LECTURES ON SOCIAL HISTORY[1]

I

SCIENCE IN THE MIDDLE AGES[2]

ONE of the paradoxes of our time is the ignorance of even men of science of what they owe to medieval and renaissance scientific research. They need to read the history of science as a prophylaxis against priggery.

While the Church and the theologians in the Middle Ages, by trying to reconcile Aristotelianism and Scholasticism dexterously performed the remarkable experiment of putting the wine of new thought into old bottles, there were other thinkers who grew tired of the endless discussion about "substance" and "accidents" and "universals" and "individuals," and would heartily have approved—if they had known them—the lines of Omar Khayyam, the poet and mathematician of Nishapur (died 1124):

> Myself when young did eagerly frequent
> Doctor and saint, and heard great argument
> About it and about, but evermore
> Came out by the same door as in I went.

"One individual," wrote Roger Bacon, "is worth more than all the universals in the world . . . God has not created the world for the sake of the universal man, but for the sake of

[1]A series of three public lectures delivered at the Rice Institute on March 6, 7, and 8, 1930, by James Westfall Thompson, Ph.D. (Chicago), Litt.D. (Rutgers), Professor of Medieval History at the University of Chicago.

[2]This lecture is to appear in the author's forthcoming volume, entitled "The Middle Ages," from the press of Alfred Knopf, New York.

individual persons." "Bacon was thirsting for reality in a barren land infested with metaphysical mirage. From the horse-load of verbal controversies, from the interminable series of commentaries on Aristotle . . . he took refuge in the visions of the harvest of new truth that was about to be reaped by patient observation of nature."[1] In a word, Bacon and many others with him in the thirteenth century were interested in science and not in theology and metaphysics.

The history of science in the Middle Ages must begin with the body of that knowledge which was received from antiquity. This amount was neither large in quantity nor of much quality. For unfortunately the Romans had been an engineering and practical people and were little interested in what the Greeks had achieved in this line. They were content with compendiums of the Greek treatises and hence the original treatises were unknown to Western thought until translations of them from the Arabic began to circulate in the twelfth century. Some of the manuals accordingly acquired an importance altogether out of proportion to their real value. For example the medical works of Galen, the greatest Greek physician, circulated in the form of a paraphrase by Soranus, and Galen did not come into his own until the school of medicine which grew up at Salerno in the eleventh century became familiar with the whole of Galen through Latin translations of the Arabic translations from the original Greek. In mathematics the Romans were interested in surveying, and the Latin treatises of the *agrimensores* survived; but pure mathematics suffered. The sole work of this sort which the West knew for centuries was Boethius's *Arithmetic,* which was a free translation or paraphrase of a Pythagorian mathematical work by Nicomachos

[1]Bridges, *Roger Bacon,* new ed., p. 25.

of Gerasa (end of first century). Geometry suffered more than arithmetic. Menelaos of Alexandria, who made astronomical observations in Rome in 98 A. D., was the author of a work on the calculation of chords and another on spherics. The first proposition of the third book of the latter work was the foundation of the solution of spherical triangles among the ancients and was used by Arab scholars to elaborate their astronomical theories. But Menelaos's works had to wait until the twelfth century before they became known in the West.

Theological expediency and ecclesiastical domination increased and prolonged this eclipse of science in western Europe. "Christian doctrine was based on faith. Science is reason." One has merely to read St. Augustine to realize how pitifully ignorant the countries of Latin Christendom were for centuries, and how dogmatism inhibited research. The emphasis laid by the Church upon introspective life closed men's eyes to the world of nature around them. St. Augustine expressed astonishment that "men go abroad to admire the heights of mountains and study the circuits of the stars, and pass themselves by." He ridiculed the idea that the earth was a sphere, though the Greeks had known it for centuries, and declared the notion of the Antipodes both ridiculous and heretical. Along with this retrogression of scientific thought went also corruption of it by universal belief in miracles and widespread superstition. Magic polluted what little genuine scientific knowledge survived; alchemy, which at least had the elements of chemistry within it, and astrology, which in like manner had the elements of astronomy within it, became paramount forms of belief, and pseudo-science instead of science became supreme for centuries in western Europe. "In the thinking of the Middle Ages it is always necessary to remember that the knowledge of the day was not only perverted and corrupted in quality, but it was also extremely small in extent."[1] Byzantine Europe was no better off. When Justinian closed the Academy at Athens (529) the light of Greek science and philosophy went out. The exiled scholars found refuge in Persia at the court of Chosroes I the Great (Nushirwan the Just), whose capital became the greatest intellectual centre of the time, where mathematics, natural science, and philosophy were cultivated and increased in knowledge by the infiltration of Hindu science out of India.

This accumulated heritage of Greek, Persian, and Hindu scientific knowledge passed over intact to the Arabs after their conquest of Persia, Syria, and Egypt, and formed the basis of the Abassid renaissance in the East about the same time as the Carolingian renaissance in the West. But the latter was an educational and literary revival, and without interest in science. The whole range of scientific knowledge in western Europe in the seventh, eighth, and ninth centuries may be measured in the *Encyclopaedia* of Isidore of Seville (died 636), the writings of Bede (died 735), and the *Glossae Salomonis,* an encyclopaedic dictionary which originated at St. Gall, but is named from Archbishop Salomo III of Constance, of which it has been written that "it illustrates how exceedingly inadequate was the state of learning and how narrow were the conceptions of life at that time."[2] The inspiration and the source of information for all three of these writers was Pliny's *Natural History* and little else.

How different was the condition of thought in Arabic lands!

While the eastern scholars were not all, or indeed many of them, Arabs, but chiefly Persians or Arabized Jews, yet

[1]Singer, *From Magic to Science,* xl.

[2]Stälin, *Geschichte Würtembergs,* I, 405.

the universal and fixed nature of the Arabic language owing to the Koran made that tongue an international language from India and even China to Spain. The Muslim renaissance from the first was essentially of an international nature and in this respect was unlike either the Carolingian or the Byzantine initiated by Leo of Thessalonica—all intellectual revivals in the same (ninth) century.

It was fortunate for Mohammedan science that the Baghdad Empire was the common meeting place of both Greek and Hindu thought, and it is a singular reflection that Hindu mathematics had developed entirely independent of the influence of Greek mathematics, and that both met together in the schools of the great Arab Empire. This double stimulation is a remarkable event. Merely to list the names of eminent Arab scientists between 750 and 1100 would fill a paragraph; only the greatest of them can here be mentioned. First in point of time stands Geber of Kufa, in the eighth century, at once alchemist and technical chemist. Then follow Al-Khwarizmi of Khiva, in the first half of the ninth century, "one of the greatest scientists of his race and the greatest of his time," mathematician, astronomer and geographer, who fused Greek and Hindu mathematics, and founded algebra—discovered by the Hindus—in the sense that translations of his mathematical works centuries later gave algebra to western Europe; Al-Battani (died 929) a Sabian, one of the most famous astronomers of Islam; Al-Razi of Baghdad (died 923–24), "the greatest clinician of Islam and of the Middle Ages," the Mohammedan Galen; Avicenna, in the first half of the eleventh century, whose medical treatises "remained the supreme authority not simply in Islam, but also in Christendom for six hundred years;" Ibn Al-Haitham (965–1039), a great physicist particularly in optics, to whom Roger Bacon over two hundred years later was indebted; and his contemporary Ali Ibn Isa, the oculist. This brilliant series may be said to terminate with Omar Khayyam, the mathematician in the first quarter of the twelfth century. By that time Mohammedan learning had spent its force; its precocious genius was burning out.

The Arabs added algebra and plane and spherical trigonometry to Euclidian geometry; they invented the sinus; they calculated tangents, cotangents and secants; they maintained astronomical observatories at Baghdad, Raqqa, Damascus, Cairo, Samarkand, Cordova, Fez. The Mongols added those of Meraga and Peking. They used the astrolabe and the sextant. The latitude and longitude of every great city of the Islamic world were calculated. Arabic mathematicians proved the enormous error of Ptolemy by reducing his estimated length of the Mediterranean from sixty-two degrees to forty-two degrees.

Fortunately, before the era of decline set in, Arabic science had begun to penetrate the scientifically benighted Latin West through Sicily and Spain. The obscure beginnings of the medical school at Salerno go back to Shabbethai ben Abraham ben Joel, a Jew of Otranto in Lower Italy who was taken captive by Saracen pirates in 925, carried to Palermo where he learned Arabic and "studied all the sciences of the Greeks, Arabs, Babylonians and Indians." Southern Italy at this time, it must be remembered, was a Byzantine possession and hence Greek and Arabic learning met in the schools of Otranto, Salerno, Rossano, etc. From this region John of Gorze before 950 brought back to Lorraine an example of Aristotle's *Categories* and of Porphyry's *Isagogia,* transcripts of which we find at Fleury-sur-Loire before the year 1000. From Calabria at the end of this century came that John, who was instrumental in the revival of Greek studies in Germany during the so-called Saxon renaissance. But part of the inspiration of that movement was of Arabic origin. And again, the vehicle of transmission was John of Gorze.

Until very recently the earliest positive date for the transmission of Arabic learning north of the Alps has been 984, a date attached to the history of the famous Gerbert. But it has now been proved that we can go back as far as 956 for this event. For in 953 Otto the Great sent John of Gorze on a mission to the Khalif Abd er-Rahman III of Cordova, and here John fell in with the great Spanish Jew scholar named Hasdai ibn Shaprut, high in the favor of the Khalif, and who was versed also in the Latin language. We are not told definitely what manuscripts John of Gorze brought back with him to Germany from Spain, or even that he brought any. But the circumstantial evidence points strongly that way. For in the schools of Lorraine in the last half of the tenth century a remarkable renaissance of mathematical studies was manifested and we can detect evidences of Arabic science in the writings of learned monks of that time. "Lorraine in the eleventh century was the chief centre for the study of the abacus and produced such eminent mathematicians as Heriger of Lobbes, Adelbold of Utrecht, Reginbald of Cologne and Ralph and Franco of Liège."[1]

We come upon slightly firmer ground in this matter of the teaching of science in the West with Gerbert of Rheims, afterwards Pope Sylvester II (999–1003), who was master of the school of Rheims by 972. He was "the first mind of his time, its greatest teacher, its most eager learner, and most universal scholar." He was the teacher of Abbo of Fleury (died 1004), who made that abbey the last shining monastic example of higher learning, and of Fulbert of

[1]Haskins, *Studies in the History of Mediaeval Science.*

Chartres (1007–29) who refounded that brilliant school. Early in life Gerbert had dwelt at Barcelona and there, perhaps, had acquired some faint perception of the value of Arabic science. He is widely credited with having introduced Arabic, or more accurately Hindu numerals into Europe,[1] but it is not established. Certainly he deplores the "iron process" of solving an example in long division with Roman numerals, a sentiment with which all will sympathize who will try to do so.

Gerbert's learning represented to the fullest degree the nature and extent of the learning of Europe just before the intellectual awakening of the eleventh century, so that it is in point to dwell upon this subject at some length. Fortunately for this purpose we have a clear account of the matter from the pen of one of his students, the historian Richer of Rheims. If one analyzes this account it will be apparent that Gerbert's learning was almost wholly the sum of European scientific knowledge as derived from Pliny, Boethius, Isidore of Seville, Bede and the Carolingian renaissance. No direct and immediate Greek knowledge, nor any that is Arabic is observable. Richer tells at length what books and which order of books Gerbert observed in his teaching and casts some light upon his method of instruction. Long as this account is—even when abridged—it deserves citation for the interest and value of it.

"He presented dialectics after the order of the books and explained that subject with comprehensible explanations. First he commented upon the introduction (i. e. the paraphrase) of Porphyry the philosopher (who died in Rome in 304) to the *Categories* of Aristotle, according to the translation of the rhetor Victorinus, (who lived in Rome about

[1] "The earliest Muslim documents containing Hindu numerals are dated 874 and 888," Sarton, *History of Science*, I, 601.

360) and afterwards also, according to the commentary of Boethius.

Therefore Gerbert had only a Latin translation of a Greek paraphrase of the original.

"He expounded Aristotle's book on the *Categories*—fundamental principles like substance, attribute, quality, quantity, etc., in ten propositions. This was followed by the *Periermenias* or the 'Interpretation'—a Latin version of the Greek—the difficulties in which he amply demonstrated. Then he presented the topic, that is to say the basis of the arguments (*argumentorum sedes*) which Tully (Cicero) had translated from Greek into Latin, and upon which Boethius had commented in six books. He also expounded with suggestion the four books upon divers methods of reasoning, two upon syllogisms and categories, three upon hypotheses, one upon definitions and one upon division of thought. After that he passed on to rhetoric and observed that it was impossible to make progress in the study of rhetoric without a knowledge of the modes of expression found in the Roman poets. He read and elucidated Maro (Vergil), Statius, Terence and the satirists Juvenal, Persius, and Horace. In history we read Lucan's *Pharsalia*. After having been thus instructed in rhetoric, we were trained in argumentation and debate by the study of logic. The study of mathematics cost us a lot of labor. He began by teaching arithmetic, which is the first part of that science, from which he passed to music, a science long neglected in Gaul. He indicated the different tones on the monocord,[1] showing their consonance or harmony in whole and half tones, and distinguished intervals of two whole tones and

[1]The monocord was a box-shaped instrument with a cord or string of gut stretched tight across it and was used to illustrate the variety and degree of musical tones.

those of half tones; he also combined the tones into accords in a most artful manner. Although the science of astronomy nearly passes human understanding, Gerbert did, however, make it comprehensible to us with the aid of apparatus. First he represented the globe of the earth by means of a round wooden sphere and indicated by other spheres the relation of the planets to our globe. The poles were represented to be obliquely opposite to each other from our point of vision and the northern and southern constellations were pictured. He determined the position of the globe by means of the circle which the Greeks called the horizon, and the Romans knew as the *circulus limitans* or *determinans*, because it forms the boundary line between the stars that are visible and those that are not seen. The rising and setting of the stars was clearly visualized, and after that he explained the constellations. On clear nights he would take us out to view the sky and he admonished us to note their oblique course and to learn to locate the great stars and constellations."

Richer goes on at length to tell in technical language how Gerbert drew parallels and meridians upon a wooden sphere, marked the equator and distinguished the zones, and by an ingenious contrivance illustrated the movement of the planets and even the great constellations. He directed no less energy to instruction in geometry. As arithmetic was the first part of the quadrivium Gerbert devoted much attention to it. Contrary to a widely circulated opinion he originated nothing in this subject, but taught it as it had been taught since Roman times and expounded by Boethius in the sixth century. Instruction was imparted by use of the abacus, a board having twenty-seven compartments or squares marked upon it, upon which, by manipulating the nine digits, any problem of simple arithmetic could be worked out mechanically. From Richer's long and technical account of the use of the abacus it is evident that when he was Gerbert's pupil Arabic numerals were not employed. Neither was the zero used or any signs of addition, subtraction, multiplication or division. Results in these processes had to be expressed by a word indicating the nature of it.

Leonard of Pisa, in the thirteenth century, who was the son of a Pisan collector of customs in North Africa, is the first European scholar of whom it can be established that he used Arabic figures. But even so, this statement needs qualification. Leonard seems to have been the first one who employed the term "cipher," which comes from the Arabic "sifir." In the same way "zero" is derived from the Arabic "zefiro." The Arabs themselves called the figures which they used "Indian ciphers," but it is today recognized that our so-called Arabic figures are not of Hindu origin. As far back as the sixth century Boethius already had displaced the cumbrous Roman notation with single signs which he called *apices* for the nine digits. Most of these figures bear a striking resemblance to the figures which we use today, especially the figures 1, 7, 8, 9; the 2 is our 2 reversed; the 6 reminds of our 6. These identical *apices* are found in the abacus of Bernelinus, a pupil of Gerbert. It is singular that Europe for many centuries failed to profit by the simple system of notation apparently invented by Boethius and that it was the Arabs who popularized their usage. The really original contribution of Arabic mathematical thought to notation was the device of the "zero," which, however, cannot be proved to have been used in Christian Europe before the thirteenth century. The invention of the "zero" made possible the simple multiplication of any of the digits 0, 9, 10, 100, 1000, etc. The invention of the "zero" is attributed to Mohammed-ibn-Mousa, surnamed Al-Kharizmi, because he was born in the province of Kharizim in the Baghdad Khalifate. By a corruption of his surname the word "algorithmism" or "algorism," meaning the science of numeration, was derived.

Gerbert represented the maximum of medieval learning as it was derived from Roman antiquity, with the limitations of that knowledge imposed by Roman indifference to Greek scientific theories and higher learning; but he was not a creator or disseminator of the new learning imparted by the Arabs. It is only through vision that any progress can be made, and Gerbert had little vision of the future of learning which was in preparation and soon to be revealed to Europe. He saw the first faint flush of the dawn, he did not see the dawn itself, the birth of an active spirit of scientific research. Increased commercial intercourse between East and West, the Crusades, the long domination of the Moors in Spain, the Arabic conquest of Sicily and prolonged occupation of Provence, the intellectual influence of the Spanish Arab universities of Cordova, Seville, Toledo, Granada, the diffusion of Arabic mathematical and scientific treatises, were all media of the transmission of Arabic culture.

The makers of this dawn were the noble galaxy of translators of the treasures of Arabic science into Latin, by whom the mind of the West was made to see a new and great light. As we have seen, Sicily and Spain were the two seats of Arabic culture in the West and it is from these two countries that Arabic learning radiated. The earliest western translator whom we know was Constantinus Africanus, a Christian who was born in Carthage and was for many years an Arabic subject; he travelled in the East and about

1056 became a monk at Monte Cassino, dying in 1087. His translations deeply influenced the study of science in southern Italy and almost created the medical school at Salerno where, however, one must make allowance for the fact that Greek medical traditions had never been entirely broken. The historian Leo of Ostia called him "the master of East and West." In the next century Spain's doors were opened by a host of translators after the Christian recovery of Toledo in 1085. "Toledo was the natural place of exchange for Christian and Mohammedan learning. At this centre of scientific teaching 'were to be found a wealth of Arabic books and a number of masters of the two tongues, and with the help of these Mozarabs and resident Jews there arose a regular school for the translation of Arabic-Latin books and science, which drew from all lands those who thirsted for knowledge.' "[1] Archbishop Raymond of Toledo (1125–51) must be given credit for his liberal encouragement of this movement.

Chief among these translators were Adelard of Bath, Plato of Tivoli, Robert of Chester, Daniel of Morley. The labor of these was supplemented by that of Jewish-Latin translators dwelling in the Mohammedan part of Spain, men like Petrus Alfonsi, and Abraham ben Ezra. While Toledo always was the chief seat of this Christo-Arabic learning, we find translators in Barcelona, Segovia, Pamplona, and over the Pyrenees in Toulouse, Narbonne and Béziers. All of these scholars lived and labored during the first half of the twelfth century, but the latter half of this century saw the most prolific of them in Gerard of Cremona (died 1187), the catalogue of whose translations totals seventy-one Arabic works done into Latin.

The volume and variety of old knowledge revised in

[1]Haskins, *Studies in the History of Mediaeval Science*, 52, quoting V. Rose.

the light of Aristotelian and new knowledge derived from the Arabs, by the thirteenth century had reached such dimension, and the general interest in it was so great that Pliny's *Natural History* and Isidore of Seville's *Etymologies,* long the standbys, failed to suffice. A host of encyclopaedists arose who endeavored to correlate the new learning. The most eminent of these were Alexander Neckham's *On the Nature of Things,* Bartholomew Anglicus's *The Properties of Things*—notice that these two were Englishmen—and Vincent of Beauvais's three volumes: *Mirror of Nature, Mirror of Doctrine,* and *Mirror of History.* These works form three huge folio tomes in the printed edition of 1624, and "perhaps one-half of the whole, say three thousand folio pages, deals with science in the more particular sense."

The effect of this mass of new and potent knowledge upon the western mind was an intellectual revolution. In order to understand how this came about one must bear in mind that other intellectual awakening in this century, viz.: the conflict between nominalism and realism, or rationalism and fundamentalism, which prepared the soil for this new seed. In this debate logic had almost imperceptibly led to physics, for there is a close relation between logic and experimental science. The spirit of research implied in this intellectual revolution was expressed by William of Conches in a noble sentence: "We toil for truth alone." One can understand how men like Roger Bacon, with the new world of science opening before them, became tired of abstruse metaphysics and endless argumentation over "accident" and "substance" and turned with relief to the new study of science.

The alarm of the Church over this new scientific knowledge was little less than its alarm over the spread of

Aristotelianism, for both might and did compromise theology. Accordingly, just as the Church endeavored to control rationalism by putting Dominicans and Franciscans into university chairs and setting St. Thomas Aquinas to his elaborate attempt to reconcile Aristotelianism with Scholasticism, so the Church also labored to conciliate the new science with its theology that ecclesiastical teaching and authority might not be undermined.

While the line between the phenomena of religion and the phenomena of science was not drawn in the Middle Ages—nor indeed until the eighteenth century—as sharply as today[1] nevertheless the great schoolmen of the thirteenth century may be divided between those who were primarily interested in theology and dogmatism, and those who were primarily interested in science. In the former class were Alexander of Hales and St. Thomas Aquinas; in the latter Robert Grosseteste, Bishop of Lincoln (died 1253), Michael Scot, a protégé of the brilliant emperor Frederick II, Albertus Magnus (died 1280), and above all, Roger Bacon (died 1294). The observant student will not have failed to note that the number of English scholars interested in the new science exceeds that from any other country. For Adalard of Bath, Robert of Chester, Daniel of Morley, Grosseteste and Bacon were all Englishmen, and Michael Scot was an Irishman or an Englishman of Irish extraction.

St. Thomas Aquinas, with his hair-splitting dialectic, tried to do homage to the new science and yet spare theology by declaring, when the Ptolemaic system was questioned, that "although the phenomena can be saved on the Ptolemaic

[1]Sarton, *History of Science,* I, 23. "Science is reason organized and systematically applied. Religion is a reasoned . . . abdication of reason with regard to problems which *are not* amenable to scientific treatment."

hypothesis we do not assert that they are true, since perhaps the phenomena of the heavenly bodies may be saved in some way not yet grasped by the mind of man." It was something to prevail upon the "seraphic doctor" to make even such a concession; but other scholars were more forthright. The whole story of the creation in *Genesis* was questioned and attacked by these bold thinkers. Why was light created on the first day, and the stars on the fourth? Why was the moon called one of the two great lights since it was smaller than any of the planets? Why were birds and reptiles said to issue from the water, and quadrupeds from the land?

Though medieval science to the end of the Middle Ages did not succeed in liberating chemistry from alchemy or astronomy from astrology, it nevertheless was science.

"Alchemy, and even more astrology, contained at least a nucleus of scientific thought. The fact that even this nucleus was proved to be erroneous by subsequent investigations does not matter much, for every truth is but relatively and temporarily true. Pure astrology was a very remarkable scientific system; it provided a congruous explanation of the world. . . . The scientific ideas forming the core of ancient astrology and alchemy influenced the progress of science . . . because they stimulated new observations and experiments. . . . For science is essentially a cumulative, a progressive activity."[1] The true intellectuality of the thirteenth century is to be found in scholars, and not in the credulity of the masses, nor are they to be impeached because astrological and alchemical ideas still invested their thinking. It would be unjust to measure them by our modern knowledge and our modern laboratory methods. It is their influence on the intellectual develop-

[1]George Sarton, *Isis,* VI (1924), pp. 78, 83.

ment of the age which must be considered, the advance in knowledge which they made.

As we scan the list of these eminent names we identify almost all of them as either Dominicans or Franciscans, and the cleavage between the groups is great. The Dominican scholars were intellectual conservatives, endeavoring to sustain authority, tradition and dogma by conciliating the old and the new learning. The Franciscans, on the other hand, were forward-looking, critical, revisionist, radical. There is immense suggestion in this fact.

The great deficiency of the medieval mind in the matter of scientific interpretation was failure to perceive the unity of nature. Things for the mediaeval man had a value independently of other things: natural phenomena were not coördinated and synthesized. Roger Bacon, more than any other scholar of the age, caught a glimpse of this underlying unity of nature and had an adumbration of a monistic philosophy. He realized, at least dimly, that physics, chemistry, astronomy, mathematics, were different functions of the same thing.

This belief in the separate reality of different things, when in actuality the mediaeval man was only observing different facets of a single thing, accounts for the intense symbolism of the Middle Ages.

"For a thinker of that time to know and explain a thing always consisted in showing that it was not what it appeared to be; that it was the symbol and the sign of a profounder reality. This is why mediaeval bestiaries and cameos and intaglios so astonish and mystify us. The very substance of the creatures and the things portrayed has been reduced to a symbolical significance. What the twelfth century lacked in order to establish concrete reality under this world of symbols was the conception of the unity of nature, of nature having a reality of its own and a value in itself." We have not yet attained complete understanding in this matter, but it was Aristotelian physics in the thirteenth century which pointed the way.

Great as Bacon was, he owed his initial inspiration to Robert Grosseteste, who reduced physics, chemistry, physiology and all other natural phenomena to cosmic geometry.[1] All natural phenomena, according to Grosseteste, were reducible to lines, angles, planes, figures. The sphere was the perfect figure because light multiplies itself spherically. It was an anticipation of Cartesian philosophy in the thirteenth century.

What the mediaeval man of science lacked was technique. The scholars of that time were intellectually as able as scholars of today, and they were far less ignorant than is commonly supposed. No scientific man in the Middle Ages believed that the earth was flat. The reason of eclipses was known and they were even calculated. Adalard of Bath spent two summers studying the tides and worked out a reasonable theory of the phenomenon of flux and reflux; he contended that matter was indestructible, though he could not demonstrate it, having no laboratory or apparatus as a modern physicist has. The same proposition was argued by Hugo of St. Victor, which does not make him seem to have been a mystic. The principles of optics were understood in the twelfth century from Arabic treatises, and the lens was also known. What shall one think of Duns Scotus, who spent a winter in Paris calculating the precession of the equinoxes, in which he employed both Greek and Arabic mathematics? Albertus Magnus, who was primarily a natural scientist, at the beginning of his work on minerals

[1]*Omnes enim causae effectuum naturalium habent dari per lineas, angulos et figuras.*

discusses the different ways in which minerals may be classified, and weighs the value of each method. Roger Bacon's *Opus Majus* has been truly called "at once the Encyclopaedia and the Organon of the thirteenth century." His famous indictment of the science and the scientists of his time is not what it seems; it is really the complaint of a great spirit, impatient as genius ever is, with the slowness with which truth is discovered, discontented with the smug contempt of the ignorant, sometimes disheartened by the limitations under which he worked, and the indifference which he met from those who had no understanding of the nature and the value of scientific research. Bacon urged the investigation of nature and the useful application of the knowledge thus gained. His epistle on the possibilities and the future of science is one of the classics of the history of science, like Tyndall's famous Belfast Address.

The debt of the world to mediaeval science is far greater than realized. To the cloistered students of the Middle Ages we owe our modern system of notation and algebra, the magnifying glass—Bacon made many microscopes for himself—the art of distillation and pure alcohol, almost every acid and alkali not already occurring in nature, the first fulminating agents, almost every remedy known to pharmacopaeia before the advent of modern chemistry, the process of manufacturing linen paper.

One must not omit to notice the rise and development of science during the Renaissance. Here Italian genius was not of most influence. The Italian scholars until very late who were interested in science, were more interested in natural history, zoölogy, medicine, and the applied or technical sciences than in pure science. Mathematics was applied to bookkeeping, architecture, and engineering; chemistry to dyeing; botany to gardening and medicine. The tendency of

Italian scientific thought was practical, not theoretical. Macchiavelli's treatise on government was a practical manual for statesmen, not a theoretical treatise on political science. For all his brilliance, Leonardo da Vinci, the most myriad-minded man of the Renaissance, apart from the technical sciences, was a brilliant amateur, working more by intuition than by experiment.

For the development of pure scientific thought in the last centuries of the Middle Ages one must look to Germany, not Italy. There, from Albertus Magnus in the thirteenth century forward to Copernicus, may be found an unbroken line of great scientific thinkers.

"The Copernican system was hinted at in a MS of 1322 and a few decades later was mathematically developed by the Paris Occamists, Buridan, Albert of Saxony and Oresme."[1] The line runs through Jordan of Saxony, a pupil of Albertus Magnus, Conrad of Megenburg, Nicholas of Cusa (1401–64), George Peuerbach (1423–61), Regiomontanus (or Johannes Müller of Königsberg, 1436–76), Albertus Brudzewski (1445–97) to Nicholas Copernicus (1473–1543), the last two of whom were Germanized Poles, and both of them deeply indebted to Regiomontanus. In the last part of the fifteenth century the University of Cracow was ahead of Prague or Heidelberg. Poland ever was in close relation with Italy (Padua University) and it was German scientific activity, though via Polish scholars, which at last awakened the spirit of pure scientific research in Renaissance Italy in the sixteenth century, of which Giordano Bruno, Galileo and Jerome Cardanus were the great expression.

The most remarkable of these German scientists were Cardinal Nicholas of Cusa and Regiomontanus. Cusanus was a mathematician, astronomer, physicist. He studied

[1]Spengler, *Decline of the West,* II, 301.

deep water pressures and invented the bathometer; he foreshadowed the law of inertia long before Galileo; he discovered the movement of the earth on its axis; he declared that "the earth cannot be fixed, but moves like the other stars," although he did not say—perhaps he may have so thought—that the earth revolved around the sun. Cusanus was therefore a progenitor of Copernicus. At least "he annulled the geocentric theory without substituting the heliocentric." Nicholas of Cusa was a philosopher, too, as well as a scientist. He said that nature was an "evolutio," an "explicatio" —an evolution or unfolding. "In his idea of motion as the combining principle of nature, and as that which constitutes the world into a totality, not less than in his idea of the development of the world as a progressive process of 'explication' and 'evolution,' Cusa anticipated future scientific theory."[1] Regiomontanus was a mathematician, the author of the first treatise on trigonometry; he introduced the *sine* and *cosine* as mathematical functions; he compiled a series of astronomical tables based upon the Spanish Alphonsine Tables of the thirteenth century, but immensely improved and expanded. This work exercised a potent influence upon discovery. Columbus, Vasco da Gama, and Magellan had each a copy of this work in their chart houses when on their epoch-making voyages.

[1]Höffding, *History of Modern Philosophy*, I, 88.