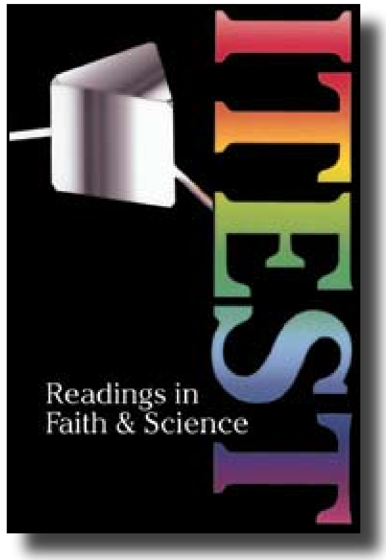

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A Brief History: A History Of Science And Faith

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A Brief History: A History Of Science And Faith

Throughout a good part of the twentieth century it has been commonly accepted among scholars that the relationship between science and religion is one of conflict. One of the chief propagators of that view was Andrew Dickson White, the first president of Cornell University, in his influential *History of the Warfare of Science with Theology in Christendom*(2 vols., New York 1896). In the period following World War II, however, with the rise of the history of science as an academic discipline, the "conflict"thesis has been increasingly questioned. Students of medieval science in particular have come to appreciate the intimate relationship between faith and reason in the pre-modern period, some even acknowledging the debt owed by science to the Catholic Church for its sponsorship, growth, and subsequent development.

In more recent times a spirit of irenicism has been fostered by a loss of confidence among scientists that their science holds all the answers. The limitations of scientific knowledge have become apparent in a century when warfare, made more cruel and devastating by instruments of destruction fashioned by scientists, has threatened to destroy civilization. The plight of the poor and homeless, urban violence, juvenile delinquency and other social problems have resisted solution through using science's empirical techniques. At the frontiers of physics, deep enigmas encountered in quantum and relativity theory have led some to seek transcendent or theological explanations for phenomena which have never been entertained before.

On top of all this it has generally been overlooked that the relationships between religion and science are only part of the larger problem of the relationships between faith and reason, one long recognized in the Catholic tradition. Once the respective spheres of these two types of knowledge are made clear, many of the difficulties arising in current debates over religion and science dissolve. Thus, in this essay we shall attempt to situate the religion-science debate in the context of the distinction between faith and reason as that distinction has been variously understood over the past twenty centuries. This is a large undertaking, but it pays ample rewards to those willing to embark upon it.

Before doing so we should make a few observations about the meanings of terms. Faith is understood here simply as belief in God and acceptance of His revelation as true. It is differentiated from reason on the basis that reason refers to the way humans acquire knowledge through their natural powers of sense and intellect, without reliance on God or supernatural revelation. Such a differentiation need not imply incompatibility: a person can have reason and faith at the same time, though probably not of the same truths. Made in this way, the distinction focuses more on the mode of acquisition of knowledge than on the knowledge acquired. A person whose reason is complemented by faith might thus be capable of knowing more truths than a person who knows through reason alone. But a limitation is here implied also, for if contradictory "truths" derive from these different sources, then the competing claims of faith and reason have to be resolved, and the problem of the proper relationship between faith and reason comes into sharp focus.

Religion has many meanings at present, being sometimes identified with magic or myth, sometimes with concern for the sacred, sometimes with the totality of human experience relating to a transcendent being known only through a special revelation. In the traditional Catholic view religion is not so much a form of knowledge as it is a virtue that disposes a person to render to God the homage due to him. Whichever view one adopts on its nature, it seems agreed that religion can be studied by reason, at least as a cultural phenomenon that has existed in various forms over the ages.

Science, on the other hand, presents more difficulty because, in some ways of viewing it, science has been in existence only for the past three centuries. (When this meaning is intended, the adjective "modern" should be added to the term and one should speak of modern science rather than of science in general.) Here the broader meaning obviously has to be employed. Our starting point is therefore an ideal that goes back at least to the time of Aristotle (4th century B.C.): science is a type of perfect knowing wherein one understands an object in terms of the causes that make it what it is. This definition is sometimes relaxed within Aristotle's own writings to include systematic explanations other than causal, including those that provide under-standing with a high degree of probability rather than complete certitude.

Today some would relax this conception even further to state that science is an ongoing effort simply to find the order of things and to assign reasons for that order. From this it is obvious that the term science can take on, and has taken on, different meanings throughout the centuries. Still, true and certain knowledge of the world of nature is the ideal toward which most scientists aspire, though invariably they must settle for results that, while well-confirmed, leave room for alternate explanations.

The science with which we shall be most concerned is natural science, particularly physics and its allied disciplines, for it was in their areas of investigation that conflicts with religion first arose. The term "empirical science" is often used to characterize this type of study. The root meaning of empirical is knowledge based on experience, but frequently the term has the added connotation that this experience is of a particular type involving experimentation and measurement. Experimentation further suggests that the results arrived at are communal in nature, that is, they are not restricted to one person's experience and insight but instead are publicly verifiable.

When measurement is involved, moreover, the implied use of quantitative techniques also involves investigators in mathematical modes of reasoning. To understand the great contributions of Galileo, Descartes, and Newton, for example, one must know mathematics as well as physics, and thus their work can be seen as largely pertaining to a hybrid type of science known as mathematical physics. All of these varieties of science, needless to say, assume importance at various stages in what follows.

A final observation might be made about the relation of science to philosophy. Although today science and philosophy are seen as different fields of study, up until the nineteenth century natural science was coextensive with natural philosophy. The full title of Isaac Newton's *Principia* (1687), for example, was *The Mathematical Principles of Natural Philosophy*, where by "natural philosophy" Newton meant "natural science." Even in the present day philosophical problems arise in the empirical sciences, and these become the special concern of philosophers of science. The history of science thus parallels to a large degree the history of natural philosophy. The two fields differ mainly in that natural philosophers in the premodern period spent much time on speculative issues, whereas in the modern era they (and their scientist counterparts) are especially concerned with how experiments and measurements can yield true information about the real world. We shall maintain the more modern focus in our overview of science's history.

Ancient Science

In the ancient period what we regard as science can best be equated with a conscious search for regularities in nature. The first such activity of which scholars are aware took place in Egypt, where calendars were in use before 2500 B.C. Timekeeping was the main purpose of astronomical observation; this led to knowledge of the four main points of the compass and the possibility of making accurate determinations with respect to them. The Great Pyramid of Khufu that was built in that period, for example, is aligned to true north within less than one-tenth of a degree. The technology involved in pyramid and obelisk building also suggests that the Egyptians had a superior knowledge of practical mechanics.

Clay tablets that survive from the early Babylonians (or Chaldeans) give indication that before 1600 B.C. these peoples possessed an arithmetic that far surpassed that of the Egyptians. They also made many astronomical observations, for which cuneiform tables dating from about 300 B.C. are available. Apart from developing a sophisticated calendar whose fundamental units were the day and the month, they observed the positions of the sun, the moon and the planets and put their results in tables from which accurate predictions could be made. Although it is often said that their astronomers were priests and that their interest was in casting horoscopes for the guidance of the government, there is little evidence to support such assertions.

The earliest systematic study of nature took place among the Greeks in Miletus, a city on the west coast of what is now Turkey, around the sixth century B.C. Thales, who is regarded as the first natural philosopher, is credited with improving the geometrical knowledge of the Egyptians and having predicted an eclipse of the sun, presumably in 585 B.C. More important is the fact that he sought to explain the entire world of nature in terms of a single principle, which he identified with water. Other Milesians such as Anaximander and Anaximenes speculated about other principles, the first identifying the underlying stuff of the cosmos as a source that was simply "boundless" (*apeiron*), the second rejecting that for air or vapor that could be rarified and condensed to form the various objects perceived in sense experience. The central feature of Milesian thought is its setting aside mythical accounts of the origin of the cosmos and seeking rational explanations of phenomena in terms of material causes.

A somewhat different line of development originated around the same time from another Greek philosopher named Pythagoras whose primary interest was in mathematics. Born on the island of Samos in the Aegean Sea, he established a school, and a secret sect, in southern Italy. Pythagoras was convinced that number is the key to the universe, and so he investigated various kinds of numbers to see how they might be applied to geometrical figures. He is celebrated for his formulation of the Pythagorean theorem, that the square of the hypothenuse of a triangle is equal to the sum of the squares of the other two sides, and also for the discovery that the square root of two is an irrational number and so cannot be known precisely. So shattering was the latter discovery that Pythagoras imposed an oath of secrecy on his followers lest it become known and imperil his research program.

The Pythagoreans apparently experimented with musical sounds and the harmonies they produce, associating their intervals with numerical ratios. They likewise knew that the earth was a sphere, and regarded the universe as spherical also. At the center of the universe was a central fire, around which the earth rotated; to this they added a counter-earth, the sun, the moon, the five planets and the sphere of the fixed stars. The total number of rotating bodies thus came to ten, which they regarded as a sacred number. They further held that the heavens themselves are numerical and musical, producing a harmony in their movements. This idea became known as "number mysticism" and was to inspire Johann Kepler when he wrote his *Harmonies of the World* in 1619.

Ionian philosophers, as has been mentioned, were concerned with the nature of matter and proposed various possibilities for the basic stuff of the universe. Around 450 B.C. Empedocles made a synthesis of these views and elaborated what was to become one of the longest-lasting theories in the history of science --- the four-element theory, according to which all terrestrial bodies are composed of fire, air, water and earth in various proportions. To these four elements Empedocles added two agents of change, one an attractive principle and the other a repulsive principle. Yet another position was advanced by an opponent, Anaxagoras, who posited an infinite number of material principles, maintaining that "there is a portion of everything in everything."

A yet later view was that of Leucippus of Miletus and his pupil, Democritus of Abdera, who flourished around 420 B.C. They introduced the notion of atom, or indivisible, and coupled it with that of the vacuum, or void space. Their atoms were posited as invisibly small, infinite in number, alike in substance but different in shape, in constant motion through the void. Although rejected by Aristotle, their views were adopted by Epicurus at the end of the fourth century B.C. and widely propagated by the Roman poet Lucretius in his *De rerum natura*, written about 60 B.C. This work became the main vehicle through which the materialism and atheism implicit in Democritus's writings were transmitted to later ages, being known, for example, to Robert Boyle and Isaac Newton in the seventeenth century.

Pythagoras's teachings exerted a strong influence on Plato, who founded an Academy in his native city Athens and himself is ranked among the greatest of Greek philosophers. Whereas previous thinkers had concentrated on material principles, Plato's focus was on form. His main thesis was that the human mind can rise above sensible appearances, the world of illusion, to grasp the other-worldly Forms that are their ideal exemplars. In his famous dialogue, the *Timaeus*, he taught how the Creator, the Demiurge, fashioned the various elements into distinctive geometrical figures and so formed the universe on mathematical patterns. These were animated by a World Soul, which along with the Demiurge created the stars and the planets with their souls, and then the souls of men. Last to be created were bodies for human souls to occupy. Man, for Plato, is composed of body and soul. The soul is the self-moving and knowing principle, imprisoned in the body, as it were, yet directing it as a sailor might a ship. It desires to be liberated from matter and return to the world of Forms, which it can contemplate and thus attain truth and happiness.

Two of Plato's students are important for the history of science. The first is Eudoxus, one of the greatest mathematicians of antiquity, who, following Plato's suggestion, was able to account for the appearances of the heavens by using various combinations of uniform circular motions. To do this he required twenty-seven spheres that were concentric with the earth but rotated at different speeds and on different axes. With the exception of two of the planets (Mars and Venus) it proved remarkably successful in accounting for the then-known appearances of all the heavenly bodies.

Plato's other, and more famous, student was Aristotle of Stagyra, usually regarded as "the Father of Science in the West." Aristotle rejected Plato's teaching that there is a separate world of Forms from which humans derive their ideas. For him all knowledge derives from experience, as the countless impressions on the senses are processed by the abstractive and inductive powers of the mind, which in turn bring the "forms" or meanings inherent in the very objects in nature to light. Mathematical forms are among those extracted from material objects when one concentrates on such properties as their number, size, and shape. Other ideas such as "cause" and "effect" serve as the means of ascertaining necessary connections in nature. All scientific knowledge, in Aristotle's view, rests on determining the causes of phenomena, which may be of four types: material, formal, efficient and final. If there are events to which none of these causes can be ascribed, these happen by "chance" and so fall outside the realm of scientific explanation.

Not only did Aristotle prescribe canons such as these for scientific investigation, but he himself studied the entire world of nature and systematically organized all the natural knowledge available to the ancients. He laid foundations for physics in his study of motion, for astronomy in his writings on the heavens, for chemistry in his accounts of the elements and how they combine, for botany and zoology in his detailed classifications of plants and animals, for psychology in his treatises on the soul and for social and political science in his works on ethics and politics. Known as "the master of all who know," he became the main repository of knowledge for scholars in later centuries, all the way to modern times.

It should also be noted, however, that Aristotle composed works on metaphysics and natural theology that were to prove problematic from the viewpoint of religion. Although he offered proofs for the existence of a First Unmoved Mover and a First Cause, easily identified with the God of revelation, he thought that the universe had always existed and so had no doctrine of creation. His God, moreover, was an impersonal deity who had no interest in humans or providence over them. And, in treating the human soul, he was somewhat ambiguous in discussing what happened to the soul after death; as a result many later thinkers took him to deny personal immortality.

Although these strains in his thought were to alarm Christians, they did not have adverse effects in the context of Greek religion. For the Greeks and the Romans the gods were mythological figures of which knowledge had been provided largely by poets. Although uneducated people were fascinated by accounts of their adventures and misadventures, the gods were fruitless for explaining nature. Thus the non-mythological accounts provided by naturalists and other philosophers gained ready acceptance among those who were literate. Gradually the gods came to be seen as either products of nature itself or as beings created by humans in their own image and, consequently, as immoral as the mere mortals who created them. In rejecting the gods some thinkers, such as Epicurus and Lucretius, ended up convinced atheists, but the majority of Greek philosophers and scientists attempted to work out a more refined and non-mythological concept of God along lines suggested by Plato and Aristotle. Thus a monotheistic religion became the ideal that appeared to be the most compatible with the emerging scientific outlook.

The Coming Of Christianity

When Christianity made its appearance on the world scene a distinctly new situation was created with regard to religious aspirations. The early Christians were surely aware that Jesus has furnished them insights that would forever alter the then reigning views of the relationships between God, the world and mankind. Yet the Gospel the apostles and disciples had to proclaim was too deep and ineffable to be easily made intelligible to non-believers, particularly to philosophers. As St. Paul realized, the learning of the Greeks was an obstacle that would make it difficult for them to see the new faith as anything other than "foolishness."

The main source available for information about the intellectual life of the Church in its early days is, of course, the New Testament. Here one finds few allusions to the cosmos as a whole or any discourse that might readily qualify as scientific. This does not mean that the apostles and evangelists were ignorant of Greek science or that they found its fundamental tenets incompatible with Christianity. Like the Judaism out of which it emerged, the Christian religion was monotheistic and so more appealing than the mythological discourse about gods that was hitherto prevalent among the Greeks. Yet there were elements of Christian doctrine that were paradoxical and that would require detailed explanation and justification.

Although Aristotle had no teaching on creation, this was clearly present in his teacher Plato, and thus when Paul preached in the Areopagos in Athens that God made the world and all things therein (Acts 17:24), this would not have scandalized those in his audience who knew Greek philosophy. Again, when Paul stressed to the Romans that God had left a certain imprint on the world, and that his invisible nature could be discerned from the things he has made (Rom 1:20), this found a resonance in Aristotle's teaching on the First Mover. After all, it was the Stagyrite (Aristotle) who deduced attributes such as God's eternal duration and infinite power from the properties of the motions He sustains in the cosmos. The Stoics also, as is clear from Cicero's treatise On the Nature of the Gods, thought that God's nature could be made manifest from a study of his creation.

Perhaps the most illuminating passage in the New Testament, however, was the prologue to the Gospel of St. John, which begins with the majestic words:

> In the beginning was the logos, and the logos was with God, and the logos was God. All things came into being through Him, and without Him not one thing came into being. (Jn 1:1-3)

For the Greeks *logos* meant not only "word," as we usually translate the term; it meant the unspoken thought or reason behind the word, or even the meaning behind everything. Thus the passage conveyed the idea that the world came into being according to rational principles and therefore must be basically intelligible --- precisely the supposition that lay behind all of Greek science. It was only when John the Evangelist went on to assert that the divine logos became flesh and dwelt among us (Jn 1:14) that his message bordered on the incredible --- what, as Paul warned, would be accounted "foolishness" by the Gentiles. Yet this linking of the intelligibility of nature with the deepest mystery of the Christian faith --- that God himself, the divine logos, had at one time become incarnate in the human world --- invited a study of his creation that promised rewards far beyond anything that had previously been expected from scientific exploration.

One may conclude from this that the first Christian literature contained a number of guidelines for a Christian reading of the Book of Nature. There was one God only whose own rationality had become immanent in his created world, from which a certain natural knowledge of the creator might be gathered. This perhaps explains why the New Testament writers left Greek science alone. Whether they were aware of it or not, they implicitly shared its fundamental assumptions.

The Fathers Of The Church

A more nuanced mediation between the Christian faith and Greek science was afforded by the Fathers of the Church in the next four centuries. This came about somewhat fortuitously because of the commentaries that many of them wrote on Genesis, the opening chapter of which contained an account of the six days of creation (in Greek, the Hexaemeron) that touched on many problems of interest to scientists and philosophers. Since the Fathers accepted the text of Genesis on face value as containing truths divinely revealed, and since they themselves were part of the culture of the times, they were faced directly with the task of aligning the account in Genesis with the teachings of their contemporaries.

The writings of the Fathers, both Greek and Latin, were addressed to the reader of general education and so did not presuppose knowledge of ancient science. They proposed to teach, not astronomy, but the way to salvation. For many of them the profane sciences satisfied only a vain curiosity. Thus St. Basil castigates astronomers for searching out all the details of the universe but missing one thing --- the discovery of God, creator of all things and the just judge of all. Similarly, St. Augustine acknowledges that he has no time for the discussions of astronomers, but only wishes that they would be more concerned with their own salvation and the needs of the Church.

The position adopted by the Fathers was understandable, particularly in view of the conflicting philosophical views of the Atomists, Aristotelians, Stoics and Neoplatonists, making it almost impossible to hold any one position as true and certain. In such a situation the teachings of Scripture seemed the only reliable criterion of truth. Moreover, astronomy in those times was dominated by an astrology that was fatalistic and opposed to Christian teachings. Thus it seems plausible that patristic attacks on pagan writings were directed more against their implied beliefs in non-Christian religions than against the science they contained.

Another factor that must be taken into account is the preference of the Church Fathers for the philosophy of Plato over that of Aristotle, mainly because of Plato's account of creation in the *Timaeus* and his teachings on the human soul. (Most of them actually favored a renewed type of Platonism called Neoplatonism that incorporated much of Aristotelian science within a general Platonic setting.) Writing in the fourth century, St. Augustine, for example, professed to find much in Platonist writings that accorded with Scripture. And the Greek Monophysite, John Philoponus, writing two centuries later, thought that Plato had read the Bible and received inspiration from it. It is not surprising, therefore, that most of the Church Fathers regarded Neoplatonism as the philosophical system that could best be reconciled with Christian revelation.

The Greek Fathers

In discussing the Greek Fathers of the Church it is customary to group them according to the geographical areas in Africa and Asia Minor in which they dwelt, for different interpretations of the Hexaemeron became distinctive of the various regions. Thus one speaks of the Alexandrians (who worked in Alexandria), the Syrians (who wrote in Syria), the Antiochenes (who resided at Antioch), and the Cappadocians (who came from Cappadocia, a region of Asia Minor in what is now Turkey). A brief description of their various teachings may prove helpful for seeing how the early Church attempted to reconcile the teachings of the Bible with the secular and scientific knowledge of the day.

At Alexandria the creation account in Genesis tended to be regarded as allegorical, mainly because of the teachings there of the Jewish theologian Philo, born a few decades before Christ, who interpreted Genesis as largely symbolic and figurative. He argued that creation was instantaneous and that the six days of creation are a device for explaining the perfection of order to be found in the universe. Influenced by Philo, St. Clement of Alexandria held that all things were produced simultaneously by God and that the distinction of days do not indicate temporal succession, only gradations in being of what was created on the respective days. Origen likewise took up the theme of simultaneous creation. He taught at Alexandria in the school where Ptolemaic astronomy originated and seems to have understood it quite well, but apparently found no need to reconcile it with what he saw merely as Scriptural allegories. Another Alexandrian who deserves mention is St. Athanasius, who held that all species had been created together and by the same command.

In contrast to the school of Alexandria, the Syrian schools rejected allegorical interpretations and sought the literal sense of the Scriptures. Reacting against simultaneous creation, St. Ephraem held for a real distinction of six days, each composed of twenty-four hours. He regarded the different works assigned to each day as succeeding each other precisely as narrated. Light was created on the first day, but only as a diffused type of entity that would become associated with heavenly bodies on the fourth day.

The Fathers of Antioch followed similar interpretations. St. John Chrysostom attempted to explain the literal sense of Genesis in sixty-seven homilies on that work, but apart from their rejection of simultaneous creation they contain little of scientific interest.

The Cappadocian Fathers --- among whom we find St. Gregory of Nazianzus, St. Basil, and St. Gregory of Nyssa ---adopted a position intermediate between those of the Alexandrians and the Syrians, inclining somewhat closer to the literal sense but preserving elements of the allegorical explanation. Thus they recognized a primordial and simultaneous creation of elementary matter, while choosing a realistic interpretation of the work of six days occupying a successive duration. And perhaps more than any other school they attempted to take account of the science of their day. St. Basil was trained in medicine and had a good competence in scientific matters; his homilies on the Hexaemeron became a prototype for many commentaries extending all the way to that of St. Thomas Aquinas in the thirteenth century. Basil's brother, St. Gregory of Nyssa, proposed the work of the six days as essentially a cosmogony. Assuming the creation of the four elements, in the Empedoclean and Aristotelian sense, Gregory deduced the entire nature of the universe and its constituents from the elementary properties of fire, air, water and earth.

With these Cappadocians we find one of the first serious attempts at concordism --- that is, seeking concord or agreement between the teachings of science and the Bible --- among the Church Fathers. This was continued by John Philoponus, who in 549 completed a treatise *De Opificio Mundi* (*On the Making of the World*). Its primary intent was to show that there need be no contradiction between science and Scripture. The last of the great Greek Fathers, St. John Damascene, writing in the eighth century, summarized much of the teachings of his predecessors. Entitled *De Fide Orthodoxa* (*On Orthodox Faith*), his systematic treatise included the study of the angels, the visible heavens, the stars, the elements, the earth and man. It served as a model for the *Sentences* of Peter Lombard, the basic theological textbook in the Middle Ages.

The Latin Fathers

The Latin writers do not fit into clear-cut groups as easily as do the Greeks. For the most part, the Fathers in the West explained in Latin the teachings of their counterparts in the East. St. Hilary, for example, borrowed from the Alexandrians their notion of simultaneous creation. St. Ambrose, on the other hand, based his exposition of the six days on St. Basil's and became one of the principal sources of Cappadocian exegesis among the Latins. He taught that the elements were created at the first instant, but that the development of this initial production came in the days that followed, which were days in the true sense. Like many of the Latins St. Ambrose was eclectic. His interpretations of Scripture often concentrated on the spiritual sense, and he seemed interested in facts mainly for the moral lessons they suggested.

By far the most important of the Latin Fathers for his influence on later exegesis was St. Augustine. Whereas earlier Latins tended toward a literal interpretation, Augustine moderated this tendency with a move toward the allegorical, though he also criticized the abuse of allegory. He actually wrote three commentaries on Genesis, then touched on similar topics in Books 11 through 13 of his *Confessions*, and finally returned to the creation theme again in Book 11 of his *City of God*. Though no more intent on composing a scientific treatise than the other Fathers, he was better acquainted with the secular thought of his day, particularly when it raised questions relating to the faith.

Augustine's explanation of, "In the beginning God created heaven and earth," provides a key to his interpretation of the Hexaemeron. "In the beginning," for him, means that the world could not have existed from eternity and that time had a beginning. "Heaven and earth" includes all creatures, both spiritual (indicated by the word "heaven") and corporeal (indicated by the word "earth"); the creation of both angels and earthly creatures he places at the very outset. Thus, Augustine makes use of the Alexandrian notion of simultaneous creation: that from the very first instant everything was created.

From this we can understand why there is really no place in Augustine's account for productions that are completely new. The remainder of the first chapter of Genesis therefore does not apply to real days, or to successive intervals of time, but must be interpreted in a more subtle way. Among the alternatives Augustine suggests, the one that most impressed later exegetes is that in which the days signify series of illuminations by which God successively acquainted the angels with works he had accomplished in one instant. The "evening" then signifies the direct knowledge of things originally possessed by the angels; and the "morning," the more perfect knowledge acquired when the angels contemplate them in the Divine Word.

Nonetheless, for Augustine, the universe did develop and thus has a history. Few of the forms created on the first day existed then in their full state of completeness. Many, particularly those of living things, existed only germinally or in their causes. Hence, Augustine was able to make use of the Stoic and Neoplatonic notion of *logikoi spermatikoi* or "seminal reasons," and the restricted type of evolution these implied. Seed-like powers, these seminal reasons may be described as latent sources of activity inserted by God into matter during the work of creation. With the passage of time these were to develop into the various types of plants and animals seen on earth. St. Augustine invoked a similar idea to explain some of the miracles of the Old Testament. For example, he attributed the instantaneous change of Aaron's rod into a snake (Ex 7:10) in terms of angelic intervention: the angels rearranged the elemental constituents of the rod so that a seminal reason latent there could be actualized and developed into a snake.

Another feature of Augustine's writing is the care he took to discern the literal sense of the Scriptures and to separate this off from other possible senses. His most important commentary on Genesis, entitled *De Genesi ad litteram* (*On the Literal Interpretation of Genesis*), abounds with useful rules and directives for interpreting difficult texts. It is noteworthy that Galileo was acquainted with this work, and in fact made one of its teachings the thematic text behind his famous *Letter to the Grand Duchess Christina*. This was Augustine's warning against taking particular texts in their literal meaning and doing this so strongly that it prevents one from understanding them in ways that later discoveries would show not to be in any way opposed to the Old or New Testament. Unfortunately this warning was not heeded by the theologians who acted to condemn Galileo in the early seventeenth century.

The theory of knowledge adopted by St. Augustine is also important for its influence on later thinkers. Augustine was aware of the limitations of sense knowledge, but did not think that man's senses are mistaken. In his view error arises from the way the human soul judges the appearances presented to it. Moreover, there are eternal truths and the soul can grasp them because it is illuminated by God to do so and to judge all things in their light. For Augustine eternal ideas exist in the mind of God, where they serve as exemplars for creation. Through the process of illumination, they also have a regulative action on the human mind, enabling it to judge correctly and so preserving it from error. These themes of light and illumination, characteristic of Augustinian thought, have resonances with Plotinus's theory of emanation and were easily reconciled with Neoplatonic interpretations of Aristotle that became popular later in the twelfth and thirteenth centuries.

Augustine is a good person with whom to end this discussion of early science and its relation to the Christian faith. As he lay on his deathbed in A.D. 430, the barbarians were at the gates of his episcopal city, Hippo in North Africa. The invading hordes had sacked Rome by that time and indeed had swept over most of the Roman Empire.

Effectively they had put out the lamp of learning in the Latin West, including what little science was known there. The Dark Ages had settled in, and it would be a long time before scientific learning would pose a challenge to the Church of Rome.

Science In The East

While science thus languished in the west of Europe, progress continued to be made to the east, mainly in Egypt, Asia Minor, and Greece. Much of the growth can be attributed to a development that was known to Aristotle but was not exploited in the writings generally attributed to him, namely, the use of mathematics in the investigation of nature. In his *Posterior Analytics* Aristotle had laid out the norms for systematizing a science in terms of axioms, definitions, postulates and demonstrations. Within his school a start was made on constructing a science of mechanics along such lines. The work in which this was done, probably in the generation after Aristotle's death, was entitled *Mechanical Problems*. It investigated the principles on which basic machines such as the lever, pulley and the wedge work, but unfortunately the work was lost soon after it was written, along with many other of his writings. (It was not recovered until the Renaissance, when it was attributed to Aristotle himself under the title *Quaestiones mechanicae*, or *Mechanical Questions*.)

In the century after Aristotle, around 295 B.C., Euclid of Alexandria followed the methodology of the *Analytics* in composing his famous *Elements*, which presented geometry as a complete deductive system and even made a start on constructing a science of numbers. It is said that this treatise, made up of thirteen books, has exerted an influence upon the human mind greater than that of any other work except the Bible. Euclid also composed an *Optics* that treated light rays as traveling in straight lines and laid the foundations for what was later called geometrical optics.

Following Euclid, and under his inspiration, a considerable advance was made in mathematics about a century later by Archimedes of Syracuse and Apollonius of Perga. The first worked out rigorous methods for determining the areas of plane and solid figures bounded by curved lines and planes, whereas the second investigated the properties of special types of curves known as conic sections. The last-named curves include the ellipse, parabola and hyperbola; these assumed importance in the science of astronomy as it developed in the seventeenth century.

Archimedes also pioneered in another type of mathematical science, the "mixed" science of statics, called mixed because it combines mathematics with physics. In it he worked out a complete theory of the lever (or balance) and also explained how one can determine centers of gravity for figures of various shapes. He then extended these principles to the science of hydrostatics, wherein he explained buoyancy phenomena, adumbrated the modern concept of specific gravity and determined the equilibrium positions in which bodies of various shapes (such as the cigar-like paraboloid of revolution) will float.

By far the most important of the applied mathematicians of this period was Ptolemy of Alexandria, who lived in the second century of the Christian era. By this time the efforts of Eudoxus and another Greek astronomer, Hipparchus, who lived in the second century B.C., had produced a number of models of the heavenly spheres that could account for the irregular movements of the sun, moon and planets. A fair amount of astronomical data had also been gathered that enabled one, with the use of such models, to predict eclipses and the positions of the planets against the background of the fixed stars. Ptolemy synthesized all of this material in a highly original way, using mathematical devices deriving from Eudoxus, Hipparchus and Apollonius, such as the eccentric circle and the epicycle, to construct a system that was to dominate astronomy for the next fourteen or fifteen centuries.

The Ptolemaic system, for such it was called, is a geocentric or earth-centered system in which a stationary earth is surrounded by a large celestial sphere in which the known stars are embedded. Between the stars and the earth are arranged the moon, sun and the various planets, all rotating on spheres that are roughly concentric with the earth, although all to some degree are "offcenter" (or eccentric) and positioned on smaller circles (epicycles) that modulate their otherwise uniform rotations in various ways. Ptolemy presented this system in a work called *The Almagest* (meaning literally *The Greatest*), which came to be regarded as the definitive exposition of mathematical astronomy. Ptolemy composed another astronomical treatise, *The Hypotheses of the Planets*, which provided a physical interpretation of the teaching contained in *The Almagest*, and thus might be called a physical or philosophical astronomy. Unfortunately this second work was lost, with the result that later thinkers regarded Ptolemy's astronomy as a mathematical abstraction, and thus as not providing an account of what actually takes place in the heavens. In addition Ptolemy wrote works on astrology, geography, optics, and other subjects, all of which enhanced his reputation as one of the most competent and prolific scientists of antiquity.

The development of Greek science we are here sketching bore a close resemblance to Aristotelian science in the analytical methodology it employed and in the world view it proposed, since the Ptolemaic system could be reconciled fairly easily with that proposed by Aristotle in his work *On the Heavens*. The Ptolemaic system also corresponded quite well with the account of the formation of the universe described in Genesis, for the sacred writings seemed to suggest a geocentric or earth-centered universe. Thus Ptolemy's "mathematical construction," for this was the original title of *The Almagest*, coexisted peacefully with the teachings of Greek philosophers and the Church Fathers throughout the early centuries of the Christian era.

It should be noted that the demonstrations offered in this science, being essentially mathematical, were usually made through formal causes. On this account the concern with efficient causes (such as forces) that earlier was manifest in the *Mechanical Problems* of the Aristotelian school came gradually to be dispensed with in the mathematical physics of this early period. The task of the mathematical astronomer, for example, was taken to be predicting the occurrence of eclipses or the positions of the planets, without regard to whatever might cause the motion of the sun, the moon or the planets. As long as their predictions were successful, the mathematicians felt that they had "saved the appearances"; that is, explained how the heavenly bodies assumed the positions they appeared to take against the background of the stellar constellations.

They felt no need to address the problem of whether the eccentrics and epicycles they employed in their calculations were real or not. They thus left to the philosophical astronomers or to the metaphysicians the task of explaining what moved the heavenly bodies, or what the physical causes might be that determined the paths they followed.

The Rise Of Islam

In discussing the relationships between science and faith it is helpful to consider here the next arena where contact would be made between these types of knowledge, namely, regions of the Near East where Arabic culture was dominant. The last school of pagan philosophy in Athens was closed by the Emperor Justinian in A.D. 529. About the same time Alexandria lost its importance as a center of learning. Byzantium then became the capital of the Greek Church, but little was done there to promote philosophy or science as these had developed in the earlier centuries. Later in the sixth century, however, the prophet Mohammed founded a new religion, Islam, in Arabia. (The Arabic term *al-Islaam* means "surrender," with the connotation that its followers had surrendered themselves to God.) The new religion spread rapidly throughout the Arabic-speaking world --- far beyond Arabia into Persia, Turkey, the Holy Land and North Africa. Soon it was the dominant religion in countries bordering the Mediterranean to the east and to the south and would quickly enter into dialogue with the emerging sciences of late antiquity.

The scientific and philosophical milieu in which Islam came into being was basically Greek in origin, although some of the treatises of Aristotle and of Galen, the great medical authority of the times, had by then been translated into Syriac. Such translations were made under the auspices of two Christian sects of the Eastern Church, the Nestorians and the Monophysites, who used them mainly in the service of theology. Some observatories were built, however, and mathematics was also studied for its use in astronomy. With the rise of the new religion, Arabic then came into theological and scientific use, and additional translations were made to that language from both the Syriac and the Greek.

At first the scientific activity in Islam was purely receptive in character, mainly because of the time required for translations and for adapting the Arabic tongue to technical uses. But in the eighth and ninth centuries notable progress was made, first with the appearance of medical and astrological works, and then with signs of interest in astronomy. New observatories were founded, measuring instruments constructed, and accurate observations made. Mathematical and philosophical treatises were also translated, so that, when the ninth century had drawn to a close, practically all of Greek philosophical and scientific literature (plus a substantial amount of Indian mathematics and philosophy) had been made accessible in Arabic, and an independent Arabic science had begun to evolve. This went considerably beyond Greek science, mainly in the fields of mathematics, optics and astronomy. Great progress was made also in medicine, particularly through systematic attempts to reconcile the teachings of Galen with those of Aristotle.

As in the case of Christianity, some of the theologians of Islam saw in Greek thought a danger to their religion. Mohammed himself had great respect for both the Jewish and the Christian traditions, teaching the unity of God, an omnipotent Being who had created the world and had divine knowledge of individual things, as well as the resurrection of the body. In defending the Prophet's teachings against unbelievers one group of theologians (the Mutazilites) began to use reason and argument (*kalaam*) in their work as apologists. They were quickly opposed by a more orthodox group of theologians (the Mutakallim), who regarded the first group as too liberal and rationalistic. The opposition between the two groups gave rise to a type of scholastic theology within Islam, wherein reason was used by both groups but was variously joined to religious belief (as expressed in the Koran, the Islamic counterpart to the Bible) to arrive at the Prophet's true teaching.

Of the many teachings that developed in Islamic theology, our concern must be restricted to two that were to impact on Christian thought in the high Middle Ages. The first was a type of atomism proposed in the early tenth century by al-Ashari, a Mutazilite who had become a Mutakallim. In an attempt to exalt the power and the arbitrary will of God, he held that matter is composed of separate and distinct atoms that are continually being created and recreated by God in each instant of time. In his view fire does not cause burning, but God creates a being that is burned when fire touches a body. For him, therefore, there are no secondary causes in the universe, since the sole cause of all change is God.

The second teaching has to do with human knowledge and came about not so much from teachings about God's activity in the universe as from efforts to reconcile Aristotle's teachings on the human soul with theories of emanation proposed by a third-century Neoplatonic philosopher named Plotinus. Intermediate between God and man, according to Plotinus, there are various intelligences that have emanated from God, the last of which is the source of intellectual knowing in mankind. This teaching was first embraced by Alkindi, a ninth-century philosopher; then developed by Avicenna, a Persian who lived at the beginning of the eleventh century; and finally completed by Averroes, a Muslim who lived in the twelfth century in Cordova, Spain. Although understood differently by these three thinkers, the upshot of the teaching was that the human soul, as seen in its highest power, the intellect, is not truly immaterial and thus will not survive the death of the body. Stated otherwise, the human soul is not immortal --- a teaching that went directly contrary to the Prophet's teaching as well as that of the Christian Church.

Averroes' own view of the matter was that only reason or philosophy sees truth as it really is, whereas belief or religion provides the believer with at best a symbolic representation of the truth. The troublemakers of Islam are not the philosophers, he claimed, but the theologians who arouse the people against each other by teaching different interpretations of the Koran. Averroes therefore urged that philosophy (and science) be kept free from religion. He himself took an aggressive stance against the Islamic theologians, who for their part opposed him as a rationalist. Averroes's personal conviction was that all truth is already contained in the writings of Aristotle, who has been given to humans by divine providence so that they may know what is knowable. It is Aristotle's doctrine that is supreme truth, for his mind was the summit of human intelligence. This teaching was to have a profound influence in later centuries, as we are about to see.

The Early Middle Ages

Meanwhile, in the Latin West, there had been practically no development in scientific thought. Under the Roman Empire a good deal of the inheritance of Greek antiquity had indeed been preserved, but during the "Dark Ages" that came after Augustine this heritage was in serious danger of being lost altogether. The early Middle Ages assume importance in our study mainly because of the few scholars who worked strenuously to keep the torch of ancient culture burning under circumstances that were not at all conducive to intellectual work. Most of that work was in fact done under the auspices of the Catholic Church. The period is important for showing that religion and science can work together to promote learning, rather than being in opposition as they have come to be portrayed.

The first great Western scholar after Augustine is the sixth-century writer Boethius, who has aptly been called "the last of the Romans and the first of the Schoolmen." A Roman consul and a philosopher, Boethius set for himself the task of translating into Latin all of the works of Plato and Aristotle. Unfortunately he never completed the task because of an untimely death for political reasons; although charged with treason, he was venerated as a martyr in northern Italy. While awaiting execution he composed *The Consolation of Philosophy*, a philosophical classic of early Latin literature, wherein he describes the pursuit of wisdom and the love of God as the true source of human happiness. Owing to his efforts, parts of Aristotle's logical treatises were preserved, as well as Porphyry's introduction (or *Isagoge*) to the basic concepts of classical philosophy. More important for scientific work, Boethius himself composed works on arithmetic, geometry and music that were to be studied assiduously in monastery and cathedral schools. Not only did these treatises assure that knowledge of Greek mathematics would not be lost completely, but they became the means whereby the thought of Pythagoras and his followers, as well as the notion of a mixed science (since the study of music combines a knowledge of physical sounds with that of abstract numbers), were brought into the West.

A second Roman statesman and scholar, a contemporary of Boethius, is Cassiodorus Senator. Having himself had an excellent classical education, Cassiodorus founded a monastery at his villa named *Vivarium* in Calabria, Italy, where he provided for the instruction of his monks in secular as well as divine learning. His fundamental idea is that the study of Scripture, which is the monk's main pursuit, requires the study of profane knowledge by way of preparation. In the latter category Cassidorus included the four "disciplines" (*disciplinae*) of arithmetic, geometry, music and astronomy, along with the three "arts" (*artes*) of grammar, rhetoric and dialectic, thus preserving foundations on which the later science of the Middle Ages would be erected. His work prepared the way for the traditional division of liberal studies into the *trivium* (the arts just mentioned) and *quadrivium* (the mathematical disciplines also) that would later become a prerequisite for a university education.

Mention should also be made of two other scholars, Isidore of Seville and the Venerable Bede, who flourished in the seventh and eighth centuries respectively. Both were encyclopedists. They are important not so much for laying scientific foundations as did Boethius and Cassiodorus as they are for passing on many of the teachings about nature that were known in antiquity. Both composed works with the same title, *De natura rerum* (*On the Nature of Things*), in which they compiled excerpts from the Church Fathers and from Roman authors who wrote on scientific matters. Isidore, a Spanish bishop, thus made available much of Seneca's *Naturales quaestiones* (*Natural Questions*), whereas Bede, an Irish monk, continued Isidore's work and added to it teachings from Pliny's *Naturalis historia* (*Natural History*). Combined, their writings became an unparalleled source for speculation about the world of nature in the early Middle Ages.

Bede is especially important for the fact that he was part of a tradition that developed in Irish and English monasteries at an early date, wherein profane sciences were studied along with theological disciplines. In the sixth century a *trivium* and rudimentary *quadrivium* already existed at the Irish monasteries of Clonard, Bangor and Iona. Classical languages were pursued in England in the seventh century, and important centers of learning were founded at Canterbury, Wearmouth, Jarrow and York. At the episcopal school at York a complete *quadrivium* was already in place: the subjects of instruction included arithmetic, geometry, natural history and astronomy. Along with these, students were taught the *computus*, a method of determining the date of Easter and other dates of the ecclesiastical year dependent on Easter, which was indispensable for the construction of the medieval calendar.

From these centers in the British Isles came missionaries who would convert the barbarian hordes in Europe to Christianity, and together with them educators who would establish an advanced system of learning. Alcuin, who had studied and taught at York, was called to France by Charlemagne in 780 and there organized the cultural revival that is now referred to as the Carolingian Renaissance. He soon became head of the Schola Palatina, an institution attached to Charlemagne's court, that was half school, half university. Not a monk himself, Alcuin later retired to the abbey of St. Martin at Tours, having laid the first foundation in France for the intensive pursuit of learning to follow.

In Germany a similar task was performed by Alcuin's pupil Hrabanus Maurus, abbot of the monastery at Fulda and later archbishop of Mainz. Like Alcuin he saw the need for the clergy to study the seven liberal arts and become acquainted with the ideas of pagan philosophers, particularly those of Plato. In his *De universo* (*On the universe*) Hrabanus collected a vast body of knowledge concerning science and medicine, much of it compiled from the encyclopedias of Isidore and Bede. One item, not seen as important at the time, is worth mentioning for its later influence. This was the atomistic teaching of Democritus as treated by Epicurus and made widely known by the Roman poet Lucretius. Hrabanus was well acquainted with ancient atomism, for his *De universo* follows Lucretius closely in its explanations of various natural phenomena.

A truly exceptional figure in the history of science is the tenth-century mathematician and astronomer, Gerbert of Aurillac. Gerbert was the first Frenchman to be elected to the papacy, taking the name of Pope Sylvester II. Trained by the Benedictines of Aurillac, he also traveled in Spain and there became acquainted with the new knowledge coming to the West from Arabic and Greek sources. In particular he perfected the abacus as a tool of calculation and introduced instruments and models that made astronomical teachings intelligible to his contemporaries. Though not acquainted with Euclid or the more advanced work of Archimedes and Apollonius, and thus deficient in geometry, Gerbert nonetheless planted the seeds from which interest in mathematics would grow steadily during the next few centuries.

Before he became archbishop of Rheims, Gerbert had taught at the school there and had infused in it an enthusiasm for ancient culture, but also biased toward studies in mathematics and science. A similar orientation soon characterized the cathedral school at Chartres, which was led and raised to a high standard by Gerbert's pupil Fulbert. In particular, a strong quadrivial tradition was present there, for Gerbert's methods and instruments for the teaching of mathematics and astronomy continued in use and were further developed. This evolution culminated in the twelfth century, under the direction first of Bernard of Chartres, and afterwards of his brother, Thierry of Chartres. Through their efforts the school of Chartres became a center of intellectual life that influenced practically all medieval authors studied by historians of science.

A representative teaching of the school is the commentary on Genesis by Thierry of Chartres. In this work Thierry tries to harmonize the story of creation with the philosophy of Plato as presented by the Roman author Chalcidius. He identifies the four causes of the universe, following the lead of St. Augustine. For him the material cause is the four elements, which are created out of nothing, and the final cause is the Holy Spirit, which he identifies with Plato's World-Soul or *Anima mundi*; the efficient cause is then God the Father, and the formal cause, God the Son or Divine Wisdom. Elaborating on the material cause, Thierry follows the *Timaeus* in explaining how each part of the universe took its origin from elemental constituents. What is significant about his theorizing is the implicit assent to Platonism as the philosophy most closely related to Christianity, the one whose basic ideas are best deployed for the understanding of Holy Scripture.

Compared to Platonism in twelfth-century Christian thought, the philosophy of Aristotle exerted an influence that was hardly significant. Largely because Boethius had been able to translate only part of the *Organon*, Aristotle was looked upon mainly as a logician whose work bore little relation to the study of nature. By the middle of the twelfth century, however, the remainder of the Aristotelian corpus began to appear in Latin translation in the

West. Soon the gap that separated Europe from Greek and Arabic thought in the East would be narrowed, for new sources of knowledge were being made available that would propel Aristotelianism to a position of prominence it would hold throughout the thirteenth and subsequent centuries.

Universities At Paris And Oxford

The early scholasticism that developed in the cathedral school of Chartres, and also in the Parisian school of Saint-Victor, foreshadowed the full flowering of the "learning of the schools" that was to take place at Paris and Oxford. Around 1200 A.D., such schools were organized as the guild or "university of the masters and scholars of Paris," and that city quickly became the center of European learning. Hitherto unknown works of Aristotle, together with commentaries and treatises composed by Arab and Jewish thinkers, were now at hand in Latin translation. Scholars were suddenly confronted with new teachings that had to be understood and assimilated into their existing syntheses. A like situation developed at Oxford, where a university was legally constituted in 1214, at which time Robert Grosseteste, who was among the first to "baptize" Aristotle, as it were, assumed its leadership.

Grosseteste is a convenient figure with which to begin discussion of the high Middle Ages, for his Aristotelianism was more allied to Augustinian ways of thought than to that developed at Paris, and it also had fruitful implications for the growth of medieval science. Unlike many schoolmen, Grosseteste knew Greek and translated many works from that language into Latin. He also was able to comment on both the Posterior Analytics and the *Physics of Aristotle*, and so could pioneer in the introduction of Aristotelian learning to Oxford, even though his interpretations were strongly influenced by Neoplatonism.

St. Augustine's theme of illumination pervades Grosseteste's writings; and, indeed, the resulting philosophy has been aptly described as the "metaphysics of light." In Grossteste's view light (*lux*) is the first form to come to primordial matter, as signaled by God's saying "Let there be light" (*Fiat lux*) at the beginning of his creative activity. Since light propagates in straight lines and radiates in spherical patterns, it multiplies its own likeness or species in all directions. In this way it actually constitutes the dimensions of bodies and so constructs the entire universe according to pre-determined laws of proportionality. Even the human soul is a special manifestation of light, although to possess knowledge it must also be illumined by God, the source of all light.

Moreover, since the multiplication of species follows geometrical patterns, Grosseteste taught that the world of nature has a mathematical substructure. This being the case, for him the key to natural science is to be found in mathematics. The science of geometrical optics provides an apt illustration of the required methodology, which Grosseteste found to be already explained in the *Posterior Analytics*. Observation and experience (*experimentum*) provide the facts, what Aristotle had referred to as *demonstration quia*, whereas mathematics is necessary to see the reason for the facts, what Aristotle had referred to as demonstration *propter quid*.

Not himself a Franciscan, and later to become bishop of Lincoln, Grosseteste taught members of that order when they came to Oxford early in the thirteenth century. His most enthusiastic disciples were the Franciscans Roger Bacon and John Pecham, the second of whom later became archbishop of Canterbury. All three experimented with light rays and wrote treatises on light and colors, providing rudimentary explanations of such phenomena as the rainbow. Historians of science see in their work at Oxford the beginnings of experimental science, along with an incipient mathematical physics that would flourish there in the next century, particularly at Merton College.

The two mendicant orders, Franciscans and Dominicans, had just then come into being, and they were welcomed at the University of Paris by William of Auvergne, a secular master (as was Grosseteste) who had been made bishop of that "city of books and learning." The Paris Franciscans, whose luminaries included Alexander of Hales and St. Bonaventure, had some knowledge of Aristotle, but they preferred to work within the older Augustinian tradition and were not particularly receptive to the new scientific learning. The same cannot be said of the Dominican masters who assumed chairs at the university, especially St. Albert the Great and St. Thomas Aquinas. These men, as it turned out, were the architects of a new Aristotelianism at Paris that put secular learning on an almost equal footing with revealed truth and laid firm foundations for the growth of medieval science.

Albert the Great was apparently the first to realize how Greek-Arabic science could best serve Christian faith by granting it proper autonomy in its own sphere. He was quite willing to accord Augustine primacy in matters of faith and morals, but in medicine, he said, he would much rather follow Galen or Hippocrates, and in physics Aristotle or some other expert on nature. Remarkable for his range of interests and for his prodigious scholarly activity, Albert was called "Great" in his own lifetime and was commonly given the title of Universal Doctor. Much of his fame derived from his encyclopedic literary activity. He made available in Latin, for example, a paraphrase of the entire Aristotelian corpus ranging from metaphysics through all of the specialized sciences. He used Arab commentators to fill out details not in Aristotle's text, and even added whole books to these accounts --- in the study of animals and minerals, for example --- on the basis of his personal observations.

Among Albert's students was the young Italian Dominican, Thomas Aquinas, destined to become the most famous theologian in the high Middle Ages. From Albert, Aquinas derived his inspiration to Christianize Aristotle, and he became so proficient in Aristotelian methodology that his ultimate synthesis of faith and science can almost be seen as an Aristotelianization of Christianity. His basic insight was a thorough grasp of the concepts of potentiality and actuality, which he used to refine the distinction between essence and existence. He then applied this doctrine in a novel way to a whole range of problems, from those relating to God and creation to that of the human soul and its activities. While best known today as a theologian, Aquinas was regarded in his time also as a competent logician and natural philosopher. Indeed, his commentaries on Aristotle's physical works rank among the best produced in the medieval period.

While treating St. Augustine respectfully, Aquinas preferred to speak of the potency of matter rather than of "seminal reasons." He saw the human soul as a unique entelechy, or single formal principle, in man, denying the teaching of a plurality of forms then popular among Franciscan and Augustinian theologians. And he substituted a theory of abstraction, effected through a power of each man's soul --- his active intellect (*intellectus agens*) --- for Augustine's theory of divine illumination.

From the viewpoint of the history of science, however, Aquinas's greatest contribution was to the study of scientific methodology. Following Albert's lead, he saw physics as a discipline prior to metaphysics, and indeed necessary for the latter's foundations. He was careful to differentiate physics from mathematics, while conceding strict scientific status to intermediate sciences such as mathematical physics, which he called *scientiae mediae* (middle sciences). In fact, he used mathematical astronomy and geometrical optics as models for the type of reasoning one finds in the science of revealed theology.

The greatest scientific achievements of the Middle Ages, apart from Albert the Great's work in taxonomy, came in these middle sciences. The astronomical teachings of Ptolemy's *Almagest*, with additions and improvements from Arab scientists, were made available for students in the Sphere of John of Sacrobosco. Jordan Nemorarius pioneered in a new Archimedean science, the science of weights (*scientia de ponderibus*), that provided principles of mechanics not surpassed until the Renaissance in the writings of Tartaglia and Galileo. With regard to experimentation, Peter Peregrinus of Maricourt studied the magnet around 1268 and provided inspiration for William Gilbert's treatise on it, to appear only in 1600. And Theodoric (Dietrich) of Freiberg, a German Dominican who followed Albert the Great, experimented with raindrops and provided the first essentially correct explanation of the rainbow --- long before the work of Descartes and Newton, who are usually credited with that discovery.

For thinkers like Albert and Aquinas, Aristotle's principles when properly interpreted not only made nature's operations intelligible; they could even lead one to a knowledge of the Author of Nature by purely rational means. In a word, they made available reasonable proofs for the existence of a First Mover that was incorporeal, immaterial, of infinite power and eternal in duration, who could be identified with the God of revelation. Small wonder, then, that for them Aristotelian science held the greatest of promise. It allowed one to reassert the autonomy of reasoning based on sense experience; it explained the magnificent hierarchy of beings from the pure potency of matter through all the higher grades of actuality; and it even provided access to Pure Actuality, God himself, who had revealed all the details of his inner being to all who accepted on faith his divine revelation.

This brief sketch of thirteenth-century thought may help to explain the enthusiasm with which Aristotle's writings came to be accepted at Oxford, Paris and similar centers in Christendom. The newly recovered Greek learning now appeared to be buttressed by Catholic faith, and an all-knowing God seemed to be beckoning scholars to uncover the rationality and intelligibility hitherto concealed in his material creation. Such diverse thinkers as Pierre Duhem, Alfred North Whitehead and Stanley Jaki have seen in this setting the basic charter that underlies the modern scientific enterprise.

The Condemnations of 1270 and 1277

Mention has been made of Islamic influences on the development of natural philosophy, and these now need to be examined in fuller detail. The problem of the relationship between reason and faith came to a head earlier in Islam than it did in Latin Christendom, with results that very often asserted the primacy of reason over faith, rather than the other way around. The main inspiration behind the Arab position was Averroes, whose thought has been characterized as a twelfth-century rationalism, much like the later rationalist movement in modern Europe. As already noted, Averroes regarded Aristotle as a god, the summit of rational understanding, an infallible guide to all attainable knowledge. Christian theologians like Aquinas, on the other hand, accepted the primacy of faith over reason and so felt compelled to question Aristotle's authority and even to modify his teachings as occasion demanded.

Among Averroes's distinctive theses was the teaching that there is only one intellect for all men. Avicenna had taught that there is a single active intellect or intellectus agens for everyone, but that each individual possesses his own receptive intellect in which ideas are conceived. Averroes disagreed with this, holding that both the receptive and the active intellects in humans are a separate substance, a subsistent intelligence, one and the same for all mankind. On this basis Averroes denied the hitherto generally accepted basis for personal immortality. Another of Averroes's theses was the eternity of the universe, for he followed Aristotle literally in maintaining that the universe has neither a temporal beginning nor an end. Thus it was not created and it will never cease to exist --- both teachings opposed to Christian doctrine. He disagreed too with an analysis of essence and existence that had been elaborated by Avicenna and was similar to Aquinas'. This affected his understanding of the relationships between God and the universe, effectively putting necessity in God's actions in ways contrary to Church teaching.

Averroes's commentaries on Aristotle were known to William of Auvergne, Albert the Great and others, who advanced the cause of Aristotelianism at the University of Paris. The fact that Averroes's teachings could be inimical to Catholic belief was not at first recognized, but as Averroes's influence increased along with the reception of Aristotle, his distinctive interpretations gradually got a hearing. Not only this, but they soon attracted adherents among professors at the university. Thus, a movement got underway that has been characterized as Latin Averroism or heterodox Aristotelianism, whose chief proponents were Siger of Brabant and Boethius of Sweden. The Latin Averroists taught the oneness of the receptive intellect for all humans, the eternity of the universe and of all its species (with the result that there would be no first man), and the necessity of God's causality in the world --- all theses at odds with orthodox Christian faith.

Theologians at the university reacted, predictably, to such teachings, and Bonaventure, Albert the Great, Aquinas and others wrote polemical treatises against Siger and his followers. Alarmed at the growth of naturalistic rationalism, ecclesiastical authorities also tried to halt heterodox Aristotelianism with a series of condemnations. In 1270 the bishop of Paris, Etienne Tempier, condemned thirteen propositions that contained Averroist teachings, including the oneness of the intellect, the eternity of the world, the mortality of the human soul, the denial of God's freedom and providence, and the necessitating influence of heavenly bodies on earthly activities. Tempier followed this on March 7, 1277, with the condemnation of 219 propositions that were linked to Averroism, including some theses upheld by Aquinas (who had died three years to the day earlier, on March 7, 1274). In the prologue to the condemnation, Tempier accused the Averroists of saying that what was true according to philosophy was not true according to the Catholic faith, "as if there could be two contrary truths." Thus he initiated what has been called a theory of double truth, although it is doubtful that this was ever taught by Averroes or Siger and his followers.

It seems undeniable that the condemnations of 1270 and 1277 had an effect on the development of medieval science, though not as profound as was maintained by Pierre Duhem, who actually proposed 1277 as the birthdate of modern science. His argument was that among the condemned propositions were two that bore on subject matters later of interest to scientists. One of these denied that God has the power to move the universe in rectilinear motion for the reason that a vacuum would result. The other denied God's power to create more than one universe. By thus opening up the possibility that theses rejected by Aristotle could be true, and by asserting God's omnipotence as a factor that henceforth would have to be taken into account, Tempier gave stimulus to the scientific imagination. In effect he opened the way to a consideration of other alternatives to an Aristotelian cosmology.

It is generally agreed that Duhem's thesis is extreme, for there is no indication of a spurt in scientific activity following 1277, and it is doubtful whether any authoritative restriction such as the condemnations could have stimulated the free spirit of inquiry that is characteristic of scientific thought. There is no doubt, however, that the condemnations did have profound consequences on the development of science and philosophy in the decades that followed, particularly on the relationships that would henceforth obtain between them and theological thought.

The Later Middle Ages

To come now to what may be called late medieval science, we begin again with the Franciscans, who took the ascendancy in the late thirteenth and early fourteenth centuries through the writings of two of their friars, John Duns Scotus and William of Ockham. Both the Scotist and the Ockhamist movements were part of a critical and skeptical reaction in philosophy, motivated primarily by theological interests, following on the condemnation of 1277. The high scholasticism of the thirteenth century had seen Aristotle welcomed once again as "the master of all who know." Now theologians had pointed out what disastrous consequences attended the uncritical acceptance of Aristotle's teachings in matters that touched their discipline. There was no doubt, then, that Aristotle had erred in matters theological. Might it not be the case that he likewise erred in matters philosophical? Both Scotus and Ockham implicitly answered this question in the affirmative, and in so doing set the schoolmen on a different course from that they had been following under the inspiration of Grosseteste, Albert the Great and Aquinas.

Duns Scotus is known as the Subtle Doctor, and his writings abound in the fine distinctions and meticulous arguments now usually associated with scholasticism. He understood Arabic thought very well, consistently favoring Avicenna over Averroes. Though he denied the theory of divine illumination, he was much indebted to Augustine, Bonaventure and the Oxford tradition within Franciscan thought. Unlike Aquinas, his main interest was not to assimilate science into theology but rather to preserve theology from encroachment on the part of an unrestricted rationalism.

Scotus attempted to do this by developing his own theory of knowledge, which focused on being as a univocal concept. He also stressed the primacy of the will, to assure God's absolute freedom and the preeminence of freedom in man. He further viewed God under the aspect of infinity as his essential characteristic. Thus he denied the use of the Aristotelian principle, "Whatever is moved is moved by another," which Aquinas had used to prove God's existence as the First Unmoved Mover. Instead he used a different type of theistic proof based on the notion of possibility, showing how this entails the existence of a Necessary Uncaused Being.

Even from this brief sketch it can be seen that Scotus was more the metaphysician than the natural philosopher. Although he and his followers did not neglect the study of nature entirely, their importance for medieval science derives less from their contributions to that discipline than from the skeptical reaction they provoked from William of Ockham. Ockham had been exposed to Scotistic teaching during his years of training as a Franciscan, and he developed his thought in conscious opposition to that of the Subtle Doctor. Like Scotus, however, Ockham's intent was theological from the outset, its motivation being similarly traceable to the condemnation of 1277.

Again, like Scotus, Ockham stressed the traditional Franciscan themes of divine omnipotence and divine freedom, being especially concerned to eliminate any element of necessity from God's action as this had been found in Neoplatonic emanationism and in Arab thought generally.

In working out his own distinctive position, Ockham consistently invoked two main theses. The first was that God has the power to do anything whose accomplishment does not involve a contradiction. The net effect of this teaching was to admit that, in the order of nature, whatever is not self-contradictory is possible. Thus, there is no *a priori* necessity in nature's operation, and whatever is the case must be found from experience alone. His second thesis, commonly referred to as "Ockham's razor," is expressed in the maxim "Beings are not to be multiplied without necessity." The application of this principle led Ockham to formulate a nominalist logic that denied reality to most of Aristotle's categories and eliminated a great number of the distinctions found in scholastic metaphysics.

Fourteenth-century Nominalism, as fathered by Ockham and quickly taken up by others, thus incorporated a view of the universe that was radically contingent in its being, where the effect of any secondary cause could be dispensed with and immediately replaced by God's direct causality. The theory of knowledge on which it was based was empiricist, and the problems it addressed were mainly those of the philosophy of language. Referred to as the *via moderna*, as opposed to the *via antiqua* of the earlier schoolmen, it is seen by many as a forerunner of present-day analytical philosophy.

The immediate effect of nominalist philosophy on medieval science is best seen at the University of Oxford, where the mathematical tradition inaugurated by Grosseteste was still alive in Merton College. The principal innovators there were Thomas Bradwardine, later archbishop of Canterbury, and a number of his colleagues and students, especially William of Heytesbury and Richard Swineshead. Bradwardine set for himself the task of examining various mathematical formulations of ratios of motions that are expressed verbally in Aristotle's Physics, and in so doing came up with an ingenious (though incorrect) law of falling bodies. In the process he introduced the concept of instantaneous velocity and adumbrated some computational methods later used in infinitesimal calculus.

Heytesbury and Swineshead continued Bradwardine's line of investigation, employing a letter calculus to resolve logical difficulties (called *sophismata* or sophisms) that arose in their discussions. The "calculations" that ensued, while evoking a critical reaction from humanists in later centuries, suggested new techniques for dealing with problems of infinity. They also led to a sophisticated terminology for describing rates of change that would have important applications in mechanics. For this reason the Mertonians are commonly regarded as the forerunners of Galileo, Leibniz and Newton in laying foundations for the middle science of kinematics.

Possibly because of their nominalist sympathies, the Mertonians did not have the realist concerns that were to become influential at Paris in the mid-fourteenth century. They were highly imaginative in their treatment of kinematical problems, but did so in an abstract mathematical way, generally without reference to motions actually found in nature. By contrast, a group of thinkers at the University of Paris devoted themselves rather consistently to investigating the physical causes of motion. They introduced the concept of impetus, known to John Philoponus in the sixth century but lost in the intervening centuries, and they quantified, in ways suggested by the Mertonians, the forces and resistances involved in the natural movements of bodies. Foremost among these were the Scotist, Franciscus de Marchia, and Jean Buridan, Albert of Saxony and Nicole Oresme. The last three were nominalist in their logic, but in natural philosophy they rejected Ockham's analysis of motion and substituted realist views of their own.

Buridan, who became rector of the University of Paris, is regarded as the leader of the Paris group, playing a role there similar to that of Bradwardine at Oxford. He is best known for his development of the concept of impetus as the cause of projectile motion and of the acceleration of falling bodies. Buridan's pupils, Albert of Saxony and Nicole Oresme, showed greater competence than he in mathematics and applied Mertonian techniques to the analysis of both terrestrial and celestial motions. Oresme, later bishop of Lisieux, pioneered in developing geometrical methods of summing series and integrating linear functions, and so adumbrated the concepts of analytical geometry. He also translated into French Aristotle's *On the Heavens* and other Latin works, and is credited with coining many scientific and technical neologisms still in use in the French language.

The writings of these authors were widely diffused throughout western Europe and were much discussed in commentaries and questionaries on the Physics. Aware of this, the pioneer historian of medieval science Pierre Duhem spoke of them as the "Parisian precursors of Galileo." Whether he was correct in this judgment or not, by the end of the fourteenth century there was at hand a considerable body of basically Aristotelian new knowledge enriched by mathematical and dynamical concepts showing marked affinity with those of modern science. All of this was attributable in large part to the work of Churchmen who had faith in God and his revelation, and yet were intent on comprehending as best they could the world of nature with the light of unaided reason.

The Renaissance and Copernicus

The fifteenth century is important in the history of science mainly because of events that would transform the culture of Europe and signal the beginning of the early modern period. A most important factor was the fall of Constantinople to the Turks in 1453, for this precipitated the flight of Greek-speaking scholars to the West. With them came many classical manuscripts in Greek along with the ability to translate these into Latin, still the common language of learning at the time. Almost coincident with the fall of Constantinople was the invention of movable type in the 1440's and the printing of the Gutenberg 42-line Bible in 1454. In 1492 Columbus reached America and the Moors were finally driven from Spain. Vasco da Gama made the voyage to India by sailing around the Cape of Good Hope in 1498, and in 1517 Martin Luther nailed his 95 theses to the church door at Wittenberg, thereby starting the Protestant Reformation.

Prior to this time Greek scientific learning had come to Europe selectively, partly from works that had been translated from Greek to Syriac to Arabic and thus transmitted by way of Islam, partly from a smaller collection translated into Latin directly from the Greek. Now the classics of Greek antiquity were made available in their entirety, and humanists started to explore in detail the art and literature they contained. The writings of Greek philosophers, scientists, and mathematicians came along with these. The complete works of Plato and Aristotle, with their accompanying commentaries, were rediscovered for the first time in the West. The *Mechanical Questions* of Aristotle, as already remarked, was among these. So were the complete works of Archimedes and others who had pioneered in the science of mechanics. Stimulated by them, Leonardo da Vinci, Niccolò Tartaglia and Gianbattista Benedetti made beginnings that would soon transform that science.

Advances were also made in astronomy, first by way of introducing new speculative ideas and then by improving Ptolemy's system of calculation and eliminating errors that had crept in over the centuries. Nicholas of Cusa, a cardinal of the Roman Church, proposed a bold revision in the classical idea of a closed and hierarchical universe, suggesting that the center of the universe is everywhere and its circumference nowhere. He rejected the Aristotelian distinction between the celestial and terrestrial regions, and regarded the earth as one of the heavenly bodies, not the center around which the Ptolemaic spheres revolve. Cusa's views notwithstanding, astronomers continued to follow Ptolemy for their calculations and made notable progress. By the late fifteenth century *The Almagest* and *The Sphere* of Sacrobosco had been replaced by works of Georg Peurbach and Regiomontanus (Johannes Müller), and these provided astronomers with more efficient and accurate mathematical means of computing the positions of the heavenly bodies than had hitherto been available.

The greatest achievement of the period, however, came in the mid-16th century with the publication in 1543 by the Polish astronomer, Nicholas Copernicus, of his *On the Revolutions of the Heavenly Spheres*. A canon at the cathedral of Frauenburg, Copernicus first studied at the University of Cracow and then went to Italy for further studies at Bologna, Padua and Ferrara. While in Italy be became acquainted with the heliocentric proposals of the Pythagoreans, and these provided the stimulus for a more radical revision of the Ptolemaic system. Instead of having the earth immobile at the center of the universe, Copernicus proposed that the sun occupy that position and that the earth, along with the other planets and the stars, be made to revolve around the sun.

Copernicus understood *The Almagest* very well, and appropriated the basic data in Ptolemy's tables of planetary positions while adding data based on his own observations. By replacing the geocentric system with the heliocentric, he was able to simplify some of Ptolemy's calculations, though he still had to retain many of the eccentrics and epicycles used by the Greek astronomer.

Until the Copernicus had prepared a draft of his system on his return from Italy around 1512, and later entrusted a brief account of it to a student of his, Georg Joachim Rheticus, in 1539. Rheticus, with Copernicus's approval, had it printed a year later with the title Narratio prima (*First Account*). This attracted favorable attention, so with the encouragement of Cardinal Nicholas Schönberg of Capua and of his friend Tiedeman Giese, bishop of Culm, Copernicus completed the work, which he dedicated to Pope Paul III. His health not good, he then entrusted the text of *De revolutionibus* to Giese, who in turn sent it to Rheticus, who had it published at Nuremberg in 1543. As Giese recounted the story, the first printed copy was handed to Copernicus on his deathbed, on May 24, 1543.

The first book of *De revolutionibus* gives clear indication that Copernicus saw his new system as giving a physical account of the universe and not merely providing a mathematical system for computing the positions of the heavenly bodies. Unfortunately his book was seen through the press by a Lutheran theologian, Andreas Osiander, who was alarmed that the system being proposed might appear to contradict the teachings of Scripture. Without Copernicus's knowledge Osiander added at the very beginning of the work a note "To the Reader: Concerning the Hypotheses of this Work," stating that it was only concerned with mathematical hypotheses and disclaiming, for example, that any motion was being ascribed to the earth. The note was unsigned, but its position in the text created the clear impression that it had been inserted there by Copernicus himself.

Largely because of Osiander's interpolation, Copernicus's monumental work was read by relatively few scholars apart from astronomers, and generally did not provoke an adverse reaction on the part of philosophers and theologians. A Dominican theologian who was Master of the Sacred Palace at the time, Giovanmaria dei Tolosani, noted that, when taken literally, Copernicus's teaching was opposed to the account of the heavens given in Holy Scripture, but he died before he could make recommendations for revision. Thus the matter lay dormant beginning of the next century, when another great scientific breakthrough advanced the Copernican cause.

Galileo and the Telescope

Galileo Galilei was born at Pisa in 1564 and received his formal education at the University of Pisa after having done classical studies at the Monastery of Vallombrosa near Florence. His father destined him for a career in medicine, but Galileo aspired instead to become a mathematician and left the university without a degree in 1585. He pursued studies in mathematics privately, and achieved such distinction in this field that he was hired back at the university in 1589 to replace Father Filippo Fantoni, a Camoldolese monk who had been teaching Euclid and Ptolemy, as the mathematics professor there. Around this time he received teaching notes from Jesuits at the Collegio Romano that acquainted him with the methodology of the *Posterior Analytics* and how this could be applied to secure demonstrations in mathematics and the physical sciences, knowledge that he would use to good effect in the years to come.

In 1592 Galileo succeeded in obtaining a better-paying position teaching mathematics at the University of Padua, where he taught and experimented with motion and mechanics for some eighteen years --- a period he later avowed was the happiest in his life. Toward the end of that time he heard of a telescope that had recently been invented in Holland. Acting on hearsay he made one for himself, improved its magnifying power to twenty times, and sought to sell it and others to the Republic of Venice, in which Padua is located, for use as a navigational and military instrument.

While negotiating over that proposal, Galileo happened to turn his telescope towards the heavens, and with it made some remarkable discoveries early in 1610. He reported these in a small book entitled The Starry Messenger, which gained him instant fame throughout Europe. What he found was, first, mountains on the moon and four satellites of Jupiter, and then, later, the fact that Venus has phases. The significance of these discoveries, all of which Galileo proposed as strict proofs, is that they gave the first concrete evidence that the Copernican system was more than a mathematical hypothesis. Since Venus exhibits phases, it must be rotating around the sun, not the earth. Mountains on the moon suggest that it has earthlike features, and thus that it (and the earth along with it) might actually be heavenly bodies. And finally, since Jupiter revolves around the center of the cosmos and carries four moons along with it, it is not impossible for the earth to do the same, carrying its one moon along in similar fashion.

Up to this point Galileo had been teaching the Ptolemaic system in his courses on astronomy, but reinforced with his telescopic evidence he became an ardent proponent of the Copernican system. In doing so he had to maintain that the sun is really at rest, even though it appears to move across the heavens, and that the earth is in motion, even though sense evidence indicates the contrary. More serious, he had to question the literal meaning of the Scriptures, which taught not only that the sun traverses the heavens and stopped at Joshua's command, but also that the earth is immovable at the center of the cosmos, as Moses had taught in the creation account in Genesis.

Nonetheless Galileo continued to propagate Copernican views, with the result that protests were made to the Holy Office (the Roman Congregation entrusted with defending the Catholic faith). Late in 1615 he himself felt it necessary to go to Rome to explain his activities. Meanwhile a Carmelite friar, Paulo Antonio Foscarini, had written a small book in which he maintained that the Bible could be interpreted in ways that allowed the Copernican system to be taught. Replying to Foscarini and, along with him, to Galileo, Cardinal Robert Bellarmine wrote a letter to both saying that if they could demonstrate that the earth actually moves there would be no objection to their holding Copernicus's heliocentrism. In that event Scripture would have to be interpreted differently from the way it had been throughout the Church's history. If they lacked such a demonstration, however, they might continue to teach the Copernican system as a mathematical hypothesis, as this had been suggested in the preface of Copernicus's book, but they were not to teach that the earth actually moves.

In an interview with Bellarmine in Rome on February 26, 1616, Galileo apparently acquiesced to the instruction in Bellarmine's letter to himself and Foscarini. Galileo surely understood what Bellarmine meant by demonstration, since Bellarmine was a Jesuit and had had access to the same teaching on the *Posterior Analytics* as did Galileo. The latter also probably recognized that the demonstrations in the *Sidereal Messenger*, while remarkable in their own right, failed to offer convincing proof of the earth's motion.

Present at the meeting between Galileo and Bellarmine were two Dominicans from the Holy Office who carried with them an injunction prepared for Galileo in the event that he proved recalcitrant. Since he did not, there was no need to serve the injunction on him, so they carried it back with them and inserted it, unsigned, in the files of the Holy Office. The document is very important, because in it Galileo is explicitly ordered to abandon the Copernican opinion and not "to hold, teach, or defend it in any way whatever." Within a week or so the Congregation of the Index placed the *De revolutionibus* on the index of prohibited books "until corrected"; it also condemned Foscarini's book outright, but made no mention of Galileo in so doing.

Some years later a Florentine cardinal who had befriended Galileo, Maffeo Barbarini, was elected to the papacy as Pope Urban VIII. By this time Galileo was thinking of a non-telescopic proof of the earth's motion, namely, that the ebb and flow of the tides was caused by the earth's moving under them rather than by the moon's attraction. In an audience with Urban VIII Galileo mentioned this to the pope, along with his interest in resuming work on the Copernican system. The pope warned him against the tidal argument, but apparently gave him permission to do a comparative study of the two chief world systems, the Ptolemaic and the Copernican. Galileo returned to Florence, and by 1630 had completed a draft of a new work on this subject, which he entitled simply the *Dialogue*, submitting it for approval to the censor, a Dominican named Niccolò Riccardi, Master of the Sacred Palace.

Riccardi was uneasy with the manuscript, for it made use of the argument from the tides, of which the pope did not approve, and it clearly presented the Copernican system as superior to the Ptolemaic. He nonetheless made suggestions for changes at the beginning and the end, and, when Galileo had made them, approved it for publication. The *Dialogue* was printed at Florence early in 1632. It was received with enthusiasm in some quarters, but in Rome it provoked a most unfavorable reaction. By summertime the pope was so distressed he ordered the printer to hold up its distribution and appointed a special commission to bring Galileo to trial for publishing it as he did.

Thus came about the famous Trial of Galileo in 1633. By that date all the officials who had taken part in the investigations of 1615-1616 had died. The prosecutor of the case therefore had recourse to the file on Galileo at the Holy Office and came upon the injunction purportedly served the Florentine astronomer in 1616. On its basis he had a number of theologians, none of whom was an astronomer, read the *Dialogue* and judge whether in it Galileo had actually held, taught or defended Copernican doctrine. Their report was that Galileo had without doubt taught and defended the heliocentric system. As to whether he personally held it, they were not so sure. When questioned on this point Galileo replied categorically in the negative. Having said this, being still suspect of heresy, he was made to formally swear that he did not subscribe to the Copernican teaching.

The *Dialogue* was thereupon prohibited, and Galileo himself was placed under house arrest, first at Florence, and then at his villa in Arcetri near that city. Cared for from a nearby convent by his daughter Sister Maria Celeste, Galileo gradually recovered his strength. He then began work on his masterpiece, *The Two New Sciences*, which was published in 1638 and for which he is commonly regarded as the “Father of Modern Science.” He died peacefully in his villa at Arcetri on January 8, 1642.

The Catholic Church has been much criticized over the centuries for its handling of the Galileo case. Replying to such criticisms, in 1979 Pope John Paul II admitted that Galileo had suffered unjustly at the hands of the Church and praised him for the faith he manifested under such difficult circumstances. Then, in 1981, he appointed a special commission to reopen the trial, as it were, and to fix responsibility for it wherever it might lie.

Some have regarded Galileo’s abjuration as a character defect, saying that he perjured himself when he denied the earth’s motion at the end of the trial. But this is to misunderstand the proper relationship that Galileo knew to obtain between faith and reason. Had Galileo been able to demonstrate the earth’s motion as being true and certain, then he would have lied (under oath) in withdrawing assent to the Copernican system. But if he still had doubts about the argument from the tides, as well he might, that left room for his following the Church’s teaching (wrong though we now know it was) until such time as proper proof became available. Although other evidences began to appear in the seventeenth and eighteenth centuries, most scientists would now agree that the earth’s motion was not made clearly manifest until Bessel’s measurement of stellar parallax in 1838 and Foucault’s experiments with the pendulum in 1851 --- both still a long time off in 1633!

Kepler and Newton

Undoubtedly, Galileo was a believing scientist, and the same is true of his contemporary, Johann Kepler, who discovered the laws of planetary motion that would serve to correct defects in the Copernican system. Unlike Galileo, Kepler was a Lutheran who lived much of his life in an area that was partly Catholic and partly Protestant, and who felt the tension that religious belief places on a person involved in scientific investigation. He wished to study theology, but was thwarted in this effort when he was sent from Tübingen to teach mathematics in a

Lutheran school in Graz, Austria. There he composed his *Mysterium cosmographicum* (*The Cosmic Mystery*), in which he used Plato's five regular solids to explain how at creation God spaced the planets in the solar system. So successful were his calculations that they attracted the favorable attention of mathematicians and astronomers. Thus he could write: "I wanted to be a theologian. For a long time I was restless. But now observe how, through my efforts, God is being celebrated in astronomy."

Later, in 1609 and 1619, using precise data on the motion of Mars given him by the Danish astronomer Tycho Brahe, Kepler discovered that Mars's orbit is elliptical and went on to formulate the three laws of planetary motion that now bear his name. He attached a mystical significance to all this, being much imbued with the spirit of the ancient Pythagoreans and Neoplatonists. The insight of the scientist, in his view, would discern the mathematical order and harmony built into the universe by God, who had created our minds to understand this.

The great English scientist, Sir Isaac Newton, likewise saw his *Principia* as providing a new type of proof for the existence of God. When approached by the Anglican theologian Richard Bentley to explain the new proof, Newton was glad to oblige with a series of letters. His mechanics, he wrote to Bentley, could explain many features of the solar system, but it could not explain the stability of planetary orbits or their orientations in space. So it must be that God himself arranged the planets in space and impelled them with forces exactly calculated to put them in elliptical orbits around the sun. Not only that, but God must continually intervene, as an active principle, to maintain the planets in those orbits and thus assure the smooth running of the universe.

Such Newtonian concordism did much to promote harmony between science and faith in England through most of the eighteenth century. Yet it contained a fatal flaw in that it focused on what is known as the "God of the gaps." Newton had produced a mechanical explanation of the universe that surpassed anything previously proposed, but it turned out that there were gaps in his explanation. What he had done in his letters to Bentley was use God to fill those gaps, invoking his religious belief to complement his scientific discourse. Unfortunately he could not see ahead a century later to the work of Pierre Simon de Laplace, whose celestial mechanics filled Newton's gaps with factors he had been unable to analyze. When those gaps disappeared, a clear invitation was at hand to make the "God of the gaps" disappear along with them, and so reject religion in the name of the very science it was being used to save.

The result of all this was that many Reformation scientists in England and on the Continent, rejecting the authoritative teachings of the Roman Church, lacked any curb on the rationalistic tendencies inherent in scientific thinking. Gradually they adjusted their religious doctrines to fit their science. Newton and Laplace had bequeathed them a clockwork universe that left no room for miracles and little room for God once its initial motion had begun. As Christians they had started with belief in the Trinity but ended up with God the Creator alone, having no room in their science for the other two Persons. Thus, for many, Christianity degenerated into what is called deism --- a system allowing that God created the universe, but that he can be known by human reason alone. This led to the eighteenth-century mentality of the Enlightenment, which rejected the very possibility of supernatural revelation and divine faith as these had been understood since the days of the Apostles.

Lyell And Darwin

The next confrontation between science and faith took place not in physics but in the sciences of geology and biology. Toward the end of the eighteenth century increasing attention came to be paid to geological studies. Fossils were uncovered in increasing numbers, and the stratification of the earth's crust was revealed in ever newer detail. Apparently strange things had happened in times past, evidences of floods and other catastrophic events that might be seen as God's hand manifesting itself in the history of our planet. Phenomenal geology soon branched out into Scriptural geology, and it is noteworthy that William Buckland, professor of geology at Oxford, devoted his inaugural lecture there in 1819 to showing that the study of geology confirms "the accounts of the creation and deluge recorded in the Mosaic writings." As Buckland saw it, science could uncover the effects of

God's actions but only divine revelation was able to tell about their causes. Science might best study the present, but religion was necessary to reveal the past and its ultimate causes.

However, just as Laplace had shown that the astronomical effects Newton explained by his God could just as well, or better, be explained by mechanical forces, so another thinker on the geological scene now sounded a deeper note of conflict. Charles Lyell, the "Father of Modern Geology," set for himself the task of showing that every geological change in the earth's history could be explained by causes similar to those still known to be acting in its interior. The success of his program, referred to as uniformitarianism, proved as rapid as it was unexpected. The end result was that God's intervention was soon recognized as superfluous in geology as it had become in celestial mechanics.

Like most English scientists of his day, Lyell proclaimed himself a believer and so did not reject God entirely as a principle of explanation. He still allowed, for example, that God's creative act was the only way of explaining how humans came into existence on the earth's surface. But a young naturalist named Charles Darwin took Lyell's *Principles of Geology*, which had appeared in 1830, with him when he set out on the voyage of the *Beagle*. It is now recognized that Darwin's monumental achievement was to apply Lyell's principles of uniformitarianism to the changing history of life itself. He would explain by natural causes operative in present experience the many transformations life had undergone in its long history. In Darwin's hands scientific laws would become the exhaustive explanation of organic development, so much so that no room was eventually left for religious belief to supply useful information about man and his origins.

With regard to all this, what Darwin held in his innermost thoughts is quite revealing. He became more and more agnostic, and by the end he was a complete atheist. But his wife's solicitude and his son's editing gave him needed protection, and he did not have to proclaim this in public. That fortume fell to his advocate and propagandist, Thomas Huxley. Darwin's *The Origin of Species* was published in 1859, and in 1860 the British Association for the Advancement of Science met at Oxford. A debate was scheduled at the meeting between Huxley and the Anglican bishop Samuel Wilberforce to debate the subject of human evolution. The debate ended disastrously for the cause of religion, for by common consensus Huxley won the argument hands down. Wilberforce was vanquished before an audience of scientists just as completely as Galileo had been in 1633 at the tribunal of theologians.

The Twentieth Century

The nineteenth century had been a period of rapid growth in chemistry, geology and biology. At its end attention was once more directed to physics, with the great discoveries of Max Planck of quantum theory around 1900 and of Albert Einstein's special theory of relativity in 1905 and his general theory of relativity in 1915. Neither of these thinkers would be regarded as atheists, and actually both have stimulated extensive discussion of the proper relationship that should obtain between science and religion, between reason and faith. Their influence among scientists has also spread far beyond the confines of physics, and thus it is best left for fuller discussion elsewhere.

A few words may nonetheless be said about the general orientation of scientists vis-à-vis religious faith in light of the long history that has been sketched. Obviously there is no longer the strong liaison between faith and science that characterized the Middle Ages and the early modern period. At the same time the tension and conflict between the two portrayed so graphically by Andrew Dickson White has largely disappeared. It seems now to be generally admitted that there is no necessary connection between scientific competence and religious faith. The predominant note has instead become one of irenicism. Where there used to be tension between scientist and believer there now tends to be a high wall of separation between them.

One could say that the attitude of most scientists towards religion is basically no different from that of other professional and university-educated people. Among the ranks of scientists and nonscientists alike an entire spectrum of views toward religion is discernible, from the hostile to the enthusiastic. Some actively combat the Church, seeing no need or room in the twentieth century for any commitment to the supernatural. Others are tolerant of religion even though it poses intellectual problems for them; for them it has great moral and inspirational value, and can tide other people over their speculative difficulties. Yet others are more sympathetic on the grounds that religious faith can complement science by providing it with a metaphysics that lies forever beyond the pale of scientific investigation. And finally there are those who are enthusiastic, seeing religious faith as basically concordant with, and even an indispensable part of, their science, with both working together to provide an integral view of God and the universe.

In a pluralistic society where one finds such a spectrum of views, much difficulty can be avoided by clarifying more precisely the respective spheres of science and faith. Perhaps this can be done along the following lines. In modern science the work of reason is paramount, even though much that results turns out to be conjectural and uncertain. A scientist may indeed be a religious person, but there is no rightful place for divine faith in his or her science. Scientists must penetrate the secrets of nature by their own ingenuity, relying only on the accumulated knowledge of their fellow humans. When they finally do arrive at the frontiers of knowledge, however, a good part of their research yields conclusions that are only probable. Frequently they have to wait years for a consensus to develop among their co-workers on the problems that most interest them.

This is not to say that it is impossible ever to attain truth and certitude in science. Though most theories may still be open to question, a vast number of facts and laws of the universe have been so well confirmed that they form the indispensable matrix on which modern scientific knowledge is based. That is the knowledge students come to college or university to learn. To say that nothing is ever certain, that one answer is ultimately as good as another, is to adopt an epistemological position that is both naive and uncritical. It is especially pernicious when extrapolated beyond the confines of science to areas about which scientists are not at all competent to judge.

Supernatural religion is one such area, for it is here that faith is paramount. Faith is not emotion, or sentiment, or feeling; rather, it is true intellectual conviction. Such conviction is generated, not by any ability to see and understand the truths assented to, but by confidence in the authority presenting such truths to the human mind. Natural faith is based on human authority: this is the faith children have in their parents, students in their teachers, and scientists in colleagues who may be remote from them in space and time. Supernatural faith is quite different: it consists in assent to matters the human intellect cannot fully understand, on the authority of God himself. This is the faith upon which revealed religion is founded. God reveals himself to us, and we accept what he tells us of himself simply because he is God, who can neither deceive nor be deceived.

On this understanding the certitude of faith is not to be confused with the certitude of science. Granted, it is extremely difficult to attain scientific certitude when investigating the secrets of nature. But when the Creator of the universe reveals to us the most important truths, namely, those necessary for our salvation and eternal happiness, we can be certain of these simply from the fact that he has told them to us. We need not understand fully all that they mean in order to be assured of their value or their fixed and immutable character.

Some scientists in the present day make much of "the freedom to doubt," citing this as an imperative for scientific progress and making uncertainty an essential part of the scientist's intellectual makeup. This, in their view, restricts them in principle from having the absolute type of certainty religious commitment inevitably implies. Here again, however, an illicit extrapolation has been made. Systematic doubt may well be part of scientific method, but even at the level of reason the scientist cannot doubt everything. To do science he must be assured of his sanity, his wakefulness, his laboratory, his instruments and his means of calculation. And yet, even in this order his certitude is inferior to that of divine faith. There is difficulty, no doubt, explaining this to the scientist who does not possess such faith. For this reason it is rarely advisable to argue the point with those who refuse assent to revealed religion. If they do not experience supernatural faith, it is futile to compare the certitude of such faith with what they find, or do not find, in their science.

Within the Catholic tradition, as stated at the outset, the relationship between modern science and religion is simply but a part of the age-old problem of the relationship between reason and faith. For Catholic scientists the most disturbing part of the long history we have been sketching has not been the Church's infallible decrees relating to faith and morals, but disciplinary decrees such as that directed against Galileo in 1633. For this reason it is fortunate that the papal commission already mentioned as working on the "rehabilitation of Galileo" has recently concluded its work. Pope John Paul II presented the main results of their labors in an address to the Pontifical Academy of Sciences on October 31, 1992. Fuller details were provided by Cardinal Paul Poupard, President of the Pontifical Council of Culture, who chaired the papal commission, in presenting his report to the pope and the Pontifical Academy.

Pope John Paul II formally acknowledged that the Church erred when it condemned Galileo for maintaining that the earth revolves around the sun. He attributed the error to the theologians who passed judgment on Galileo, for, though they acted in good faith, they proved "incapable of dissociating faith from an age-old cosmology," that, namely, which regarded the earth as the center of the universe. This was a "subjective error of judgment," one that caused Galileo much suffering, added Cardinal Poupard. The pope used the occasion to stress the need for theologians to keep themselves regularly informed of scientific advances to see whether there is cause for "introducing changes in their teaching." He foretold that this might create pastoral difficulties, but that it was especially necessary in the areas of biology and biogenetics, because their applications affect human beings "more directly than ever before."

In his report Cardinal Poupard noted that although the Church had not previously taken the formal action it now has, it had in several ways already revoked Galileo's condemnation. The first action came in 1741, when Pope Benedict XIV gave the *imprimatur* to the first edition of the complete works of Galileo. The 1757 edition of the Catalogue of Forbidden Books then removed from the index all books favoring the heliocentric theory. In 1820 Canon Settele, a professor of astronomy at the University of Rome (La Sapienza), still encountered difficulty obtaining an *imprimatur* for a textbook he was preparing. Upon Settele's appeal to Pope Pius VII, the Dominican in charge of the Holy Office, Father Benedetto Olivieri, drew up a document in 1822 granting the *imprimatur* to works presenting Copernican astronomy as an established thesis and not merely as a hypothesis. Each of these steps was made on the basis of increasing scientific evidence, and it is interesting to note that this decisive step, in 1822, preceded by several decades the discoveries of Bessel and Foucault on which proofs for the earth's motion are now based.

The pope's announcement to the Pontifical Academy of Sciences thus closed the book on what has long been called "the Galileo Affair." He made it in a session of the Academy devoted to the discussion of complexity in modern science. Recall that Bellarmine had insisted that Galileo actually demonstrate the earth's motion before the Church would consider revising its longstanding interpretation of Sacred Scripture. Pope John Paul II admitted in his address that this requirement is much too stringent to be enforced in the present day. If a scientific theory cannot be known to be definitively true, he said, at least it should be "seriously and solidly grounded." In fact, he went on, the purpose of the Academy of Sciences as advisor to him is "to discern, and to make known, in the present state of science and within its proper limits, what can be regarded as an acquired truth or at least enjoying such a degree of probability that it would be imprudent or unreasonable to reject it. In this way, unnecessary conflicts can be avoided." This seems to be the most important lesson the modern papacy has learned from the Galileo case, one whose recognition can only be applauded by those concerned lest there be future conflicts between science and their religious faith.

Suggestions For Further Reading

Literature on the history of science is vast, and anyone wishing to delve into it should have access to a good university library. With regard to science's relation to the Catholic faith, a number of key works have been published by the Vatican and other European presses and may not be readily available in the U.S. The following is a select list of books on which the above account is based and which may be consulted to flesh out fuller details.

The best general source for the history of science in all periods is the *Dictionary of Scientific Biography*, ed. C. C. Gillispie, New York: Charles Scribner's Sons, 16 vols., 1970-1980. This may be supplemented, on points of interest to Catholics, by articles in the *New Catholic Encyclopedia*, ed. W. J. McDonald et al., New York: McGraw-Hill Book Co., 1967, 15 vols. plus three supplements (1974, 1979, and 1989). On the general subject of science and faith, the best overall treatment is *God and Nature: Historical Essays on the Encounter Between Christianity and Science*, eds. D. C. Lindberg and R. L. Numbers, Berkeley-Los Angeles-London: University of California Press, 1986. This is especially good for periods prior to the seventeenth century; it is weak in its treatment of Galileo, and thenceforth concentrates mainly on the encounters of science with Protestant theology.

For the ancient and medieval periods, the best brief introduction is Olaf Pedersen, *The Book of Nature*, Vatican City: Vatican Observatory Publications, 1992. Also helpful is *Science in the Middle Ages*, ed. D. C. Lindberg, Chicago: University of Chicago Press, 1978; A. C. Crombie, *Augustine to Galileo*, London: Heineman, 1952, reissued in 2 vols. as *Medieval and Early Modern Science*, New York: Doubleday Anchor, 1959 and Etienne Gilson, *Reason and Revelation in the Middle Ages*, New York: Charles Scribner's Sons, 1938. Specialized studies include A. C. Crombie, *Robert Grosseteste and the Origins of Experimental Science*, Oxford: The Clarendon Press, 1953; J. A. Weisheipl, *Albertus Magnus and the Sciences*, Toronto: Pontifical Institute of Mediaeval Studies, 1980; Thomas Aquinas, *Summa theologiae*, 60 vols. under the general editorship of Thomas Gilby, Vol. 10: *Cosmogony*, ed. and trs. W. A. Wallace, New York: McGraw-Hill, 1967; and J. A. Weisheipl, *Nature and Motion in the Middle Ages*, ed.

W. E. Carroll, Washington, D.C.: The Catholic University of America, 1985.

On Galileo and his trial, the basic documents are given in *The Galileo Affair: A Documentary History*, ed. and trs. M. A. Finocchiaro, Berkeley-Los Angeles-London: University of California Press, 1989. *Studies made by the Papal Commission to evaluate the trial include Galileo Galilei: Toward a Resolution of 350 Years of Debate*, 1633-1983, ed. Paul Poupard, Pittsburgh: Duquesne University Press, 1987; *Reinterpreting Galileo,* ed. W. A. Wallace, Washington, D.C.: The Catholic University of America Press, 1986; and *The Galileo Affair: A Meeting of Faith and Science*, eds. G. V. Coyne et al., Vatican City: The Vatican Observatory, 1985. The report of the Papal Commission to the Pontifical Academy of Science is given in *French in Atheism and Faith*,

27.4 (1992), pp. 241-255, and in English translation in *L'Osservatore Romano*, Weekly Edition in English, November 4, 1992. Special studies include W. A. Wallace, *Galileo and His Sources: The Heritage of the Collegio Romano in Galileo's Science*, Princeton: Princeton University Press, 1984, and *Galileo's Logic of Discovery and Proof*, Dordrecht-Boston: Kluwer Academic Publishers, 1992; and R. J. Blackwell, G*alileo, Bellarmine, and the Bible*, Notre Dame-London: University of Notre Dame Press, 1991.

On more recent science, see Amos Funkenstein, *Theology and the Scientific Imagination from the Middle Ages to the Seventeenth Century*, Princeton: Princeton University Press, 1986; *Religion, Science, and the Search for Wisdom*, ed. D. M. Byers, Washington, D.C.: U.S. Catholic Conference, 1987; *Physics, Philosophy, and Theology: A Common Quest for Understanding*, ed.

R. J. Russell et al., Vatican City: The Vatican Observatory, 1988; *John Paul II on Science and Religion: Reflections on the New View from Rome*, ed. R. J. Russell et al., Vatican City: The Vatican Observatory, 1990; and *Newton and the New Direction in Science*, ed. G. V. Coyne et al., Vatican City: The Vatican Observatory, 1988.

Stanley L. Jaki has written much on the relations between science and the Catholic faith. His works relating to this essay include *The Relevance of Physics*, Chicago: University of Chicago Press, 1966; *Science and Creation: From Eternal Cycles to an Oscillating Universe*, New York:

Science History Publications, 1974; *The Road of Science and the Ways to God* (The Gifford Lectures 1974-75 and 1975-76), Chicago and London: University of Chicago Press, 1978; and *Uneasy Genius: The Life and Work of Pierre Duhem*, Dordrecht: Martinus Nijhoff, 1984. See also R. A. Brungs and Sr. M. Postiglione, eds., *A Seminar with Father Stanley Jaki* (ITEST Workshop, October 1991), St. Louis: ITEST Faith/Science Press, 1992.

Questions

How did Islam contribute to the development of science? How did the rise of Islam in the sixth century foster the spread of new scientific knowledge?

Please learn the history of faith and science in its detail. It is quite important to understanding why things are the way they are. In fact, this is a very old debate in both Judaism and Christianity long antedating the faith-science debate. It is known in the early Church as the debate over reason and faith, as this article clearly shows. It is quite appropriate to use the arguments of the early Church Fathers to discuss some aspects of the very modern conflict between faith and science. For example, compare and contrast the treatment of creation in the Greek and Latin Fathers of the Church. Then compare this treatment also with the Greek philosophers of the same period. Whom do moderns follow? Give some examples if you can. Does modern science confirm or deny either the Fathers of the Church or the Greek philosophers?

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