the seven liberal arts, which continued to be the foundation of human knowledge, and the study of the Christian faith found in the Bible and in the writings of the Fathers of the Church.

In the twelfth century a more thorough synthesis of the two ancient classifications was presented in the various *Didascalia*, or general introductions to the *artes*. These summary treatises follow the general pattern of the traditional *Disciplinarum libri*, discussing the nature and classification of learning, and briefly explaining the nature of each art. The best known of these is the *Didascalicon* of Hugh of St. Victor (1096–1141). In this remarkable treatise seven mechanical arts are introduced as parts of "philosophy" in order to balance the seven liberal arts; all seven liberal arts, including grammar, find a place in this classification; and it is a successful combination of the Boethian and Stoic divisions of "science." Hugh of St. Victor says, "Philosophy is divided into theoretical, practical, mechanical, and logical; these four branches embrace all scientific knowledge."[15] Except for the mechanical arts, the basic division of scientific knowledge is that of the Stoics. In this case "physics" is taken to be equivalent to "theoretical" and coextensive with Boethius's tripartite classification of speculative "philosophy" (see chart 5).

- Theoretical, or speculative (= *naturalis*)
  - Theology—deals with forms truly separated from matter
  - Mathematics — deals with forms of bodies conceived apart from matter
    - Arithmetic
    - Music
    - Geometry
    - Astronomy
  - Physics—deals with forms in matter and motion
- Practical, or active (= *moralis*)
  - Ethics of the individual
  - Ethics of the family (economics)
  - Ethics of the state (politics)
- Mechanical, or "adulterine arts"
  - Fabric-making
  - Armament-making
  - Commerce
  - Agriculture
  - Hunting
  - Medicine
  - Theatrics
- Logic (= *sermocinales*)
  - Grammar
  - Dialectics (logic)
  - Rhetoric

Chart 5

Hugh of St. Victor's classification of scientific knowledge was taken over by Clarenbaud of Arras around the middle of the twelfth century, and it enjoyed continuous circulation from the time it was written. But in practice it did not affect the actual teaching of arts in the schools of Chartres, Paris, or elsewhere. Although men like Peter Abelard fully recognized the scientific character of logic, it was taught mainly as an art, in keeping with Boethius, who had said that logic "is not so much a science as an instrument [or tool] of science."[16]

Science in the High Middle Ages

The period between roughly 1170 and 1270 was the high watermark for treatises on the nature and division of the sciences. In the late twelfth century, works of Arabic authors who had discussed the

classification and meaning of "science" were translated into Latin in Spain. Dominic Gundissalinus not only translated al-Farabi's important *De scientiis* and *De ortu scientiarum*, but also compiled a lengthy work of his own on the division of the sciences drawn from Arabic and early Latin writers.[17] Later Gerard of Cremona produced a new version of al-Farabi's *De scientiis*, and Michael Scot composed a treatise *De divisione philosophiae*, fragments of which have been preserved in the encyclopedic *Speculum doctrinale* of Vincent of Beauvais (fl. 1244–64). The impressive encyclopedia of Vincent presents at least ten definitions and divisions of the sciences, drawn from earlier and contemporary sources.[18]

The work that contributed most to a more profound understanding of the nature and scope of the sciences was Aristotle's *Posterior Analytics*, which was translated three times in the second half of the twelfth century. But, as John of Salisbury noted, it was so difficult to understand that there was scarcely a master willing to teach it.[19] The earliest Latin scholastic to comment upon it and make it his own was Robert Grosseteste, between 1200 and 1209. Albertus Magnus and Thomas Aquinas also commented upon it at a later date. The influence of Aristotle's *Posterior Analytics* on the minds of these two giants is most conspicuous in their grasp of the nature of science in general, and of physical science in particular.

The essence of scientific knowledge was clearly revealed to the scholastics by the translation of the actual texts of Aristotle and the incorporation of them into the university curriculum. Until it could be seen what Aristotle meant by physics, ethics, and metaphysics, it was useless to speculate on the classification given by Boethius in his *De trinitate*. The problems encountered in incorporating the Aristotelian *libri naturales*, or "books of natural science," into the faculty of arts are well known. The condemnations of Aristotle's *libri naturales* in 1210 and 1215, as well as succeeding proscriptions, eventually fell into disuse; and by 1255 the faculty of arts at the University of Paris required that almost all of these books of Aristotle's natural philosophy be read in the schools. Despite ecclesiastical condemnations of Aristotle as dangerous to the Christian faith, the medieval university adopted Aristotle and his writings as its very own. In fact, the *libri naturales* were thought to be the only books of their kind that could illumine the mind about man and the physical world in which we live. Despite numerous corrections that had to be made to the views of Aristotle in the Middle Ages through further observation and experimentation, nothing was written to replace the Aristotelian books on physical theory (*Physics*), physical astronomy (*De caelo*), primitive chemistry (*De generatione et corruptione*), meteorology (*Metheora*), psychology (*De anima*), and biology (*De animalibus*). Even in the seventeenth century, when criticism of Aristotle was at its height, nothing comparable was written to replace his books in the schools of Europe.

When the books of the new Aristotelian learning were incorporated into the medieval universities, it was simply a matter of adding physics, ethics, and first philosophy (metaphysics) to an existing structure of the seven liberal arts. There was no need for a new mathematics, for Euclid, Ptolemy, and Boethius were already taught as parts of the quadrivium; similarly, logic, grammar, and rhetoric were already in the university as the trivium. The new Aristotelian learning was simply tacked on to the liberal arts program as "the three philosophies": natural philosophy, moral philosophy, and first philosophy (metaphysics). With the addition of these new "sciences," the faculty of arts became known as the faculty of arts and sciences.

With the introduction of the new disciplines, the temptation became increasingly great to see a hierarchical gradation of the sciences after the manner of Plato. For the Platonists, mathematics supplied the principles for understanding the ever-changing images in nature, and the door to an understanding of metaphysics. The three parts of speculative philosophy enunciated by Boethius were seen as "three degrees of abstraction," whereby the mind ascended from the transience of nature to the stability of mathematics and, finally, to the immateriality of metaphysical being. In late scholastic philosophy, the doctrine of "the three degrees of formal abstraction" is fully enunciated: the *first degree* is formed by abstraction from "individual" matter, leaving the subject of consideration with only "sensible" matter, the realm of the natural sciences; the *second degree* is formed by abstraction from "sensible" matter, leaving only "intelligible" matter, the realm of the mathematical sciences; the *third degree* is formed by abstraction from *all* matter, leaving only pure being as such, the object of metaphysics.

At the very beginning of his paraphrase of the *Metaphysics*, composed probably between 1265 and 1270, Albertus Magnus directed his attack on "the error of Plato, who said that natural things are based on mathematical things, and mathematical things on divine things, just as the third cause is dependent on the second, and the second on the first; and so [Plato] said that the principles of natural things are mathematical, which is completely false."[20] The basis of this error, Albert explains, is that Plato had seen a certain ascending order from natural bodies to mathematical, to divine being, but he had misunderstood the explanation of this order. Perceiving that all changeable beings in nature are continuous, and that all continuous beings are simple, Plato had thought that the principles of natural science are mathematical, and that the principles of mathematical being are metaphysical, or "divine." "And this is the error which we have rejected in [our commentary on] the Books of the *Physics*, and which we shall again reject in the following books of this science [of metaphysics]."[21] The metaphysical error that Plato made was frequently pointed out by Thomas Aquinas and by Albertus Magnus: Plato equivocated on the word *one*. The "one" which is convertible with "being" so that we can say "a being" is "one" is not the same kind of "oneness" which is the principle of number, that is, the "one" we use in counting.[22] Because of this error Plato could identify the "one" in mathematics with the "One" in metaphysics (God) and make all knowledge and all reality dependent upon the "One" and "Good" *secundum se*, which is contemplated in the divine science of metaphysics.

From the vehemence of Albert's criticisms, it is clear that the "error of Plato" that he attacks was promulgated by "the friends of Plato" in Albert's own day.[23] These Platonists could easily be Grosseteste, pseudo-Grosseteste, Roger Bacon, and possibly Robert Kilwardby, for all of whom the *key* to natural science is mathematics. For Albertus Magnus, mathematical being, such as number and figure, is a mere abstraction of the mind from the quantified constitution of physical bodies, and not an intrinsic constituent of natural species. Since such mathematical abstractions are made *from* natural bodies, they are thereby equally applicable to them to the extent to which those bodies are quantified. This is particularly true in the aforementioned *scientiae mediae*, which use mathematical principles to investigate natural phenomena. That is to say, the "intermediate sciences," such as astronomy or optics, deal only with quantified aspects of natural phenomena and not the whole phenomenon.

A *scientia media* for the medieval scholastics was intermediate between physics and pure mathematics in such a way that mathematical principles are used to "demonstrate" certain properties of a subject that is truly quantified in some determinable respect. Astronomy, for example, was a true "science" dependent on geometry, because geometrical principles are applied to the quantitative aspects of celestial motions, such as speed, size, distance, and proportionality. The purpose of astronomy, it was thought, was to explain rationally the movements of the heavens in such a way that all phenomena seen in the heavens could be "preserved" or "saved," predicted, and explained. Thus, the role of astronomy was to "save the phenomena" in the heavens through mathematical principles. Simplicius, the sixth-century Aristotelian commentator, explains the origin and nature of astronomy as follows: "Eudoxus of Cnidos was the first Greek to concern himself with hypotheses of this sort, Plato having, as Sosignes says, set it as a problem to all serious students of this subject to find what are the uniform and ordered movements by the assumption of which the phenomena in relation to the movements of the planets can be saved (*sozein tà phainómena*)."[24] As Simplicius explains it, the purpose of astronomy is "to save the appearances, or the phenomena."[25] In order to render such phenomena open to mathematical treatment, all nonquantitative aspects must be disregarded, such as the nature of celestial bodies and the causes of celestial motion, as well as their purpose. Just as mathematics itself must "abstract" from all nonquantitative aspects of natural bodies, so too its applicability is limited to the quantitative aspects of natural phenomena. Since potency, act, form, substance, causality, and even motion itself are nonquantified factors in natural philosophy, they are not open to mathematical treatment. They are considerations and aspects that necessarily elude mathematical treatment. However, since all physical bodies and motions of all kinds are quantified in some respect, they are open to mathematical treatment; such mathematical treatment constituted the medieval sciences of optics, harmonics, astronomy, statics, dynamics, and kinematics. Although Aristotle raised the problem of "intermediate sciences" in his *Posterior Analytics*, his description left much to be desired, and the thirteenth-century scholastics, notably Robert Grosseteste, Albertus Magnus, and Thomas Aquinas, were in a much better position historically to amplify and specify the nature of a *scientia media* between mathematics and natural philosophy. In the seventeenth-century Scientific Revolution the study of such intermediate sciences became considerably expanded as new mathematical principles came to be applied to a wider range of natural phenomena. Thus, Sir Isaac Newton could present his revolutionizing volume entitled *Principia mathematica philosophiae naturalis*, "The Mathematical Principles of Natural Philosophy."

We cannot leave the medieval period, however, without considering the most ambitious and astute consideration of the nature, scope, and classification of the then-known sciences in the thirteenth century. It was the widely known treatise entitled *De ortu scientiarum* ("On the Origin of the Sciences") by the famous Robert Kilwardby, an Englishman who was a renowned master of arts at Paris around the middle of the thirteenth century.[26] Kilwardby, who had become a Dominican of the English Province shortly before 1250, was apparently asked by his religious superiors to write a comprehensive treatise on all the arts and sciences as an aid to younger men in the Order. Its popularity is attested to by the eighteen complete and two incomplete manuscripts extant, but it was not printed until our own day. In it Kilwardby not only presented a classification of all the known sciences, but also raised fundamental metaphysical questions about the sciences discussed. The sixty-seven chapters of this highly balanced work give not only the origin, nature, scope, definition, and division of all the known sciences and arts, but also their interrelationships and the basic problems with which each science is concerned. The skeleton division here presented reminds one very much of Hugh of St. Victor's classification, but one would be greatly deceived if he assumed from this that Kilwardby's treatise is a mere recapitulation of Hugh's, for it is infinitely more sophisticated, rich, and thorough (see chart 6).

After Robert Kilwardby's *De ortu scientiarum*, philosophers ceased to write treatises on the nature, scope, and classification of the sciences. All such information was given briefly as part of an introduction to a specified course of study.

Early medieval treatises on the nature and classification of the sciences, such as those of al-Farabi, Hugh of St. Victor, Michael Scot, Gundissalinus, and Kilwardby, were special introductions to the study of the human sciences in general. Such introductions or treatises, it was well recognized, belong to the office of the metaphysician reflecting on the whole of human knowledge. For example, Roger Bacon states: "A noble part of metaphysics, since it is common to all sciences, is to show and demonstrate the origin, distinction, number, and order of all the sciences and what is characteristic of each."[27] Although the writing of such treatises belonged to the metaphysician, the intention of such introductory literature was to show beginners the scope and nobility of each science, and why it should be studied with diligence. Treatises contemporary with Kilwardby, such as those of Nicholas of Paris,[28] Arnulph of Provence,[29] and John of Dacia,[30] had the same purpose, but they are all conspicuously inferior to the masterly treatment by Kilwardby.

For some reason, scholastics of the fourteenth century were no longer interested in writing this type of literature. While the division of the sciences was well known to all students, fourteenth-century scholastics were no longer interested in discussing problems of the nature, scope, and classification of the sciences. They were more

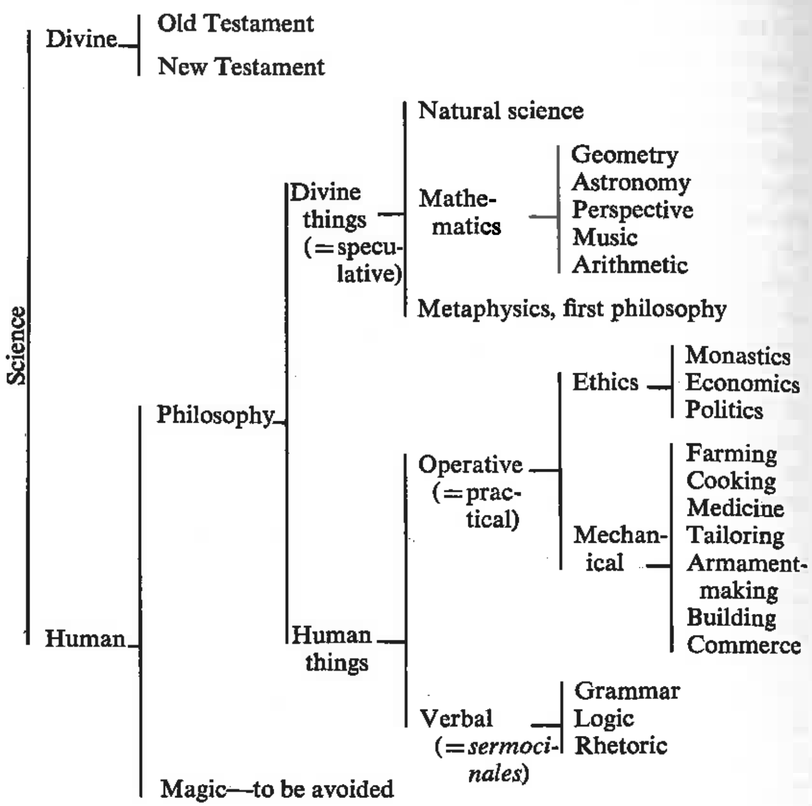

Chart 6

interested in the new logic and the new problems of physics that arose in the early fourteenth century, first at Oxford, then on the Continent. The age of recovering the "new Aristotelian learning" was past. A new age was inaugurated with new problems of its own leading to the seventeenth-century revolution in scientific knowledge.

Notes

1. On the ideal of Greek education, see Henri Marrou, *A History of Education in Antiquity* (New York, 1956), pp. 61–115.
2. For further detail, see James A. Weisheipl, "The Concept of Scientific Knowledge in Greek Philosophy," in *Mélanges à la mémoire de Charles De Koninck* (Quebec, 1968), pp. 487–507.
3. On the origin of Greek scientific knowledge, see George Sarton, *A History of Science: Ancient Science through the Golden Age of Greece* (Cambridge, Mass., 1952), pp. 168–73; G. E. R. Lloyd, *Early Greek Science: Thales to Aristotle* (London, 1970), pp. 1–49.

4. H. Diels, *Fragmente der Vorsokratiker*, 5th ed. (Berlin, 1934–1938), 28 B frag. 6.
5. Aristotle, *De caelo* 3. 1. 289^{b}21; Diels, *Fragmente der Vorsokratiker*, 28 B frag. 6.
6. Aristotle, *De generatione et corruptione* 1. 8. 324^{b}35–325^{a}3.
7. Theophrastus, *Physicorum Opiniones* 1, frag. 8, 19–21, in H. Diels, *Doxographi Graeci* (Berlin, 1929), p. 483.
8. Plato, *Parmenides* 130 B–D; cf. Aristotle, *Metaphysics* 12. 3. 1070^{b}19–20.
9. Augustine, *De civitate Dei* 8. 4, in *Patrologiae cursus completus, series latina*, ed. J.-P. Migne, vol. 41 (Paris, 1845), col. 228.
10. Augustine, *Retractationes* 1. 6. This is the reading printed in the edition of Pius Knöll (Corpus scriptorum ecclesiasticorum latinorum, vol. 36 [Vienna, 1902], p. 28); one might have expected "astronomica" in place of "arithmetica," to give a closer parallel to *De ordine* 2. 15. On the other hand, "philosophy" should perhaps be viewed as including astronomical matters.
11. Martin Grabmann, *Die Geschichte der scholastichen Methode* (Freiburg, i. B., 1909), 1: 148–77.
12. Boethius, *Commentarii in librum Aristotelis Peri Hermenias*, editio secunda, 2. 3, ed. C. Meiser (Leipzig, 1880), vol. 2, pt. 1, pp. 79–80.
13. Cassiodorus, *Liber variorum*, 1, ep. 45, *Patrologia latina*, ed. Migne, vol. 69 (Paris, 1848), vol. 539.
14. See James A. Weisheipl, "Classification of the Sciences in Medieval Thought," *Mediaeval Studies* 27 (1965): 54–90.
15. *Didascalicon*, 2. 1, ed. C. H. Buttimer (Washington, D.C., 1939), p. 24.
16. Boethius, *Super Porphyrium*, editio secunda, 1. 3 (Corpus scriptorum ecclesiasticorum latinorum, vol. 48 [Vienna, 1906], p. 140, line 13 to p. 143, line 7).
17. Cf. Dominicus Gundissalinus, *De divisione philosophiae*, ed. Ludwig Baur (*Beiträge zur Geschichte der Philosophie des Mittelalters*, vol. 4, pts. 2–3 [Münster, 1903]); Alfarabi, *Über den Ursprung der Wissenschaften*, ed. Clemens Baeumker (ibid., vol. 19, pt. 3 [Münster, 1916]).
18. Vincent of Beauvais, *Speculum doctrinale* (Douai, 1624), vol. 1, cols. 9–21.
19. *Metalogicon*, 4. 6, ed. C. C. J. Webb (Oxford, 1929), p. 171.
20. Albert, *Metaphysica*, 1.1.1, ed. Bernhard Geyer, in *Opera omnia*, ed. Geyer, vol. 16, pt. 1 (Cologne, 1960), p. 2, lines 31–35.
21. Ibid., lines 45–47.
22. Thomas, *Summa theologiae* 1, quest. 11, ans. 1, ed. Institute of Medieval Studies (Ottawa, 1953), vol. 1, pp. 56a–57a; *In I Metaphysica*, lect. 7–8, ed. M. -R. Cathala (Turin, 1926), pp. 38–46. Cf. Plato, *Republic* 478 B; *Parmenides* 144 B; *Sophist* 237 D – 238 A; Albert, *Metaphysica*, 1.4.13, ed. Geyer, vol. 16, pt. 1, pp. 65–67.
23. See James A. Weisheipl, "Albertus Magnus and the Oxford Platonists," in *Proceedings of the American Catholic Philosophical Association*

33 (1958): 124–39; and "Classification of the Sciences in Medieval Thought," pp. 72–90.
24. Simplicius, *In II De caelo*, 12, comm. 43 (Venice, 1548), fol. 74r–v.
25. On this role, see Pierre Duhem, *To Save the Phenomena: An Essay on the Idea of Physical Theory from Plato to Galileo*, trans. E. Doland and C. Maschler (Chicago, 1969).
26. Robert Kilwardby, *De ortu scientiarum*, ed. Albert G. Judy, O.P. (London, 1976).
27. Bacon, *Communia naturalium*, in *Opera hactenus inedita*, ed. R. Steele, vol. 2 (Oxford, 1905?), p. 5; also *Communia mathematica*, in ibid., vol. 16 (Oxford, 1940), p. 1.
28. Oxford, Merton College, MS 261, fols 67ra–69vb.
29. Ibid., fols. 13ra–18va.
30. *Johannis Daci Opera*, ed. A. Otto (Corpus philosophorum Danicorum medii aevi, vol. 1, pt. 1 [Copenhagen, 1955]), pp. 3–44.

15

Bert Hansen

Science and Magic

People have long associated magic with the Middle Ages. An "age of belief" is assumed to foster the occult; Merlin and witches are standard props in everyone's picture of pre-modern Europe. Modern scholarship, however, has reassessed and clarified this picture in several respects. Almost single-handedly Lynn Thorndike demonstrated that magic in the Middle Ages was not marginal to intellectual life, nor an activity of ignorant, credulous, or superstitious people—or at least not of these alone. Magic, as he revealed, formed an important part of medieval thought and experience. Thorndike also amassed tomes of documentation for his claim that magic was, in the Middle Ages and early modern period, a source of the empirical and experimental approach to nature.[1] More recently a number of other historians have reassessed Neoplatonic magic and Hermeticism in the Renaissance and have perceived them to be factors in the creation of "modern science" in the seventeenth century.[2] These two important developments in the historiography of magic and science condition the task of this study: to set forth the basic outlines of the magical world-view of the Middle Ages, comparing and contrasting magic with the contemporary natural philosophy, and briefly relating this to the interactions of magic and science in the sixteenth and seventeenth centuries.

At the outset, two comments on my approach are in order. I distinguish here between the ubiqui-