1. Science and Cultural Values

The passage of Greek science into Western Europe through medieval Spain has been one of the focal points of medieval intellectual history. Although the movement has been typically portrayed as a bipartite one, with translation from Greek into Arabic antecedent the florescence of Arabic science in the ninth century, and a later phase of translation from Arabic into Latin (eleventh and twelfth centuries) and finally into Romance vernaculars (thirteenth century), recent research demonstrates the continuous nature of the phenomenon.\(^1\) The studies of Millàs Vallicrosa show not only the continuity in scientific tradition between eastern and western Islam but also highlight the virtual contemporaneity of the production of Andalusi science and its transmission to Christian Europe.\(^2\) It is paradoxical that in both phases of transmission, the Islamic and the Iberian, the receiving societies have been characterized as the loci of cultural traditions inimical to the practice of science. The case is made for medieval Islam by G. E. von Grunebaum, who asserts that science and its technological applications had no root in the "fundamental needs and aspirations" of Islamic civilization. In the case of medieval Spain, Américo Castro was but one in a long series of participants in the "polemic of Spanish science" who have argued that science was a casualty of the wars against Islam, which had the effect of encouraging certain values and practices (honor, courage, religious fervor) and discouraging others (rationality, science, manual labor). A similar case has been made for the Christian West generally, as when Richard Lemay cites the inability of medieval Christianity, due to a pervasive obsession with the redemption myth, to come to grips with nature realistically.\(^3\)

That similar points appear to have been made about all medieval cultures must affect the general evaluation of the impact of science on medieval societies. These kinds of essentialist generalizations are, in my view, extremely questionable because they assume, first, that values are homogeneously distributed among all strata of society and, second, because they rest on the ultimate association of the practice or non-practice of science \(^{249}\) with modal personality ("national character"). It seems dubious on the face of it that a complex society, composed of a variety of social and cultural interests and backgrounds, can even be characterized as having "fundamental needs" (a concept much less easy to apply to group, than to individual, psychologies), much less "aspirations" (a teleological concept markedly out of place in objective historical analysis).

Von Grunebaum, in the passage just cited, in fact identified the true locus of the problem when he added that scientific accomplishment was achieved in the Islamic world only when and where elites were willing to exceed the bounds generally imposed by orthodox thought. In other words, the practice of science has a class basis which can be defined in social terms. (The same is true of "orthodox thought." Indeed, different segments of a society may well hold differing views of what is orthodox.)
The problem of medieval science is, then, less one of inhospitable cultural contexts and more one of selective barriers to its practice, each of which has a specific social or cultural locus. To the extent that both Islamic and Christian cultures prescribed definite bounds for scientific inquiry for the purpose of explicating a rather well-defined cosmology, the cultural climate may be defined as, if not inhospitable, then at least restrictive. On the other hand, the conceptualization of natural knowledge and its actual pursuit were two distinct phenomena. Belief did not necessarily interfere with practice: ibn Rushd was a religious judge. (Such examples could be multiplied.) Everyone believed that man was the center of a hierarchically organized universe and was in the power of non-corporeal beings. The culture of elites who practiced science was in part an expression of, and therefore fully congruent with, popularly held beliefs. Given these generalized views, medieval theology (which formulated the same beliefs according to different canons) offered selective barriers to the sciences, differing in impact to the extent that theological dogma might be challenged, and Christian theology offered relatively more barriers than did its Islamic counterpart.

2. Diffusion and Synthesis

Two chronological facts reveal much regarding the inception of scientific activity in medieval Spain. First is the late appearance of organized scientific activity in al-Andalus (mid-tenth century), and second is the rapidity of the transmission of Islamic science to Christian Spain. The late [250] start of Andalusi science has nothing to do with orthodox rigidity but simply reflects the changing demographic situation. Scientific activity began only when the phase of explosive conversion was well underway, implying the emergence of the necessary demographic weight to foment the division of labor requisite to the support of highly specialized individuals within the learned class, whose educational system could not have been institutionalized with any great depth prior to the tenth century.

An example of the rapidity of the movement of diffusion is the heavily Arabized Latin scientific miscellany from the monastery of Ripoll (MS 225, studied by Millás Vallicrosa), dating precisely to the late tenth century. This manuscript contains a treatise on the quadrant translated into Latin in the mid-tenth century from a contemporaneous Arabic manuscript, which in turn was based on older, non-Arabic sources. The scriptorium of Ripoll was the site of the first attempts in the West to synthesize the Arabo-Greek corpus in Latin (a manuscript of Boethius on arithmetic, with marginal notes in Arabic, for example, and a Latin translation of Máshá'alláh's treatise on the astrolabe). To Catalonia (and perhaps to Córdoba) went Gerbert of Aurillac in search of Arabic science in the 960's. When he returned to France, he wrote a friend in Spain requesting Joseph of Spain's work on multiplication and division, which, according to Millás, must be reckoned within the tradition of the diffusion of al-Khwârizmî. The putatively controlling values of these societies, therefore, did not affect the rate of transmission, which, in general, was very rapid. If the dominant values were both inimical to science, yet failed to slow the diffusion of scientific ideas, there is, at the very least, a contradiction in terms to deal with.

A different historiographical problem has been the nature of the diffusion process itself. Because of the fame of medieval translators, particularly those of Toledo, and their encouragement by royal patrons such as Alfonso the Wise, the role of cultural diffusion in Spanish science has long been recognized. But the impact of that diffusion is open to speculation. Américo Castro has argued that medieval Spanish culture acted as a passive medium through which the scientific legacy of antiquity passed, leaving only minimal traces: "Muslim science and philosophy passed through Toledo on its way to Europe without affecting the Castilian mind." This characterization, which somehow conjures the image of Peruvian silver, flowing through Spain to the mercantile centers of sixteenth-century Europe, while leaving the peninsula as impoverished as before, in part reflects the deficiencies of research in this area, but, more significantly, is a misconstrual of the way science functions. The
process of transmission is by no means as mechanical as Castro seems to imply.

The practice of science, involving the observation of nature and the formation of hypotheses explaining the ordering and function of natural phenomena, requires certain social and cultural prerequisites. Scientific advance is a cumulative process and presupposes the constant evaluation and reevaluation of past and contemporary research. Historically, therefore, diffusion of scientific ideas across cultural boundaries (the "internationality" of science) has been a normative constituent of scientific growth.

The general thrust of Spanish historiography has been to regard the phenomenon of scientific translation as symbolic of what was most idiosyncratic about the medieval Spanish experience: the convivencia (to use Castro's term) of the three religions. This is a significant commentary on the current historiographical perspective, because diffusion is not only normal, but necessary, in order for science to develop.

As a movement of the passage of ideas from east to west, the diffusion of science closely parallels that of technology, with the distinction that the Chinese terminus is diminished in importance. Chinese culture, so productive as a source of technological innovation in the West, did not diffuse its theoretical ideas. This role was to a certain extent filled by India (in mathematics and astronomy) and Persia, but the most active center was the Arab-speaking East itself, where, especially during early 'Abbâsid times, a vast corpus of Greek scientific and philosophical writings was translated into Arabic, sometimes through a Syriac intermediary.

In contrast to the history of technological diffusion, the agencies and mechanisms of which often seem so problematical, the broad contours of the scientific movement present no great difficulties of interpretation. The cultural anonymity prevalent in the passage of so many techniques was largely obviated, in the case of science, by the conscious perpetuation of traditions of diffusion in written texts. Thus ibn Sâ'id al-Andalusî, author of an eleventh-century survey of the scientific production of various civilizations (really a primitive historical sociology of science in the Islamic world), devotes chapters to Indian, Persian, and Greek science, specifying those elements which had passed into the Islamic corpus. He is able to [252] trace the passage of the Indian astronomical tables known as the Sindhind into the corpus of Arabic science, through Persian intermediaries.\(^{(7)}\)

It was characteristic of medieval science that unified bodies of scientific knowledge -- cosmographies, in fact -- were diffused in toto (the encyclopedia and the summa are typical products of this process). The diffusion of the corpus thus can be viewed as a holistic process, although certainly the diffusion of individual elements can also be traced. The process by which Greek science passed to the Arabs and was worked into a new synthesis, and the later process, whereby the Arabic synthesis itself was transmitted to the Latin West, were virtually identical in structure: in each instance, classical texts were synthesized and systematized through a process of translation and commentary, which included the addition of new elements (in the form of criticism, theoretical innovations, incorporation of new observations), forming a new corpus which could then be transmitted through a further phase of translation and synthesis.

Although general barriers appear to have existed (e.g., Muslim qualms about Greek rationalism, Western fears of Islamic sorcery), in neither instance were these strong enough to have affected anything more substantial than delaying actions. Forces which hastened the diffusion of certain elements within the corpus and barriers which delayed the transmission of others seem to have been operative, but are not, as yet, well understood. For example, the extremely rapid diffusion of the Sindhind, Indian numerals, and algebra must have been linked to demand arising from specific interests within Islamic society; navigation, calendrical calculation, the administrative needs of state bureaucracies, and so forth. Sometimes a theory diffused faster than its practical application: the decimal place-value theory underlying Indian numerals was known to mathematicians long before
businessmen started using them in commercial transactions. Sometimes, and Indian numerals again provide the example, a partial barrier had to be averted before full acceptance of the idea: the Indian method of calculating by writing numbers on a dust board was overly associated with the way astrologers cast horoscopes and so had to be adapted, in the tenth century, to writing on paper with ink. Moreover, the spread of certain innovations seems to have been impeded by the persistence of older scientific methods. Thus, al-Battânî's late ninth-century application of the principle of orthographic projection to achieve new solutions in spherical trigonometry did not reach Europe until the fifteenth century. (8)

3. The Social Bases of Transmission

The process of scientific interchange is predicated upon the emergence of concrete networks of scientific communication ("schools") within the various disciplines. The earliest such network to appear was the group of astronomers and mathematicians associated with Maslama of Madrid (d. ca. 1007). The creation by Maslama of a "school" of astronomers constituted by his own disciples and their students marks the beginning of science as an organized activity in al-Andalus. Maslama, according to Sā'id al-Andalusî, was the best mathematician of his time, applying himself to the observation of the stars and to the study of Ptolemy's Almagest. He wrote a summary of al-Battânî's zij, or astronomical tables, and refined the works of al-Khwârizmî, substituting the era of the Hejira for that of the Persians but without correcting any of the great mathematician's errors. All of Maslama's students adopted his concerns and worked within the disciplinary framework that he established; all immersed themselves in the works of al-Khwârizmî; all commented on the uses of the Sindhind and the astrolabe. The students of Maslama, as enumerated by Sâ'id al-Andalusî, and their students are enumerated in Figure 4. All those for whom no other field is mentioned cultivated mathematics in the sense conveyed in al-Khwârizmî's or al-Fârâbî's classifications of the sciences, with astronomy subsumed within the rubric of mathematics. Note the dispersion of members of the school to virtually every important Taifa capital, where they formed autonomous clusters interlinked by virtue of master-student relationships. Thus 'Abd Allâh b. Ahmad, a student of ibn Bargûth's who lived in Zaragoza, was involved in a polemic with Abû Muslim b. Khalûd of Seville, concerning errors in the movements of the stars reflected in the Sindhind. (9)

Similar patterns of communication, although less formally constructed, are noted in the Andalusî school of agronomists of the mid-eleventh and early twelfth centuries. The early nucleus of the school formed in Toledo, where ibn Wâfîd was employed in the royal garden of al-Ma'mûn. After the conquest of the city in 1085, ibn Wâfîd's student ibn Luengo and his colleague in the royal garden Ibn Bassâl removed to Seville, where they came into contact with another nucleus of agronomists, ibn al-Hajjâj, Abû'l-Khayr, and the mysterious "anonymous botanist" of Seville (studied by Asín Palacios), as well as al-Tignarî of Granada. The pattern of their personal contracts and intercitations is reproduced in Figure 5 and [256] illustrates the kind of complex network that was bound to underlie the "dense climate of botanical study and experimentation" described by J. M. Millás. (10)

The same kind of connections, more concentrated spatially, underlay the work of the great twelfth-century school of Aristotelian philosophers, centered mainly in Seville. The axial figure of the school was the Tufayl (d. 1185), linked to his teacher ibn Bâjja (d. 1139), and to a cluster of contemporaries with whom he met informally in Seville, a group which included ibn Rushd (Averroes) (d. 1198) and ibn Zuhr (d. 1162).

Groups involved in translation were more cosmopolitan but structured along the same lines. It should be stressed that, in the medieval milieu, translation was by no means a mechanical or uncreative function. It was one of a number of things a scientist did -- one of the most important and creative of scientific functions, particularly if it came early in the process of diffusion and synthesis. Thus typical
figures of that stage -- such as Hunayn b. Ishâq (in ninth-century Baghdad) or John of Seville and Abraham bar Hiyyâ’ in twelfth-century Spain -- both translated and wrote original scientific works, the latter highly colored by their work in translation. It is this generation of scholars that makes the largest contribution to the creation of a new scientific vocabulary, in which the work of synthesis can be articulated, and which also substantially selects those areas of the transmitted work which will form the basis of the new synthesis.

An example of an Andalusi group involved with translation is a circle of men interested in botany and pharmacology in the court of ’Abd al-Rahmân III and patronized by the Jewish physician Hasdây ibn Shaprût. This was the group entrusted with the evaluation of a Greek manuscript of the *Materia Medica* of Dioscorides sent by the Byzantine emperor as a gift to the Caliph in 948/949. Although translation was not the purpose of their research (they had available Stephan ibn Basîl's Arabic translation, as revised by Hunayn, and were concerned only with elaborating an Andalusi nomenclature, including Romance variations of plant names, in order to adapt Hunayn's text to Iberian biogeography), the Cordoban scholars took pains to include colleagues with linguistic accomplishments in their group. On request of the Caliph, a Byzantine monk, Nicholas, was dispatched in 951/952, and he collaborated with a Greek-speaking Sicilian Arab, five Andalusis, and ostensibly Hasdây himself. Roughly the same group was still functioning during the reign of al-Hakam, and was joined at that time by ibn Juljul, physician and pharmacologist, who continued [257] to work on materia medica, producing a Treatise (*Maqâla*) on Dioscorides containing his personal synthesis. This group of naturalists patronized by the Caliph was well-known for its Hellenizing interests, and Vernet assumes that Maslama of Madrid was associated with them as a young man. (11)

The "schools of translators" of twelfth and thirteenth-century Spain likewise formed cohesive groups with clearly identifiable lines of intercommunication. The important group of the mid-twelfth century, which included Hugh of Santalla, John of Seville, Domingo Gundisalvo (González), Gerard of Cremona, Plato of Tivoli, Rudolph of Bruges, and Hermann of Carinthia, worked in dispersed foci but remained in contact with the axial center of Toledo. As Richard Lemay points out, with the exception of Hugh of Santalla, a Spanish priest who worked alone in Tarazona, all these translators knew one another, exchanged views, shared the same methodology of translation and synthesis, and responded to the demands of a specific, and substantially the same, reading public. The patterns of intercitation (Plato of Tivoli's dedications to ibn Dâwûd and John of Seville; Rudolph of Bruges' to Hermann of Carinthia and ibn Dâwûd; and so forth) substantiate this assertion.(12) Alfonso the Wise's innovation, the following century, was to concentrate the work of the scholars in one center, Toledo, and to regularize research procedures by instituting a greater division of labor (there were researchers -- ayuntadores -- as well as translators).

Although numerous translators from Arabic into Latin worked alone, the usual *modus operandi* was for two scholars to work in tandem, a practice which lent characteristic social coloring to the process. The basic procedure was for one scholar to translate aloud from the Arabic text into the vernacular and for the second to translate from the vernacular, producing a Latin draft. Thus John of Seville characterized the translation of the *De Anima* of ibn Sîna: "The book ... was translated from Arabic, myself speaking the vernacular word by word, and the archdeacon Dominic converting each into Latin."(13) Frequently, the translator from Arabic into Castilian (or Catalan) was a Jew (or a converted Jew, as is probable in the case of John of Seville in which case the other member of the team would be a Christian, typically a cleric. Thus ibn Dâwûd worked with Gundisalvo; Abraham bar Hiyya probably translated with Plato of Tivoli; among Alfonso the Wise's collaborators, Judah Mosca and the priest Garci Pérez translated the *Lapidario*, and the *Libro de la ochava* [258] *esfera* was the work of Yehuda Cohen (el Cohenenso) and Guillen Arremon Daspa. Gerard of Cremona worked with a Mozarab named Galippus, who may merit greater recognition than he has generally received.
The place of Jews in this scheme is obvious: many were trilingual, knowing Hebrew, Arabic, and a romance language. Jews had indeed been accustomed to translate from Arabic into Hebrew, not a difficult task, given the linguistic and semantic similarities between the two languages, or to write in Judeo-Arabic (Arabic written in Hebrew characters). In the latter case, they were able to create a flexible medium for scientific and philosophical expression. This fitted them ideally for the work of translation, which involved the creation in the vernacular and in Latin of virtually an entire new scientific language (particularly in astronomy, where Arab scientists had vastly enlarged the range of observational data, and mathematics, particularly algebra, where the translations were conduits of methodologies unknown in the Latin tradition). For similar reasons, converted Jews -- still bilingual, but educated in Latin -- felt less bound by Latin conventions. No doubt one can agree with Américo Castro that Jews played an influential role in the creation of a Castilian language that could be used as a vehicle for philosophical and scientific thought. However, this is probably more owing to their biculturalism and to their ability to transmute Arabic into a number of different forms than to their supposed religiously motivated hostility to Latin. In any case, Jewish translations into Castilian became committed to writing when Alfonso the Wise assigned to translating sessions an additional scribe to write down a Castilian draft as well as the customary one to write down the Latin. Other Alfonsine scholars, such as Isaac ibn Sid, also composed scientific treatises in the vernacular languages.  

Science, then, was not in evidence as an organized activity in medieval Spain until the mid-tenth century, the direct reflection of the institutionalization of education in al-Andalus in response to the explosive wave of conversions. One would in consequence expect *muwallads* to be visible amongst these early circles of naturalists. Considering the physicians in the court of al-Hakam II, one notes a number of men who were the children or grandchildren of converts of the late ninth or early tenth century; ibn Juljul (whose father's name was Hasan, a typical secondgeneration *muwallad* name); Ahmad b. Hakam b. Hafṣūn, whose grandfather would also appear a convert; and 'Arîb b. Sa'd al-Kâtib al-Qurtubi, author of the *Calendar of Córdoba*. A similar case is Yahya b. Ishaq, a [259] physician in the court of 'Abd al-Rahmân III, whose father had been a prominent Christian doctor in the epoch of the emir 'Abd Allah.  

An indirect corroboration of the thickening of scientific networks within the country is the observation that, on the whole, fewer Andalusis traveled east in search of knowledge in the tenth century than did in the ninth. Before the formation of Andalusi scientific schools, scientific knowledge was imported from the East, through the agency of Andalusi scholars who went there to study. Before the impulse given the study of pharmacology by the gift of the Dioscorides manuscript, for example, Andalusi pharmacological students were generally trained in Baghdad. From the same city, 'Abbâs b. Fîrnis is said to have brought the *Sindhind* first to al-Andalus, in the late ninth century. In succeeding centuries, Andalusi scholars were still much in evidence in the East, as they maintained scholarly communication with the far-flung scientific community of the Islamic world. Thus, Maslama's student al-Kirmânî had also studied as far to the east as Harrân in northern Iraq (now in Turkey). In the eleventh century, ibn Bassâl gathered agronomical lore in Sicily, Egypt, and Khurasân and, towards the end of the century, Abûl-Salt, an eclectic scholar from Denia who wrote on philosophy, astronomy, and pharmacology, studied in Alexandria and Cairo. In the thirteenth century Yahya ibn Abî Shukr al-Andalusî worked at the Mongol observatory at Marâghah (Azerbaijan) and wrote reports on Chinese astronomical and calendrical observations.  

The demand for scientific information was a function of the differential development of scientific centers. When the Islamic East had scientific centers and the West had none, Andalusi scholars had to travel in order to learn. The same is true with regard to the later quest of the Latin West, including Christian Spain, for Islamic science. Juan Vernet has shown that the numbers of scientists in the Christian West and in the Islamic world as a whole did not reach parity until the second half of the
eleventh century (Figure 6). Parity in quality of research was achieved at roughly the same moment as equality in numbers. The lowering of Islamic superiority from an order of nine-to-one in the ninth century to three-to-one in the late tenth century explains why the initial demand for Arab science came when it did, in Catalonia in the last quarter of the century. The shift in the balance of scientific production in favor of the West accounts for the demand for translations which became acute in the half-century directly following the establishment of parity.

Growth in numbers of scientists brought a corresponding thickening of linkages among them, a process we have described as the formation of networks of scientific communication. Frequently, such clusters enjoyed the protection of a king or lord, and the most important scientific circles all had such patronage. The model for such enterprises was perhaps the famous "academy"-- Dâral-hikma -- of the 'Abbâsid caliph al-Ma'mûn, where scientific observation and translation were encouraged on an organized basis. In al-Andalus, one might mention 'Abd al-Rahmân III's support of botanists and pharmacologists, al-Hakam II's patronage of astronomy (not the least among the benefits this monarch could offer was his magnificent library, containing numerous works of Hellenic inspiration later burned by al-Mansûr); the work of the agronomists for the kings of Toledo and Seville; the support of Almohad rulers for Andalusî Aristotelians; and Alfonso the Wise's encouragement of both translation and scientific synthesis. With regard to the latter, Menéndez Pidal's suggestion that Alfonso was imitating the 'Taifa kings is a moot point. There was ample precedent among his own progenitors for such largesse. The [261] princess Teresa, for example, daughter of Alfonso VI and mother of Alfonso Henries, discussed physiology with John of Seville, who, in turn, dedicated some medical translations to her. Knowledge-loving kings frequently had scholarly conversations with their protégés; Alfonso's intervention was more direct and structured. He personally determined research strategies not only by commissioning work (both translations and original treatises) but by supervising the research groups in regular conferences (18).

4. The Unity of Scientific Knowledge

The hallmark of medieval science in Spain was a basic identity in aims and techniques among Muslim and Christian naturalists. At the foundation of the whole enterprise was a pervasive Aristotelianism, inflected with Neoplatonic concepts of a hierarchical chain of being which knitted the diverse disciplinary threads of scientific inquiry into a unified cosmology, presenting a structured conception of nature compatible in most respects both with Islamic and Christian theology. (In comparative perspective, it is well to note that both religions tended to have difficulty with the same problems, for example, the eternity of the universe, and that those who accepted the rationalist outlook constituted a minority of educated people.)

Aristotelian cosmology as a general basis for scientific explanation manifested itself most typically in astrological works through which, according to Lemay, the initial diffusion of the Aristotelian corpus, as synthesized by Muslim scholars, was received in the Christian West. Thus the earliest Aristotelians in the Christian West were not scholars interested in philosophy, but, rather, naturalists who looked to astrology for theoretical orientation. Astrology was viewed by such thinkers as the highest natural science, based upon the central Aristotelian propositions that celestial motion accounts for all physical activities in the universe and, therefore, that the motion of celestial bodies influences earthly ones and causes their motion. Astrology, as the science of "judgments" (the medieval iudizios) was closely related to astronomy proper, which involved the observation of celestial movements; the practice of the two was intertwined. Those who rejected the "judicial" (i.e., prognosticatory) aspects of astrology did not necessarily reject it as a general explanatory system (19).

The assumption that bodies interconnected in the great chain of being [262] had mutual influence over each other accounted for the blurring of boundaries between observational astronomy and interpretive
astrology, between alchemical technology and its mystically tinged theory, and between science and magic generally. Because it was the place of transit of Arabic astrology, Spain, and Toledo in particular, became associated with "black magic" in the European popular imagination, notably in the thirteenth century. Throughout Western Europe *ars or scientia toletana* became synonymous with magic -- a local specialty, just as Almería stood for fine cloth. Thus Caesar of Heisterbach tells the story of two Swabians studying the *arte nigromantica* in Toledo, just as later Don Juan Manuel (nephew of Alfonso the Wise) would describe the fictitious Dean of Santiago as wanting to learn the art of necromancy and, hearing that Yllan of Toledo knew more about it than anyone else in the world, he came to Toledo to learn that science. But the distinction between science and magic was a subtle one: both partook of the classical theory of the elements and of notions of celestial harmony which indicated that creation was ordered and that matter could be transformed in accordance with celestial cosmology. Science and magic were blurred in the Islamic world, according to A. C. Crombie, because the Muslim approach directed the search for natural knowledge into those areas that would yield the most power over nature. Yet I doubt if Muslims emphasized this value more highly than did Christians. As Lynn White has argued in numerous essays, medieval Christians eagerly embraced technologies which aided in the fulfillment of the Biblical commandment to subdue the earth. Alchemy and astrology were no less integral in Christian than in Muslim science.

Perceptions were muddled. Gerbert of Aurillac was described by Ademar of Chabannes as having travelled to Córdoba for the sake of knowledge -- *causa sophiae*. But throughout the twelfth century it was also said that Gerbert had practiced Saracen divinations and incantations in Seville and Toledo and had stolen magic secrets from Muslim necromancers. The discrepancy between the towns mentioned is significant. The learned source (Ademar) correctly judges Córdoba to be the center of Islamic learning in the late tenth century; the popular legends reflect the aura of Toledo in the heyday of the movement of translation.

As my mentor Samuel Waxman concluded a half century ago, there was a marked tendency in the later Middle Ages "to associate all learning and learned men, regardless of their epoch, with Toledo." Late in the thirteenth century, a member of Alfonso the Wise's scientific circle, Gil de Zamora, summed up the scientific movement in retrospect, citing magic and science as if the two were synonymous: "In the magical art and the science of astrology there were few more learned than Spanish philosophers. So declare the books and tables of Toledo, where almost all philosophical books were translated from Arabic into Latin. Therefore John of Seville and some others in Seville and Murcia stood out as the most learned in astrology." Toledo thus became the palpable symbol for the scientific enterprise and assumed all its ancillary connotations as well. In point of fact, however, scientific activity was dispersed throughout the peninsula, with Toledo playing, in the twelfth and thirteenth centuries, an axial or coordinating role. More generally, Arabic itself was regarded in the Christian scholarly world as a language in which secrets of the natural world were hidden. Arnald of Vilanova remarked that he had read in the Arabic language the entire necromantic literature, which, with critical discernment, he regarded as a false doctrine.

Aristotelian notions regarding the order of the universe and, in biological sciences, Hippocratean and Galenic theories of the correlation of humors (dependent in turn on classical notions of the four elements of air, water, fire, and earth, and their interrelationship) recurred at all levels of thinking about the natural world. Easily noted are the intrusions of classical scientific theory in popularizing texts of the thirteenth century: for example, in the Hispano-Magribi cookbook edited by Huici Miranda, the recipes are interrupted by several pages of Galenic digestion theory noting the necessity of balancing different kinds of food in a meal according to the principles of correlation of the elements. Likewise, the *Lapidario* of Alfonso X, a descriptive enumeration of minerals containing numerous fabulous elements, translated from an Arabic manuscript, begins with an observation from Aristotle that all
things are ordered according to the movements of celestial bodies, which accounts for the arrangement according to the signs of the zodiac of the rocks described.\(^{(25)}\)

The theoretical basis of the works of the Andalusi agronomists has been described by Lucie Bolens as an eclectic Aristotelianism, transmitted through Galenic medicine, to which they recurred whenever they wished to provide a theoretical framework for their experiments or observations. Since earth is cold and dry by nature, it must be made warm and humid in order to render it susceptible to cultivation. Plowing restores heat to the soil, modifying its basic nature, as does the application of fertilizers, which were classified according to heat and humidity. Ash could be [264] applied, for example, to temper the excessive heat or moisture of a given fertilizing substance. Rain and irrigation water were viewed as balancing mechanisms, reconciling the nature of fire with that of earth to attain a harmonious equilibrium by adding moisture and cooling the earth at the same time. Thus, Bolens concludes, the Andalusi agronomists made Aristotelian philosophy operative by measuring its principles against their own observations, which were then cast in Aristotelian language. In these works, natural knowledge was liberated from the Neoplatonic esoterism prevalent in the science of the Islamic East.

The sources of the agronomic school were eclectic in the extreme: Aristotle, Columella (who was known directly from the Latin tradition), a variety of late imperial and Byzantine sources, as well as the Nabatean Agriculture -- ibn Wahshiyya's ninth-century compilation of eastern agronomical traditions and practices.\(^{(26)}\) Andalusi agronomical lore passed on to Christian Spain in a number of medieval translations (for example, the fifteenth-century Castilian version of ibn Wâfid studied by Millás) and the sixteenth-century agricultural treatise of Gabriel Alonso de Herrera. These notions, so widely diffused that they passed into folklore, were transmitted by a variety of agencies, both formal (eastern and western manuscript traditions) and non-formal (generalized practice of cultivators).

The development of astronomy was somewhat less eclectic. Medieval Islamic astronomy was mainly a continuance of the Hellenistic norms of Ptolemy, improved by the addition of new and more precise observational data as well as the use of Indian trigonometric techniques. According to this system, the earth remains at rest in the center of eight spheres, the last of which contains the planets and revolves from east to west daily. In general the planets proceed in the same direction as the stars, but some appear at times to move backwards. Andalusi and other Muslim astronomers were much concerned with establishing with accurate calculations these relatively minor anomalies of planetary motion, in order to enhance the precision of astrological and calendrical computation. Thus there is a great deal of discussion, much of it polemical, concerning the prograde and retrograde motion of planets (about which there was little agreement, except to contradict the Ptolemaic notion of a constant precession), and the trepidation or oscillation of the eighth sphere. These intricacies were explained by a complicated system of epicycles and eccentrics in order to "save the phenomena" by whatever contrivance.\(^{(27)}\)

[265] As a practical science, then, astronomy was centered on the use and refinement of astronomical tables and of certain instruments such as the astrolabe and the armillary sphere, designed to achieve precision in observation and calculation. The family of medieval Arabic astronomical tables (\(z\=j\acute{a}t\); singular, \(z\=j\)), which were used to calculate planetary motion, eclipses, solar declination, as well as various trigonometric functions, were descended from Indian tables called Siddhanta. They were first brought by an Indian traveller to the court of al-Mansûr in Baghdad, where they were translated into Arabic under the title \(Z\=j\) \(a\=l\)-\(s\=i\)ndhind (the latter word yields an evocative pun in Arabic, combining the names of the Sind, the region around Karachi, and Hind, India). A number of scholars revised these tables, including al-Khwârizmî (first-half ninth century), who produced a version with the same title, adding some material from Ptolemy but not any original observations.
E. S. Kennedy has studied the entire genealogy of \textit{zijat} as continuous elaborations on basic themes of Ptolemaic astronomy. According to Kennedy's synoptic table, the Andalusi family of \textit{zijat} betrays a concentration of astronomic activity in the eleventh and twelfth centuries, bracketed by two periods of eastern preeminence centered in Iraq and Persia.\(^{(28)}\) The shifting geographical focus is significant. In astronomy, as in other sciences, ideas flowed eastward to al-Andalus until the twelfth century, after which the direction reversed itself, reflecting the coming of age of Andalusi science.

Al-Khwârizmî's \textit{zij} was the one revised by Maslama of Madrid (who adopted it to the era of the Hejira) and possibly by ibn al-Saffâr. Parts of this version concerning lunar motion were incorporated into a treatise by Pedro Alfonso (apparently written in Arabic), which was translated into Latin around 1110 by Walcher of Malvern; the entire work was rendered into Latin by 1126 by Adelard of Bath.

Al-Battânî, a ninth-century Iraqi astronomer, also compiled an influential \textit{zij}, more eclectic and innovative (he included his own observations) than al-Khwârizmî's. Al-Battânî's tables were very influential in medieval Spain. They were cited by bar Hiyyâ' and ibn 'Ezrâ and translated into Latin by the former's colleague Plato of Tivoli and into Castilian on orders of Alfonso the Wise. Nevertheless, the excellence of al-Battânî did not diminish either the popularity or the influence of al-Khwârizmî's tables, which were diffused in the West not only through Adelard's translation, but also through the so-called Toletan Tables. These latter were a [266] new synthesis, based on the work of al-Zarqâl (Azarquiel, d. 1100) and the group of astronomers in Toledo patronized by the judge ibn Sā'id, and reflected the influence of al-Khwârizmî, as revised by Maslama, of al-Battânî, and of Thâbit ibn Qurra's theory of trepidation. Al-Zarqâl also wrote a treatise on the movement of the fixed stars, a discussion of theories regarding the solar year implicit in the \textit{Sindhind} and which was critical of ibn al-Samh's treatment of the same issue. Al-Zarqâl and his associates constructed refined astrolabes for observing the sun's movement, on the basis of which they were able to state that the Persians, Indians, and their Muslim followers had been deficient not in observation but because of errors in the root used for calculations. The Toletan Tables were translated into Latin near the end of the twelfth century by Gerard of Cremona. Alfonso the Wise's contribution to this tradition, the \textit{Tablas alfonsinas}, were based on al-Zarqâl's work but included numerous corrections and additions based on observations carried out by his court astronomers in Toledo between 1252 and 1262. Abraham Zacut, whose solar declination tables were used by explorers of the sixteenth century to calculate latitudes, followed al-Zarqâl on planetary and solar motion and said that both his and the Alfonsine tables erred on the nature of prograde and retrograde motion.\(^{(29)}\)

The astrolabe was a composite astronomical instrument which performed a variety of operations. The most common form, the planispheric astrolabe, had on its front a zodiacal circle and a disc (\textit{safîha}; \textit{azafea}, in medieval Castilian) designed for a specific geographical latitude, with a stereographic projection of the equator, the tropics, and the horizon. From this, various problems of spherical astronomy could be solved, the hour of the day measured, and horoscopes cast. The back of the instrument was divided into four quadrants, upon which the declination of the sun with respect to its observed height could be read directly (with the use of a sight or alidade), without the observer having to consult declination tables. This aspect was of immense significance to navigation since the latitude of a place could thereby be determined by the elevation of the sun, and vice versa. The quadrant with alidade also became a common surveying instrument.

The major contribution of Andalusi astronomers to the design of the astrolabe was the so-called "universal plate" (\textit{lámina universal}), generally associated with al-Zarqâl, who was perhaps inspired by the navigational chart of 'Ali ibn Khalaf, also of Toledo. This innovation, which avoided [267] the inconvenience of having to change the \textit{safîha} for each latitude, was perhaps a logical reflection of the general experience of Andalusi astronomers who, being located on the periphery of the Islamic scientific community, had perforce to adjust all tables and instruments to their own latitude before they
could proceed with observations. The universal plate was illustrated in the Alfonsine *Libros de saber de astronomia*, through which it became known in Europe, as did the armillary sphere.\(^{30}\)

The adjustment of the tools of classical astronomy to Iberian latitudes was also reflected in astrological lore, whereby signs of the zodiac became associated with specific Spanish towns or regions. An astrological treatise written by 'Ubayd Allâh al-Istîjî, a member of al-Zarqâl's circle, and which was later translated (and doubtless emended) by two Alfonsine astronomers, Jehuda b. Mosse and John Daspe, specified that Virgo had power over Córdoba, Cancer over Seville and Cádiz, Leo over Murcia, Valencia, and Barcelona, and so forth. This *Libro de las Cruces* also associated the power of individual planets with specific ethnic groups -- Jupiter with Christian Spaniards, Mars with Arabs, Saturn with Berbers, Venus with Franks. In this manner, the specific contours of medieval Iberian society could be accommodated within the classical cosmology.\(^{31}\)

Calendrical calculation was the work of specialized astronomers called, in the Islamic world, *ahl al-hi'sâb* ("people of computation"). The calendrical system employed was an astrological one of Indian inspiration which tracked the course of the sun through twenty-eight lunar mansions (*anwâ'†), which were held to determine the nature of the progression of the seasons and the agricultural year. Actually the Muslims maintained a dual calendrical system: a lunar one for religious purposes, standard throughout the Islamic world, and a solar one for agricultural use, which bore regional inflections, the Arabs adopting the local calendar to their needs. Representative of the latter is the Calendar of Córdoba, the *Kitâb al-anwâ'†*, compiled in the ninth century by 'Arîb b. Sa'd. Under each month of the Christian calendar there follows the name of the month in Syriac and Coptic (two other solar calendars of Christian origin), and the number of days in the month, its sign of the zodiac, and the mansions through which the sun passes during it. (Note that Andalusi astrolabes also used the Julian calendar, allowing astronomers to provide calculations for both solar and lunar calendars.) Then follows information relating to classical element theory and related notions of humoral pathology: the elemental nature of the month, its "conformity," and the controlling[268] humor. Thus, January was cold and humid by nature; its conformity was the nature of water, and lymph was the reigning humor. In contrast, August was hot and dry, with the nature of fire, and yellow bile the dominant humor. This system provided a framework for dietary and medical considerations, as well as an indication of what crops were favored by the astrological conjunction. Also included are astronomical calculations, such as the average length of day and night, the times of sunrise and sunset, the height of the sun at noon, and so forth.\(^{32}\) This scheme, of course, encompassed many of the same theories as appeared in the work of the agronomists and was an interpretation for a non-scholarly reader of the same cosmology that we have been discussing.

In sharp contrast to the prevailing Ptolemaic wisdom were the exaggerated, purist Aristotelian views of ibn Bâjja (known in the Latin West as Avempace), adopted and further elaborated by his followers ibn Tufayl (Abubacer), ibn Rushd (Averroes), and al-Bitrûjî (Alpetragius). At the core of their astronomical theory was a rejection of the Ptolemaic system of explaining the observed irregularity of planetary motion by movable eccentrics and epicycles, an explanation which, according to ibn Rushd, may provide an adequate mathematical model but one which in no way corresponds to physical reality. The methodology of saving the phenomena had to be abandoned in favor of Aristotelian homocentric spheres (a less accurate explanation than Ptolemy's, in fact) because, in ibn Rushd's view, the entire Aristotelian cosmology had to be accepted in the interests of philosophical coherence. In al-Bitrûjî, the celestial spheres revolve around different axes, producing a spiral motion which explains the observed irregularity of planetary orbits.\(^{33}\) The conflict between the two systems became general among European scientists after Michael Scot translated al-Bitrûjî's *Liber Astronomiae* (*Kitâb fîl-hay'a*) at Toledo in 1217.
5. Patterns of Cultural Influence

Although the growth of medieval science was predicated upon diffusion of ideas from east to west, these ideas were by no means received uniformly. Here we will first examine three disciplines- arithmetic, chemistry, and pharmacology -- in which the Islamic imprint upon Christian thought was marked; but in each case the pattern of intercultural influence was somewhat different, highlighting distinct aspects of the process of diffusion: variation and selectivity in the case of arithmetic, the screening effect of translation in the case of chemistry, and cultural adaptation in the case of pharmacology. Finally, the entire movement of transmission will be considered in its totality, particularly as regards the overall organization of the natural sciences.

It is well known that the Arabs transmitted both Indian numerals and the decimal place-value idea to the medieval West. There were two families of number forms, Hindi or Indian in the Islamic East, ghubâr or "dust numerals" (from the practice of performing numerical operations on dust boards) in the West. In fact, the names were frequently interchanged and the forms of the numbers were chaotically intermixed. Adding to the complexity of the process, the place concept and the number forms diffused at different rates. Indian numerals were known in the East in the eighth century and turned up in Christian Spain in the ninth -- in the Oviedo miscellany, which has marginal notes in Arabic with Indian numerals, including the zero. The Albeldense codex of 976 contains Indian numerals from one to nine, written from right to left. Mozarab scribes appear to have learned the numerals a century before their northern correligionaries, but did not understand positioning. In any case, these examples were precocious because the Indian system was not very widely used at this time by Arab scholars themselves, who preferred a notation system of Greek inspiration, whereby letters were assigned numerical value.

The transmission of Indian numerals bears a strong Toletan stamp. In Toledo, al-Khwârizmî’s book on the Indian style of calculation (hisâb al-hind) was translated into Latin under the title Algoritmi de numero indorum ("algorithm" being a bastardization of al-Khwârizmî’s name). The numerals themselves became so strongly identified with the translation movement centered in Toledo that they were known in Europe as Toletan numbers -- toletane figure. The presence or absence of the zero in medieval manuscripts is the strongest indication of whether or not the place-value concept was known. The term "zero" itself comes from Arabic sifr ("void"). Sifr was Latinized as zephirum and then, since among Castilian speakers f was confused with h and was often lost, zephirum gave rise to zero. Through a parallel transmission, sifr gives Spanish cifra, English "cipher," and so forth.

The emergence of standard notations for each number yields insight into the process of cultural diffusion in medieval Spain. Gonzalo Menéndez Pidal demonstrates that the nine figures themselves were in a continual state of change throughout the middle ages; for example, a shape similar to our modern 2 was used at various times in writing 4 and 8. The same author hypothesizes that there was more variation in numeral form in Spain than in other European countries because Spain was a focus of multiple innovations. This conclusion is extremely perceptive and, without doubt, accurate. In the constantly shifting cultural milieu of medieval Iberia there were no strong institutional supports for any standard set of numerals. Moreover, the processes of calculation in Christian Spain were generally individualized and private, with the results frequently given in Roman numerals. Therefore, numeral form was a personal choice. The factors affecting selection are not understood but, according to Richard Lemay, the 4, 5, 6, 7, 8, and 0 as we now know them all evolved in medieval Spain.

The relationship between practical chemistry and alchemy parallels that between astronomy and astrology, alchemy being described by Islamic alchemists as "inferior astronomy," the seven basic metals corresponding to the seven planets. According to Jâbir, gold was the most perfect metal because in it the four qualities were perfectly balanced, just as the four humors were in a healthy individual. The
basic practices of medieval alchemists were processes of distillation, sublimation, and cupellation, used to purify or amalgamate mineral substances. Certain of these processes were not only complex but had economic significance as well. Cupellation procedures, whereby gold and silver were extracted from alloys with baser substances, had obvious ramifications in the monetary economy of the medieval Islamic world. The hardware used in these practices (such as the oven used in the reduction of cinnabar to mercury, *shabîka* in Arabic, yielding the Arabism *xabeca*), as well as the most common substances employed (for example, the "Seven Spirits") were known in medieval Castilian by mainly Arabic terms (*Table 5*), a strong indication of the almost total reliance of Christian upon Muslim chemistry.

The *theory* underlying alchemical practice, however, aside from its astrological or cosmological implications and associations, was the result of a quite different process, highly colored by the mechanics of transmission itself. The alchemical tradition, according to M. P. Crosland, was "plagued by errors in the copying and translation of texts and, more fundamentally, by semantic changes," so that it was never clear whether an alchemical term stood for an object or for the idea of that object. Thus, as a method for transforming base metals into gold, alchemy was largely the result of errors accrued during the transmission of ideas from one language or culture to another. To the Alexandrine alchemists, "gold" meant any metal or alloy so colored (it was the quality associated with the substance, not the substance itself), and the original sense of transmutation was that of dipping, as when dyeing a fabric. Alchemical theory therefore was the creation of the process of transmission and translation and was constructed upon misunderstood, misconstrued ideas which receded further from their original sense with each new act of transmission. Alchemy was an extreme case, but all scientific information was susceptible to analogous terminological and semantic distortion.

Medieval pharmacological theory, like medieval medicine generally in Islam and the West alike, took the form of an extended commentary upon Galen, comprehended within the broader structure of Aristotelian cosmology. According to Galen, the humoral imbalance which constituted illness had to be treated by administering to the patient a drug equal in strength (on a scale of four degrees) but opposite in quality to the imbalanced complexion it was supposed to cure. But the Galenic theory was of no practical use to pharmacologists so long as the intensive effect of a drug could not be measured quantitatively. Arab medical writers attacked Galen on the grounds that each individual differed in complexion (thereby negating the necessity for a unified theory of pharmacology), but they were nonetheless able to improve the theory by formulating precise mathematical relationships between a medicine's weight and its therapeutic value. Thus al-Kindî, in a treatise translated by Gerard of Cremona under the title *Quia primos*, asserted that the complexion of a compound medicine could be mathematically derived from the qualities and degrees of its component samples and that there was a geometrical relationship between increasing quantity and degree of effectiveness.

Al-Kindî's work had been known in the West for a century before its value was appreciated, or even understood. It was assimilated and made palatable to Christian physicians by Arnald of Vilanova, by a process of synthesis admirably explicated by Michael R. McVaugh, whose analysis I follow here. Arnald was conversant with Arabic and translated a number of medical works: the *De rigore* of Galen, Abu'l-Salt's treatise on simples, and ibn Sina's *Liber de viribis cordis*, among others. Moreover, he used these works and others that he had read in Arabic, but had not translated, in his university lectures. In his treatise *Aphorismi de gradibus*, edited by McVaugh, Arnald accepted al-Kindî's views on the relationship between quantity and degree in formulating dosages, molded these together with ibn Rushd's notion of prime quantities, and with ideas on the role of fermentation (chemical reaction) in confecting a compound medicine from a mixture developed earlier by Peter of Spain and John of St. Armand, in order to form a unified theory of pharmaceutical action.

Thus far the mechanisms of cultural synthesis seem obvious: Arnald was able to read Arabic works available in Spain and to fit them to his own needs. But to understand the delay in the diffusion of al-
Kindî’s ideas is more difficult. McVaugh makes clear that Amald’s creativity lay not only in the pharmacological synthesis that he was able to achieve but also in the fact that he was able to make these notions intelligible to the Christian scientific community by locating them within a philosophical context relevant to dominant Western interests. Scholastic philosophers had been interested in the problem of qualitative change (as in such questions as whether, and how, charity might be said to increase) and [273] within this framework Arnald was able to interest others in the problem of how, for example, qualities like heat and cold might increase in the complexions of individuals or medicines.\(^{(37)}\)

In this discussion, a further dimension of the process of scientific diffusion is elucidated: even if the agencies of diffusion are abundantly present (Arabic manuscripts, translated versions, physicians who read Arabic), an idea may not diffuse unless it is congruent with the dominant modes of thought of the recipient culture. If incongruent (or apparently so) it must be stated in familiar terminology or placed within a recognized framework which makes it intelligible and renders its acceptance reasonable.

The impact of Islamic science on the West transcended the total of the elements diffused individually. This is particularly so when one considers that this impact set in motion a chain of events leading to the emergence of modern science. But in a more limited sphere, there was the creation of language in which the new scientific knowledge could be articulated, the semantic reality underlying that language, and, finally, a structural framework in which the natural sciences could continue to expand.

The nature of the act of translation imposed its own idiosyncratic effects. Some were purely mechanical: in the transmission of scientific names or technical terms seven Greek vowels had to be represented by only three in Arabic -- and these three had then to be accommodated to the five Latin vowels. Deformations were bound to occur. Words had to be supplied where none existed before; the obvious solution was to adopt the Arabic expression outright. Some of these words were the same as had been borrowed from the Greeks centuries before but which, under the influence of constant use, had been pressed through an Arabic mold. It was typical of scientific translation, those of Ripoll in the tenth century as well as the vastly more polished ones of Alfonso the Wise, that scientific narrative was larded with Arabic terms describing (1) instruments unknown in the Latin West or which had not been known in classical antiquity; (2) concepts which had been introduced into the corpus by the Arabs; and (3) descriptive names, such as those of stars and planets, which represented newly observed data. Larding with Arabic terms, typical particularly of the earlier phases of the translation movement, simply reflected the lack of cognate terms or concepts in the Latin tradition.

In later times, other problems arose, as the two cultures grew more familiar with one another, but were still unable to bridge semantic gaps. The early translators tended to maintain the grammatical structure of [274] Arabic intact in translations which were overly literal. (This explains how modern scholars are able to reconstruct lost Arabic originals from clumsy Latin translations.) An example of literalism is John of Seville's uniform translation of the Arabic preposition \textit{min} by Latin \textit{ex}. Both the Arabic and the Latin words certainly do mean "from," but the Arabic word has a variety of other senses (cause, relationship, etc.) and the result is translations at times baffling to the reader. Lemay, who provides this example, identifies such confusion with John's struggle to master a linguistic structure vastly different from his maternal Semitic one.\(^{(38)}\) The point could be made more generally: the radical difference between Romance and Semitic language groups caused inherent semantic problems in the process of translation.

The Alfonsine translators who were able on the whole to overcome the trammels of literalism (if they had not, they would have been unable to effect the creation of Castilian scientific prose, which was one of their major achievements) still were unable to escape certain semantic difficulties caused by a lack in Latin or Romance of abstract nouns so easily formed in the Semitic languages. In the Alfonsine works romance suffixes were freely used to create new nouns of abstraction. For the most part, such clumsy neologisms (Millás mentions ascensionario, circulario, appositario) did not pass into common usage.
But who can doubt that this process represented a stage in the maturation of Spanish Christian thought, whereby it became possible to encompass theoretical abstractions of scientific provenance within the structure of the Castilian language and mind?

The translators were, on the whole, scrupulous in their fidelity to the Arabic text, in keeping with the norms of literalism established by Boethius, who demanded a precise, word for word *(verbo ad verbum)* rendition. John of Seville was explicit about his task; he seems to have been aware of the mechanisms, function, and traditions of translating. He states that he does not always translate literally but attempts to do equal justice to both the meaning and the letter. All scholars who were translators *(ornnes sapientes qui fuere interpretes*, indicating, I think, the notion that the two activities -- scholarship and translation -- were closely intertwined) have done the same. In most instances, John avers that he has translated literally, lest he stray too far from the way of truth.

The mode of translation, with its slavish devotion to the text, as well as the choice of subjects translated, responded to the specific tastes and demands of the scholarly community. The Arabs, as inheritors of the classical tradition, were accorded the veneration owing to Greek and Latin authorities (although not without ambivalence -- some translators decried the prolixity of Arabic style, while Arnald of Vilanova freely altered ibn Rushd's ideas in order to defeat them and decried the dependence of Christian upon infidel scholarship). Western scholars were first interested in the more practical sciences: astronomy (with its calendrical and navigational uses), astrology, geometry, mathematics. Only later were philosophical subjects translated.

Not only was information belonging to discrete sciences transmitted, but also a system of arranging these data and viewing them as parts of an interrelated scheme. Therefore, as Richard McKeon asserts, the impact of scientific diffusion not only encompassed the sum of discrete elements transmitted but involved as well "the rearrangement of schemata which they shared and the modification of the data, methods, and truths organized in those schemata to new specifications and evidence." Here McKeon has in mind the modification of the structure of the Latin encyclopedia in consonance with norms elaborated in the Arabic encyclopedia. The emphasis was shifted from the significance of words (as in the *Etymologies* of Isidore of Seville) to the things described, thereby enlarging the explanatory horizons of the sciences through the infusion of new data, new methods, and an encompassing framework which stressed systematic research. Facts which had appeared in atomized form in the Latin encyclopedia could now be grouped within a structure under the norms transmitted from the Arabic encyclopedia.

A case in point is Gundisalvo's *De divisiones philosophiae*, which was instrumental in diffusing al-Fārābī's classification of the sciences in the West. This was not a simple translation on Gundisalvo's part but a recasting of the received structure of the sciences in the Western tradition to open it up to the inclusion of new disciplines. Following Fārābī, he included mathematics within the theoretical, rather than practical, sciences and then divided it into seven arts (one of which was geometry), each subdivided into theoretical and practical components. Practical geometry, in turn, was itself divided into three varieties, altimetry, planimetry, and cosimetry -- responding to the increasingly complex and specialized methodological and theoretical needs of astronomers, navigators, surveyors, master masons, and so forth. Where only one science had previously existed, a multiplicity now sprang up, as the classical quadrivium became too restrictive a framework within which to fit a proliferation of new specialties.

The distinct impression that one receives from viewing medieval science at the crossroads of civilization is that, in spite of the divergence in cultural values alleged to have divided Christendom from Islam, these values were considerably less divergent than is generally supposed. Perhaps science
is less hermetical and more "international" than other areas of culture. Historians of science would certainly have us believe that to be the case. But I doubt that this is true and that science is less inflected with distinctive cultural variations than is, say, art. Scholarly tradition has it that way, as well as the internal traditions of the scientific disciplines.

The preceding discussions of technology and science are sufficient to illustrate the complex patterns of cultural diffusion in early medieval Spain. Similar patterns could be established for art, architecture, or literature, manifesting analogous mechanisms and processes of transmission.

Notes for Chapter 8


2. See Millás, *Assaig*, and his other articles cited below, n. 5.


4. For the general point, see Carolly Erikson, *The Medieval Vision: Essays in History and Perception* (New York: Oxford University Press, 1976), p. 10. I am indebted to Professor Nancy Roelker for this reference, as well as for a perceptive evaluation of the relationship between medieval science and general culture.


12. Richard Lemay, "Dans l'Espagne du XIe siècle: Les traductions de l'Arabe au Latin," Annales, 18 (1963), 647-649. Lemay's sociological perceptions are insightful and valid, but I agree with C. Sánchez-Albornoz that he fails to prove his contention that John of Seville was the same person as John of Toledo and John ibn Dâwûd; "Observaciones a unas páginas de Lemay sobre los traductores toledanos," Cuadernos de Historia de España, 41-42 (1965), 313-324.


14. J. M. Millás Vallicrosa, "El literalismo de los traductores de la corte de Alfonso el Sabio," in Estudios sobre historia de la ciencia española, p. 356. Gonzalo Menéndez Pidal states that when the translator from Arabic was a Jew, the other member of the team had to be a Christian because Jews spoke an archaic dialect; "Cómo trabajaron las escuelas alfonsíes," Nueva Revista de Filología Hispánica, 5 (1951), 367. See also Castro, The Spaniards, p. 561. R. Menéndez Pidal sees the role of the Jews in the formation of literary Castilian as a more or less adventitious intrusion into a normal process of secularization; España, eslabón entre la cristiandad y el Islam (Madrid: Espasa-Calpe, 1956), pp. 52-53- Jews had played a similar polycultural role in al-Andalus, as when ibn Buklârish of Zaragoza composed tables of synonyms, including Romance variants, of different simples; Dubler, 'Materia Médica' de Dioscorides, I:52. Marcel Destombes points out that Andalusi Jews, when migrating to Christian Spain, played a role in the diffusion of Islamic scientific instruments; when they made instruments, they did not use Hebrew letters but formed them in Latin or had them translated (there is no case for aversion to Latin here); "La diffusion des instruments scientifiques du haut moyen âge au XVe siècle," Cahiers d'Histoire Mondiale, 10 (1966-67), 50-51.


16. Makkî, Aportaciones oriento, p. 280. See the discussion of scholarly travel in Chapter 9, below.


21. The episode from Juan Manuel is from El Conde Lucanor, exemplo XI (cited by Waxman,
Chapters on Magic, p. 28): the Dean "avia muy grant talante de saber el arte de la nigromancia. Et oyo dezir que don Yllan de Toledo sabia ende mas que ninguno que fuese en aquella sazon. Et porende vinose para Toledo para aprender de aquella sciencia."


38. Lemay, Abû Ma'shar, pp. 25, 26n.


40. Lemay, Abû Ma'shar, p. 21.

41. Thorndike, "John of Seville," p. 26 (paraphrased from Thorndike's translation); also, Lemay, Abû Ma'shar, pp. 27-28.

42. Lemay, Abû Ma'shar, p. 21; McVaugh, ed., Aphorismi de gradibus, pp. 113-115.


45. Ibid., pp. 183-187. McKeon is insistent that modern science emerged in the West only through contact with the Arabic tradition, the movement of translation causing an explosive reaction in twelfth- and thirteenth-century Europe.