

***ISLAMIC AND CHRISTIAN SPAIN
IN THE EARLY MIDDLE AGES***

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PART TWO

MOVEMENT OF IDEAS AND TECHNIQUES

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TECHNOLOGY

1. Modalities of Innovation and Change

[217] Technology, in its broadest sense, includes all those artifacts and techniques that human beings use to adapt the natural environment to the needs of the species. Thus I have already discussed (in Chapter 2) the development of *technologies* of agricultural land use in consonance with the differing cultural, economic, and environmental conditions prevailing in Islamic and Christian Spain. In the present chapter the discussion will focus on the artifacts of agricultural and industrial development, in the hope of illustrating, with the movement of concrete cultural elements, general trends in the contact of cultures. In so doing, I hope to avoid, for the moment, the polemical charges carried by other areas of cultural and social experience (religion, art, and literature) and to develop lines of argumentation drawn from evidence which, in the context of the polemic of medieval Spanish historiography, may be considered as neutral. Earlier, I mentioned that both Castro and Sánchez-Albornoz regard technological evidence as essentially devoid of historical significance, a judgment which contemporary historiography cannot accept. Not only do economists well appreciate the correlation between technological innovation and economic growth, but geographers, anthropologists, and historians of technology have established the central significance in human society of technological diffusion and the factors controlling it.

In general, the movement of technological diffusion in the high middle ages followed a trajectory from China and India to the West, through the mediation of Persia, which was also a hearth of technological innovation. Sinologists, like Joseph Needham, tend to stress the consistency, longevity, and hence the slowness of this cultural flow. Islamists, like Juan Vernet, tend to stress the speed of diffusion. Both viewpoints are correct as generalizations. There tended to be substantial lags between the invention of a technique in China and its eventual arrival in the West; after the Arab conquests, however, Eastern techniques diffused much more rapidly once they gained the borders of the Islamic world. Thus the Chinese were more than one thousand years ahead of Europeans in the development of certain [218] foundry techniques, or even simpler devices such as the wheelbarrow. Yet, the use of paper was diffused from Samarkand in the mid-eighth century to al-Andalus by mid-tenth, and "Arabic" (that is, Indian) numerals diffused throughout the Islamic world in the ninth century, in a matter of decades. ⁽¹⁾

The spatial configurations of technological diffusion were largely controlled by patterns of trade and by local or regional supplies of resources. These two sets of factors together produced foci of regional specialization whereby each town had one or more specialty products, assuring it a place in the regional or international market. The imitation of foreign products (which can be traced in historical sources owing to the generalized custom of naming a certain product after the place where it was originally manufactured) was both a function of the configuration of commercial networks and a stimulus for technological change in localities along the path of diffusion. ⁽²⁾

The close technological interdependence of contiguous districts is also apparent. Several examples will suffice to illustrate this point. A twelfth-century letter published by Goitein reveals the ordering by a Jewish goldsmith in Fez of a set of scales from a scales-maker (*mayâzînî*) in Almería. (The *mîzân* is the common Persian scale, suspended from a central, fixed pivot.) The incident makes clear the technological interdependence of Morocco and al-Andalus, which is a concomitant of the commercial interdependence alluded to in Chapter 3. Not only did Islamic Spain supply the Magrib with precision products, such as scales and weights, but apparently imposed its weighing standards upon Fez as well. ⁽³⁾ The technological interdependence of Christian Spain both with al-Andalus and with France is seen in the development of the textile industry in the thirteenth century, based upon the diffusion of Andalusî and French styles and techniques, as well as by the migration of artisans familiar with them. ⁽⁴⁾

Environmental constraints were particularly crucial in the Islamic Mediterranean world, which was lacking in resources necessary for the development of certain crafts. Chronic wood shortages limited the growth of industries that consumed large amounts of fuel: pottery, glass, sugar refining, and the metal trades. The last was particularly critical and, although Islamic Spain was better endowed with wood than the Islamic East, my impression is that iron was less widely used there than in Christian Spain at a comparable stage of development, and that Andalusî [219] tended to use hardwood for implements (mill and noria bearings, for example) commonly made of iron in the northern kingdoms. ⁽⁵⁾

On the other hand, lack of water was a spur to technological innovation, as demonstrated by the multiplicity of hydraulic devices diffused from east to west. (To the extent that their efficiency was affected by the availability of suitable woods and iron for fittings, these devices were also developed in consonance with availability of materials locally, and their construction differed accordingly from place to place.)

The study of technology in medieval Spain presents a host of difficult methodological snares. The two cultures frequently had duplicate sets of terms for the same, or similar, artifacts. Thus when interpreting a chance mention of a technological device described in a Latin document by an Arabism, or in an Arabic source by a Latinism, the scholar must decide whether the artifact itself has been diffused, or only the name. According to Bertrand Gille, foreign names are generally not applied to autochthonous artifacts, although imported ones may be renamed in the language of the recipient culture. Artifacts with foreign names can be assumed to have originated in, or at least to have been transmitted through, the culture in question. ⁽⁶⁾ Some refinements of this general scheme will be suggested below. In many instances, a definitive conclusion regarding the origin of a technological artifact (without archeological, iconographic, or ethnological evidence to support it) is impossible. Yet in all cases terminology is significant, because names represent perceptions based on some real situation. Arabs did not invent the olive press, but they developed olive oil production to such a great extent that the Christians, who depended on Andalusî sources of supply, adopted the Arabic terminology for most of the implements used. Because technological artifacts tend to pick up descriptive terms which stay with them as they cross cultural boundaries, it is generally simpler to trace the history of a borrowed element than one which develops autochthonously. ⁽⁷⁾

There always seems to be a fairly significant lag between the invention or adoption of an artifact and its first documentation. Indeed, in traditional artisanal societies many innovations were kept secret and passed down among members of a family (for example, formulae for glazes and dyes), presenting the historian with insurmountable problems. On the other hand, many medieval techniques extended into modern times, protected intact and unchanged by the inflexible structure of traditional craft organization. To what extent, for example, are Henry Cock's 1585 [220] description of the earthenware potting techniques of Morisco artisans, or Floridablanca's very similar 1785 account of lustreware glazing, representative of medieval practices? What is the value to the medievalist of contemporary ethnological evidence? George M. Foster surveyed the traditional crafts of contemporary Spain in order to ascertain to what degree Spanish techniques influenced the traditional technologies of Latin America.⁽⁸⁾ It seems feasible to apply the same method to reconstructing the traditional techniques of Muslim Spain.

2. Continuity and Change in Medieval Iberian Technology

The basis of medieval craft industries was the small workshop operated by a family within which the mastery of a given trade was passed down from father to son. This sharp circumscription of career mobility is generally viewed by anthropologists as resistant, if not inimical, to technological innovation. The extended family serves, therefore, as a medium for technological continuity (particularly in crafts where secrets are passed on), enhanced by the constraints of a local economy that afforded a rather slight return on investment. Traditional artisans place a high value on a rigorous adherence to proved techniques. The economic risk involved in trying a new technique will generally be thought too high. In a family-run pottery establishment, for example, any change in the composition of clay or glazes, or in the firing procedure, could result in the loss of an entire kiln-load, or, even if the change were successful, in the loss of clientele accustomed to a particular ware. The view of French *urbanistes* that technological stagnation is at the root of occupational immobility in traditional Islamic towns is a reversal of the sequence of causation. The occupational structure, which in turn is related to that of the family, is a hindrance to technological innovation.⁽⁹⁾

The social structure of traditional artisanry to a great extent precluded the internal generation of technological innovation. In medieval times the cycle was typically broken in two ways: by the creation of a market for a product necessitating new techniques or by the migration of artisans who practiced them. Mere exposure to a foreign product did not result automatically in its imitation by local craftsmen. In general, imitation seems to have been predicated on the migration of artisans. If market demand could be fulfilled by trade, there was no incentive to imitate. Imitation, both in Andalus and Christian towns, seems to have occurred only when the demand of the urban population was so great that local production [221] was deemed economically competitive. The same pull of demand acted as an attraction to foreign artisans, so these two causative factors were intimately intertwined. Moreover, the rupture of established commercial ties or the destruction of centers of manufacture by conquest also resulted both in the dislocation of technologies and in the imitation of foreign goods to fill the vacuum caused by the commercial disruption.

MIGRATION OF ARTISANS

The migration of artisans was a hallmark of economic development in Islamic and Christian Spain alike and only serves to underscore the interdependence and lack of autarchy of medieval economies. The mobility of artisans was a function of economies of scarcity, wherein finished products, technical services, and the skilled persons who provided them were all in short supply. Migration was a response to demand for the artisan's particular skills, providing an obvious avenue of social and economic

betterment. Frequently, though, such movements were not left to the whims of the marketplace but were encouraged and even mandated by rulers or powerful persons.⁽¹⁰⁾ A number of examples will serve to illustrate the generality of these phenomena.

In the Islamic world, people involved in maritime technologies were particularly mobile, owing to the salience of sea-borne commerce. Red Sea navigators were prominent in the ports of southern Spain. The pottery center of Málaga attracted eastern potters, particularly in the wake of social upheaval. Thus Egyptian lustreware potters migrated there after the Fatimid collapse in the twelfth century, and their descendants were joined at the end of the thirteenth by Persian potters fleeing the Mongols. Under the Almoravids and Almohads, technological exchanges between al-Andalus and Morocco were frequent. To build a palace and fortifications at Gibraltar, 'Abd al-Mu'min, the Almoravid caliph, recruited carpenters and masons from Seville, as well as an architect, Ahmad ibn Bâso, and at the same time sent to Marrakesh for another Andalusí engineer and geometrician, Ya'ish of Málaga, then working in the Magrib. Early in the next century Muhammad ibn al-Hajj of Seville was commissioned to build a great hydraulic wheel in Fez. Andalusí artisans -- for example, shoemakers -- also migrated to Egypt and other points in the east.⁽¹¹⁾

An incident recorded by al-Khushanî in tenth-century Córdoba further illustrates the function of Islamic internationalism in the transfer of techniques. In a case heard before the judge Sulaymân ibn Aswad, a complaint [222] was raised against an oven whose smoke was considered a public nuisance. The judge ordered that a tube should be placed on top of the oven to carry the smoke away. Al-Khushanî comments that Sulaymân must either have personally observed this custom in the East or heard that ovens were built in that form there, and consequently ordered that the technique be imitated in al-Andalus. The Islamic legal system, involving the circulation of traditions and precedents in jurisprudential circles throughout the Islamic world, functioned in this way as a medium for technological diffusion.⁽¹²⁾

In Christian Spain, we have noted, easy access to the finished products of Andalusí artisanry retarded the development of local craft industries and inhibited the migration of technical specialists, at least until after the cessation of tribute payments in the late eleventh century. Nevertheless, artisans were certainly prominent among Mozarab immigrants in León. The defenses of tenth-century Zamora were built by masons (*alarifes*), presumably Mozarabs, from Toledo. Mozarabs were also prominent in mill-building activities: a document of 905 describes the construction of a mill by a converted Jewish monk named Habaz, clearly of Andalusí origin, along with his own workmen. In 1032, another Mozarab, Cidi Domínguez, rebuilt some mills on the Bernesga River. Twelfth-century documents literally effervesce with citations of French artisans: Robert the Smith, Archimbault the cask-maker, Rainault the goldsmith, in Estella; Clement and Gervasion, tailors, in Salamanca; Bernard *tiser* (weaver) and Bertrand, of the same profession, in Zaragoza; Pictavi of Poitiers, a tanner in Lérida, whose urban industries also attracted weavers from southern France. The development of Romanesque architecture and the great need for defensive constructions in the eleventh century motivated the importation of foreign architects and masons: French and Italians to rebuild the ramparts of Salamanca; Italians to work on projects in Catalonia. To enhance the development of crafts deemed Islamic specialties, Muslim artisans were sought. In the early thirteenth century, James II of Aragón both imported Muslim cotton masters from Sicily to Catalonia and dispatched Muslim silk masters from Spain to Sicily.⁽¹³⁾

TECHNOLOGICAL CONSEQUENCES OF CONQUEST

The contact of cultures that results from conquest either has the effect of inducing technological diffusion from the dominant to the conquered [223] group, or in the opposite direction, or it may result,

through the assimilation or emigration of the conquered, in technological loss or displacement. Sources shedding light on early technological exchanges between Arabs and Berbers, on the one hand, and Neo-Muslims or Mozarabs, on the other, are entirely lacking. Nevertheless, the Hispano-Romans had skills that their conquerors lacked and subsequently adopted. We know that the Mozarabs retained skills connected with cart-making, as the migration of wheelwrights to León testifies. A related craft, that of the cooper, was also diffused from the native population to the conquerors. The Andalusí Arabic term for cooper was *kawwâb* (from Romance, *cubo*, cask); there was a cooper's mosque (*masjid al-kawwâbin*) in Córdoba.⁽¹⁴⁾

There is considerable documentation to illuminate the technological transitions accompanying the Christian conquests of the thirteenth century. In general, Christian rulers made concerted efforts to keep Muslim-owned industries going, particularly those crafts deemed to be Islamic specialties. Thus Alfonso X ordered in 1281 that no pottery works were to be built in Córdoba unless in the Muslim style; similarly, James I of Aragón encouraged the continuity of the paper industry in Játiva and supported it by forbidding the making of paper by Muslims elsewhere in the kingdom of Valencia. Continuity in other crafts was achieved through less formal mechanisms: Muslim artisans would remain if there was a good market for their wares. Esparto-weaving in Murcia was in *mudéjar* hands, and the precocious development of the textile industry in Valencia may be owing in part to continued activity by Muslim weavers, imitating Andalusí-style fabrics for the Christian market. There are frequent mentions of individual Muslim artisans in thirteenth-century Christian towns, like Mahomat, the "Moorish weaver" of Seville (1282).⁽¹⁵⁾

The similarity between industrial specifications in *hisba* manuals and the municipal ordinances of Andalusian towns, previously mentioned, indicates that a great deal of technological interchange occurred, wherever substantial numbers of Muslim artisans remained. Nevertheless, examples of displacement and loss are also characteristic. In many cases, masses of artisans departed for Granada or North Africa, and whole industrial sectors were wiped out in specific towns. (Mudéjars were free to migrate from some areas and forbidden to do so from others; the terms of capitulation agreements thus had differing technological consequences.) In Murcia, for example, Muslim weavers departed en masse, the silk industry was destroyed, and fulling mills were converted by new Christian [224] owners to rice-husking. Some Murcian potters were attracted to the developing pottery center at Manises, where they continued for generations to produce Murcian-style wares. Through a similar process, lustreware techniques associated with the destroyed workshops of Madína al-Zahrâ' were continued by Muslim artisans in twelfth-century Calatayud, under Christian control. Groups of Muslim workers were enticed from their homes by royal or seignorial privilege and settled en masse elsewhere, to develop particular industries. Thus James I established Muslim silk weavers in Játiva (possibly to compensate for the extinction of that trade in Murcia), and the Hospitallers settled one hundred Muslim fishermen, with their fleet, on the Albufera of Valencia to develop a fishing industry.⁽¹⁶⁾

In the survey that follows, I attempt to sketch the main lines of development in specimen technologies, a discussion which must be superficial owing to the lack of monographs for most of the techniques discussed. Rather than grouping related techniques, I prefer to categorize by the process by which these technologies developed. Thus I will discuss, first, shared technologies, techniques that both cultures inherited from Roman or pre-Roman cultures. Then I will discuss bilateral movements of diffusion of the same or homologous technologies to each culture by different routes (although this primary movement need not preclude secondary waves of diffusion between Christian and Islamic cultures). Finally, technologies exhibiting clear, unilineal paths of diffusion -- typically from east to west, from al-Andalus to Christian Spain -- will be considered.

3. Shared Technologies

A variety of agrarian and industrial techniques, of Roman or pre-Roman origin, were diffused throughout the Mediterranean world in antiquity. The most obvious of these were simple and universal agricultural or building procedures retained by the Hispano-Romans and Berbers which the Arabs had learned from an earlier diffusion from Persia or had acquired in the course of conquering the Middle East.

(a) Construction with tamped earth. This is a widely diffused, simple method of building inexpensive walls by tamping down dry earth or earth mixed with aggregate and a binding agent (straw or quicklime) in a wooden mold. When one layer is completed, the mold is moved up and another layer added until the wall is complete. It is found all over the [225] Mediterranean basin, as well as in parts of northern Europe and sub-Saharan Africa, a distribution that suggests multiple invention in prehistoric times. It is typically associated with areas where field stone is lacking (e.g., León) and where, as a result, it is used both for field walls and for house construction, or in areas where wood is in short supply (as in most of the Islamic orbit). Both Muslims and Christians used tamped earth for the construction of thick fortification walls (possibly because of the speed and convenience with which such walls could be built) and it was widely used in al-Andalus for more luxurious construction, such as palaces and mosques, because Muslim architects frequently preferred to use inexpensive wall construction which could then be disguised with ornate wood lattice or stucco work. The fact that the Romance term *tapia* passed into Arabic usage (*tabiya*) does not in this case warrant the conclusion that the technique was diffused from the Christian north to al-Andalus. The opposite assumption (made by Nicolau Primitiu) that *tapia* was an Islamic technique which, in eastern Spain, lost out to concrete construction is also unjustified. A *tapia* mixture with an aggregate and binding agent is identical to concrete, which is also poured into molds. Both cultures appear to have employed a range of simple wall-building methods, dictated by the availability of alternative sources of construction materials. When stone or wood was unavailable, *tapia* or bricks would be used. (17)

(b) Dams. The stone, rubble, or masonry dam to divert water from a stream into a canal is the simplest hydraulic appurtenance to make and doubtless is another prehistoric invention with multiple foci. Both Muslims and Christians knew the technique, which was amply diffused throughout the Roman Empire as well as in ancient Arabia. Moreover, much damming activity in the high middle ages must have consisted in rebuilding Roman dams. It is characteristic of diversion dams that the sites, once established, tend to be permanent, their use being changed in consonance with the economic needs and technological skills of successive occupants. In the diversion dams serving the canals of the huerta of Valencia, some of which must have occupied Roman sites, the Muslims appear to have added the innovation of de-silting sluices. Otherwise, little structural differentiation can be noted. The early evidence for parallel terminology to describe these structures is a further indication of a common origin of Andalusian and Christian dams. In spite of the presence of Mozarabs in early León and Castile, diversion dams there were called *presa*. With the exception of a citation from Jaca in 1128, the Arabism [226] *azud* (from *sudd*) did not become commonly diffused in Castilian until the thirteenth century. The same is true in the east of the peninsula, where Catalan dams were called *resclosa*, and *açut* did not become common until after the conquest of Valencia. It is interesting to note that *resclosa* and *sudd* both connote closure; that their function was understood identically in both cultures cannot be doubted. Subsequent to the thirteenth century a process of semantic differentiation took place, whereby *presa* came increasingly to signify a storage dam, while the usage of *azud* meaning only diversion dam spread into regions relatively untouched by Arabic influence. Although the Romans had built storage dams in Spain, the medieval Muslims did not. This is partly due to an ecological choice: the concentration by the Arabs of irrigation farming along large rivers where storage dams were not needed. The earliest Christian storage dam built at Almansa in the fourteenth century was an arched

dam, perhaps manifesting some secondary Persian influence, although by what process of transmission cannot be guessed. ⁽¹⁸⁾

(c) *Qânâts* and aqueducts. The *qânât*, or chain-well, was a Persian hydraulic technique *par excellence*. It is a method for tapping deep ground water without the use of lifting devices by sinking a series of wells and linking them underground. The technique was widely diffused in antiquity and the Romans used *qânâts* in conjunction with aqueducts to serve urban water supply systems (a *qânât*-aqueduct system was built in Roman Lyons). A Roman *qânât* system built near Murcia was described by al-Himyari. The Arabs vastly extended the use of *qânâts*, building one system at Crevillente, most likely for agricultural use, and others, at Madrid and Córdoba, for urban water supply. The Catalan *qânât* systems, described by Humlum, however, do not seem to have been related to Islamic activity and are more likely later constructions, based on knowledge of Roman systems in southern France. Both Muslims and Christians had difficulty keeping Roman urban water-conduction systems in working order. The idle aqueduct, whose arches were used as walls for dwellings in the tenth-century Barcelona suburb called Archs Antichs, was a mute testimony to the loss of Roman technological expertise. Nevertheless, with the passage of time, Roman aqueducts were restored and new ones built. The Almohads restored the Roman water system of Seville and an aqueduct was built at Santiago de Compostela in the early twelfth century to supply the cathedral with water. Such constructions or reconstructions did not require any new technologies, and the Roman techniques were [227] perfectly well-known and generally observable in the structures still standing throughout the peninsula. Just as the Romans had conjoined *qânâts* and aqueducts, the Muslims were able to link together different hydraulic appurtenances to form viable supply systems. Thus at Córdoba a mammoth zig-zag dam which powered a number of mills featured a *noria* at one end which raised and deposited water into an aqueduct which transported river water into the city. ⁽¹⁹⁾

(d) The balanced bucket or swape. This simple hydraulic device whereby one man could scoop water from a canal or well by manipulating a counter-balanced bucket at the end of a pole was probably an ancient Egyptian invention and was known throughout the Roman Mediterranean. Isidore of Seville alluded to the use of the *ciconia* ("stork") in the seventh century and both Muslims and Christians used the device contemporaneously in the high middle ages. In Murcia the device was called *alhatara* (from *khattâra*, the up-and-down waving motion of a camel's tail), rather than the more common Arabic term *shadûf*, and lands in the huerta irrigated with it are so identified in the Repartimiento. In Castile the *cigoñal* was used typically in the salt-extracting industry to lift water from cisterns onto evaporation flats. ⁽²⁰⁾

(e) The Roman plow. The scratch plow, the universal plow of Mediterranean antiquity, consisted of a hardwood share-beam, attached to the ox-yoke by a yoke-beam and guided by a stilt which controlled the tilling of the furrow. Medieval documentation is scant; generally only those plows with iron shares, share-caps, or coulter were considered valuable enough to list in an inventory of possessions. Therefore the very lack of documentation is indicative of the persistence of the Roman plow. In Christian Spain, only the wealthy could afford iron fittings; the poor tempered their shares with fire to make them more durable. There may have been some wheeled, heavy plows in humid areas of the north (Catalonia, Galicia) as early as the eleventh century, but the evidence is inferential. Ethnographic mapping of contemporary plows has demonstrated complex patterns of regional variations upon the basic model and has permitted the identification of the Berber plow of northern Morocco, fitted with two small mouldboards, with areas of Berber settlement in southern Spain (southeast Granada, the south of Córdoba province, and points in Jaén and Málaga), indicative of the Roman imprint of this technology common to ancient Hispania and Mauretania. ⁽²¹⁾

(f) Surveying. Surveying techniques in Islamic and Christian Spain [228] alike appear to have been practical, minimal, and generally simplified versions of Roman practice. Ibn Bassâl describes a simple triangular level with a plumb line, bearing the unusual, Romance-sounding name, *murjiqâl*. Arabic terms (from the roots *'adala and wazana*) conveying the meaning of "correcting the land," the surveying procedure necessary to prepare a parcel for irrigation, have the sense of the Latin expression *librare terram* (to balance or equalize the land) and must therefore represent a procedure of Roman agriculture common throughout the Empire. On the other hand, coexisting with homely procedures of Roman inspiration was the practice of triangulation, unknown to Roman *agrimensores* and introduced from the East in the astrolabic treatises of the Andalusí astronomers Maslama of Madrid and ibn al-Saffâr. (In addition, an Umayyad official of the tenth century, Ahmad ibn Nasr, wrote a formal description of surveying practices.) Generally, when astrolabic literature was translated into Latin, geodesic uses of the instrument were omitted and Christian surveying treatises on the whole remained within the Roman tradition. An exception is the tenth-century *Geometria incertiauctoris*, a compilation of Hispano-Arabic inspiration which Millás Vallicrosa relates to the Arabized scientific corpus of the Monastery of Ripoll. *The Geometria* details a variety of triangulation procedures that can be effected with the astrolabe, including the measuring of height and distance by right-angled triangles and squares. Therefore, alongside Roman surveying procedures, simple triangulation was practiced with an alidade -- a rule with sights at either end -- in both Islamic and Christian Spain. Simplified Roman procedures appear to have been used by individual farmers, while triangulation was associated with institutions that commanded the services of professional surveyors (such as the Monastery of Ripoll, which was acquiring huge donations of land during the tenth century). In the course of *repartimiento*, parcel boundaries were simply measured with a cord (*soga*) along a straight boundary such as a road or canal (the basic Roman agrimensorial procedure). But when the boundary was not clear, triangulation was resorted to. Large-scale or difficult surveys were carried out by specialists in land measurement (the *muhandis* in al-Andalus, the *soguejador* in eastern Spain) and in the surveying, more specialized, of irrigation canals. The *livelladors* (revelers) of medieval Valencia seem not to have practiced land surveys at all, but were master masons, specially trained for the building and repair of canals. In the later middle ages, after the diffusion of Profêit ibn Tibbon's astrolabe [229] rule with trigonometric functions (ca. 1290), triangulation must have become a more common procedure. (22)

(g) Cork-soled shoes. The Andalusí Muslims fell heir to a number of oak-based industries developed by the Romans, including the making of cork-soled shoes. Under Islamic aegis, the technique was intensified and diversified, and the cork-soled shoe became universal in the country and a staple of the export trade. The Muslims made of the Romance *corco* (Latin, *quercus*) an Arabic root, *q-r-q*. The shoe was designated *qurq* (plural, *aqrâq*), which subsequently returned to Castilian in the form *alcorque*. The artisan who made the product was a *qarrâq*, as in the case of one 'Abd Allâh, sandal-maker of Seville a Sufi mystic mentioned by ibn 'Arabî. There was a quarter of *qarrâqin* (Caraquín) in Granada and another so named in an oak district near Madrid. Both the word and the technique diffused from al-Andalus across North Africa, where it was identified as an Andalusí technique. Al-Saqatî and ibn 'Abdûn provide detailed specifications concerning the making of cork-soled shoes, notably that the leather stitched to the back should not be skimpy, and that leather should be sewn to leather with no filler inserted in between (some shoemakers inserted sand below the heel to make it higher, causing it to break when worn). The ordinances of Christian Málaga, Saqatî's town, contain analogous stipulations. Oliver Asín cites this case as an example of the absorption and reelaboration in vulgar Arabic of the Ibero-Latin lexicon and the reincorporation of these elaborations into Castilian. This linguistic process is an apt model for the techniques described by the terminology as well: a relatively simple Roman folk technique was adapted to the mass market demand of urban Muslims and, in response to this, diversified and complexified. The more sophisticated styles and methods were then adopted by Christians after the conquest of al-Andalus. (23)

Numerous other techniques merit discussion under the rubric of shared technologies, were there but documentation. The Catalan smelting furnace was the same used by the Romans in the Rio Tinto mines and therefore, one can assume, the Andalusis fell heir to the same technique.⁽²⁴⁾ A similar continuity with antiquity is found in the procedures for pressing olives and grapes: the two techniques were virtually identical and both were Roman in provenance. Because of the location of the olive oil industry wholly within al-Andalus for several centuries, the terminology is heavily Arabized: *almazara* (from *mi'sara*), olive press; *alfarje* (*farsh*), lower grinding stone (in both olive and grape mills); *algorin* (from *hury*, [230] granary), holding platform for olives; and the terms for olive-oil can, both in Castilian (*alcuza*, from *kuza* jug) and in Catalan (*setrill*, from *zait*, olive oil). But there is no reason to suspect that the *almazara* differed in any significant way from the *torcularium* (*trujal*, in Castilian), a term which appears in Christian documentation to describe both the grape and olive press.⁽²⁵⁾

4. Bilateral Diffusion

Other techniques appear to have been introduced in the middle ages by twin currents of diffusion, describing a pincher movement, whereby eastern techniques reached al-Andalus through the Islamic orbit and Christian Spain through Europe. In each case the sequence of diffusion is difficult to verify, as is the level of interpenetration of currents between the two Iberian zones.

(a) The water mill. The development of the water-driven mill is the thorniest problem in medieval technology, although probably the best studied (in the European literature; there is no systematic study of mills in the Islamic world).

Water mills are of two types: the non-g geared horizontal mill, powered by a horizontal wheel with paddles (the ancestor of the turbine), connected directly to the bedstone by a shaft; and the vertical mill (either overshot or undershot), whose motive force is transmitted to the stone by a gearing mechanism. The two types of mills probably bear no genetic relation to each other. According to Joseph Needham, the horizontal mill is a downward extension of the hand quern, while the vertical seems related to the *noria*, or hydraulic wheel.⁽²⁶⁾ In medieval times, grain mills were typically horizontal, industrial mills vertical. However, because of the frequency of vertical mills in industrial towns, urban grain mills may also have been vertical, while in al-Andalus, because of the universality of the *noria* (see below) and because of the association of irrigation agriculture with town huertas, there may well have been a relatively high incidence of vertical gristmills.⁽²⁷⁾

The tendency for terms describing analogous instruments or components to become synonymous or interchangeable makes interpretation of documents difficult. In the Christian kingdoms all mills were called *molendinum* (Castilian, *molino*; Catalan, *moli*), whether horizontal or vertical. Thus the simple listing of a mill as an appurtenance in a [231] property transaction gives no indication of what kind of mill it was. If an agricultural parcel, the mill is assumed to be horizontal. Whenever the paddlewheel is mentioned (Castilian, *rodeznó*; Catalan, *rodet*), it must refer to a horizontal mill. When individual millstones are differentiated according to use, as in a customs tariff from thirteenth-century Sahagún, wherein a distinction is made between *muela de molino* (the assumption being that a *molino*, unless otherwise qualified, was a gristmill) and a *muela de ferrero* (smith), one can assume that the stones were destined to different kinds of machines, in this case, a horizontal gristmill and vertical, water-driven forge.⁽²⁸⁾ In Castile-León, a vertical gristmill was designated by the Arabism *azenia*, from *sâniya*, the generic name for a vertical waterwheel. Thus Ramiro II donated three *azenias* in Zamora (in the suburb of Olivares, and thus they may have been olive-oil mills) in 945, and six years later Ordoño II donated another, also of the Duero River near Zamora. The semantic differentiation which applied the Arabism to vertical mills is supported in the *Libro de Alexandre*, which describes fulling mills, always vertical, as *açenas que las dizen traperas*.⁽²⁹⁾ After the tenth century, fulling mills were generally called *molinos traperos*, suggesting that the earliest vertical mills in Castile and León were

introduced from al-Andalus, and were undershot mills powered by rivers with strong currents.

The horizontal mill was known in Christian Spain from as early as A.D. 800, the vertical mill probably not until the mid-tenth century. Subsequently, there may have been a progressive displacement of horizontal by more efficient vertical mills, especially as more mills were built by relatively large collectivities of peasants and particularly as they came increasingly under seignorial domain.

Horizontal mills were inexpensive to build and simple to maintain, inasmuch as they could be made without recourse to iron. The millstone in the Sahagún customs list cost three pence and would have lasted about four years, if a bedstone, three if a runner; a *rodezno* cited in the tariff likewise cost three pence. It is scarcely credible that ten or twelve peasants would have joined together to build a mill which required such small expenditures; more likely, these small companies were building vertical gristmills. Nevertheless, the horizontal mill, because it was economical to build and maintain, must have predominated throughout the Middle Ages. A Calle de Rodezneros (paddlewheel-makers) in twelfth-century León attests to broad participation in this enterprise. [\(30\)](#)

[232] In the northwest of Catalonia horizontal mills were widespread by mid-tenth century. They were typically located on mountain streams of small volume with small debits and fashioned by local artisans from granite stones and pine shafts. The ridges of the stones were dressed periodically by sharpening them with carbon. On the plain of Barcelona, because of irregularity of flow, mills were built at some distance from the water course on a canal (*rego*) into which water was diverted from a dyke (*resclausa*). [\(31\)](#)

Archeological research cannot be expected to yield much information on the replacement of horizontal by vertical mills, inasmuch as the same diversion sites would have been used and the new mill constructed on the site of the old. It was fairly common for mills to fall into desuetude and laws provided for the reoccupation of such emplacements. The Fuero of Jaca (thirteenth-century redaction) stipulates that if a man finds an old mill and the stone still moves "through the force of the water that runs below it" (a horizontal mill is probably implied) he may begin milling, after which no valid claim for recovery of the mill could be lodged against him. [\(32\)](#)

In al-Andalus, mills were likewise known by a universal term: *raha* (plural, *arhâ'*), which applied to all kinds of water mills, as well as to windmills and hand querns. Therefore, casual citations are impossible to identify with precision. A gristmill moved by animal power was denominated *tahûna*; however, the Arabism *atahona* or *atafona*, which is documented in Castilian in the thirteenth century, was applied both to windmills and watermills. *Raha* is also reflected in peninsular Romance, in toponyms such as Rafelbunyol (mill of the bath, Valencia) and Realage (*riha al-hajj*, mill of the pilgrim, Seville). There was also a competing Latinism, *farnat* (from *farinarius*, flour mill), recalled in the name of a Malagan village Alfarnate, where there were numerous gristmills. The presence of the Latinism in Andalusi Arabic is probably indicative of the survival of simple horizontal mills. [\(33\)](#)

The spatial disposition of gristmills both in Islamic and Christian Spain follows the typical southern European pattern of the massing of small mills on natural watercourses or irrigation canals. Thus the previously cited place-name, *al-farnât*, derived from the Latin plural, had the sense of a collectivity of mills, as did the Field of the Mills (*fahs al-rahî*) near Córbova. Another place to the west of Córdoba, Munyat Nasr, was the location of an unspecified number of henna mills (*arha' al-hinna*). In **[233]** Christian Spain the occurrence of such expressions as *ribulo molendinis* is indicative of the emplacement of a number of mills along a watercourse. There is no certainty, particularly in al-Andalus, that multiple mills on the same course were horizontal. Henna mills must have been vertical, and it was a common pattern to place overshot and undershot mills in sequence, so that the latter could take advantage of the head needed to operate the former. Such sequences must have been found in the Barcelona region, where a variety of types of industrial mills were built along the same course. In

addition, Andalusí engineers used river dams to increase the efficiency of horizontal or undershot vertical mills, as at Córdoba, where four mills were emplaced on the downstream zig-zags of the dam across the Guadalquivir. ⁽³⁴⁾

The notoriety and economic importance of watermills, as Marc Bloch indicated, has tended to obscure the persistence of hand querns. Hand querns were not only a recourse of the poor to avoid seigniorial monopolies, but they were carried by armies and merchants and, in the Islamic world, were a commonplace in nomadic camping grounds. This would seem to be the most plausible explanation of a reference in the *Poema de Fernán González* to Berber warriors carrying "ovens and mills" (*sus fornos y molinos*) on their camels. The mill must have been a hand quern for grinding bread flour which could then be baked in small, jug-like, earthenware ovens (*tanûr*). ⁽³⁵⁾

Industrial mills appeared in Christian Spain, notably in Catalonia, during the twelfth century, the period of expansion of milling technology throughout western Europe. As such, it is difficult to state with precision whether the Catalan mills were inspired by European or Andalusí models. The prototype of the common tilt-hammer fulling mill was the Chinese rice-husking mill, which was vertical and undershot. Assuming that this mill diffused to al-Andalus along with the cultivation of rice, it is logical that its use should have been applied there to other industries and have diffused northward. If so, then I may be right in guessing that Ramiro's *azenias* on the Duero were undershot vertical mills. There are frequent citations of fulling mills (*molendino drapario* or *trapero*) throughout Catalonia from 1150 on, during an epoch when fulling was still being done (as witnessed by regulations in the Fuero of Cuenca) in the Roman fashion, by trampling the cloth by foot. Towards the end of the century, the technology was applied to the mechanization of Catalan forges, a precocious development relative to the rest of western Europe. Paper mills [234] also appear in Catalan documentation during the 1150's and, although there is no hard evidence that the mills themselves were of Islamic inspiration, there is no reason to doubt they were not, inasmuch as the rest of the technology of paper-making (see below) was identical with Andalusí techniques. ⁽³⁶⁾

The windmill may also be an example of bilateral diffusion, with those of La Mancha related to European types and those of the Balearics and other sites dependent upon an Islamic tradition. The application of the Arabism *atahona* to the windmill is not in itself evidence enough of Islamic origin. In any case, the windmill appears on the scene rather late, in the thirteenth century, the same period as it reached China from a Central Asian hearth. ⁽³⁷⁾

(b) Harnessing. The received view is that the three-component Chinese equine work harness, consisting of shafts, a curved wood crossbar to hold the shafts together, and a padded collar must have reached Merovingian Europe through Central Asia. Indeed, a Chinese type, with characteristic cords linking the ends of the crossbar, is still in use in southern Spain, where Needham observed examples on a field trip in 1960. But Needham hesitates to claim an Islamic diffusion since analogous styles of harnessing reached northern Europe independent of the Islamic world. Richard Bulliet proposes a complex, bilateral model of diffusion whereby the horse collar was diffused into northern Europe across Central Asia and the breast strap from Tunisia, which in Roman times had been a particularly fecund source of technological innovation (the breast or withers strap, the whippetree, and single-animal harnessing). In Bulliet's view, then, modern harnessing (except for the padded collar) reached Europe from the south, as Tripolitanian techniques were diffused through Spain and Italy. Judging by harnessing terminology, Bulliet includes Spain within a Mediterranean technological sphere, including North Africa, Italy, and the Western Mediterranean islands, in contrast to a sharply distinct French-Provençal terminological sphere. Elements of the riding harness, which is ancient and classical, are described in Castilian with Arabisms. Examples are the crupper, *atahorra* (*al-thafara*) and *jâquima*, the bridle, from Arabic *shakîma*, yielding hackamore in English. Here, the development of the military uses of the horse by the

Arabs and the common exporting of leather tack from al-Andalus to Christian Spain may have colored the terminology.⁽³⁸⁾

(c) Military technology. That styles of horsemanship diffused both [235] from east to west (as in riding *a la jineta* -- after the Zanâta Berbers with short stirrups) and in the opposite direction as well is generally appreciated. The stirrup itself seems to have diffused from Christian Europe into al-Andalus. Christian and Muslim warriors used a mixture of North African and Frankish combat styles, depending on the weapons used. The armies of al-Hakam II used both Christian (*afranji*), Arab, or Berber (*'idwi*) swords; bows of Arab (long) or Frankish (cross) style; javelins of Christian origin. A common type of Andalusí helmet was the *tashîna* from Latin *testa*, while in Castilian the mail colf worn under the helmet was denoted by the Arabism *almófar* (*maghfâr*) -- an apt example of the complex interpenetration of military styles. Christians adopted the standard Muslim cowhide shield, *adarga* (*darqa*).⁽³⁹⁾

5. Flow of Techniques from East to West

By far the most common pattern of technological diffusion in medieval Iberia was the reception of elements of Eastern culture in Christian Spain through the mediation of al-Andalus. Within the context of this general movement, a number of distinctive processes can be discerned. Although there were cases of the implantation of elements (including technological ones) of Eastern culture in al-Andalus through the concerted action of formal institutions and policies (e.g., cultural Syrianization under 'Abd al-Rahmân I; importation of 'Abbâsîd styles of Persian inspiration under 'Abd al-Rahmân II), most technological innovations were diffused by non-formal mechanisms (involving such agents as merchants, artisans, scholars, books) and were generally in response to market demand. Typically, a style (of weaving, glazing, etc.) will diffuse first, promoting the importation of the desired product from its place of original manufacture. As demand increases, local imitation of the product will be motivated, requiring the importation of the techniques or apparatus necessary to produce the product in question. The same processes apply to the diffusion of techniques from al-Andalus to Christian Spain. The Islamic towns served the Christians as a vast emporium; when they disappeared, products had to be purchased from more distant places in the Islamic world or else produced at home, by a process of imitation. Processes of diffusion seem to have been largely non-formal, but royal direction was applied in the case of certain basic industries.

(a) The *noria* or hydraulic wheel. Although *norias* exist in copious [236] variety, two principal types were utilized in medieval Spain. The first was an ungeared wheel, compartmented or with a rim of pots, moved by the force of the water alone, which lifted water from large rivers or canals. These wheels, although mechanically simple, were typically very large in size and were associated with public works such as dams, royal gardens, or major irrigation installations, indicative of their dependence on adequate financing for construction and maintenance. In this category were the great *noria* of Islamic Toledo, driven by water from an aqueduct over the Tajo River, and the wheel at La Rora, Murcia, driven by the current of Aljufía canal. When placed on a river or canal the current-driven wheel lessens susceptibility to water shortages owing to fluctuations in the level of the channel.⁽⁴⁰⁾

The second wheel, the short-shafted, geared wheel moved by animal power, was ubiquitous. This made it possible to irrigate individual plots with well water, and the cultivated belts around many Andalusí (and later Christian) towns owed their prosperity to its introduction. This modest device is constructed from around two hundred separate parts, all of them wood, and so could be kept in repair by the farmer himself or a local carpenter. The animal, usually a donkey, is hitched to a shaft which moves a horizontal lantern wheel which engages teeth set in a vertical [237] wheel which, in turn, raises the water by means of an endless chain of pots affixed to its rim with a continuous rope. The Andalusí aeronomical writers mention this *noria* and suggest practical measures whereby the farmer can enhance

the efficiency and longevity of his machine. Thus Abu'l-Khayr and ibn al-'Awwâm recommend the use of hardwoods (such as olive), most likely for the teeth of the potgarland wheel, inasmuch as softwoods were usually employed for the lantern wheel. Abu'l-Khayr prescribes the arrangement of five pots to every cubit of rope, while ibn al'Awwâm recommended that the pots be supplied with an air vent to prevent breakage as the force of the water pushed each pot against the wall of the well or into the pot behind it. Ibn al-'Awwâm also noted that the longer the shaft, the less force required of the animal to move the wheel; the track diameter could vary from five to seven meters depending on the force required.⁽⁴¹⁾ Besides their agricultural uses, *norias* seem also to have associated with royal parks. 'Abd al-Rahmân III's favorite residence as a young man was a park outside Córdoba, known as *munyaṭ al-nâ'ûra* (estate of the *norias*). In Toledo, al-Ma'mûn's garden had a pavilion similarly called *majlis al-nâ'ûra*, which raised water from the Tajo to supply elegant fountains in which lions spouted water. In the palace of al-Mu'tamid of Seville, an elephant fountain was likewise supplied by a wheel, described as a *dawlab*, a synonym which usually connoted an animal-driven wheel. Al-Hakam II installed a *noria* to supply the cisterns of the mosque of Córdoba. Animal-driven wheels were used in conjunction with canals, not only wells, and wheels mentioned in a literary document cannot be identified with precision. Numerous thirteenth-century documents, for example, the *Repartimientos* of Murcia and Valencia, refer to wheels drawing water from canals. Christian documents of this era use the terms *noria* and *aceña* (from *sâni'ya*, originally a long-shafted, geared wheel) interchangeably.⁽⁴²⁾

The Andalusí *noria* is unrelated to the typical Berber *noria* of North Africa. Both the wheel itself and the pots seem related to Syrian prototypes, according to comparative ethnological research carried out by Thorkild Schiøler. Thus, like so many other elements of hydraulic agriculture, the Andalusí *noria* must be regarded as Syrian in inspiration, probably introduced as one element of the Syrianization of the landscape in early Umayyad times. The intensity of its presence in al-Andalus established a secondary focus for the diffusion of the technique. Andalusis introduced the Syrian-style wheel in Morocco and the Christians acquired [238] the technique through the migration of Mozarab farmers and, later, by conquest. In the later middle ages the *sēnia* (from *sâniya*, but, as mentioned before a short-shafted, animal-driven wheel) diffused northward from Valencia and Tortosa and became widespread in Catalonia proper.⁽⁴³⁾

Because of its universality, the *noria* became the model and point of reference for all geared machines. This was true in the Islamic East, where al-Jazarî, a thirteenth-century technological writer, tinkered with fanciful machines which were, in effect, parodies of *norias*: one pictured a fake ox which appeared to provide a wheel with motive force which was in fact supplied by a hidden current of water. The same was true in the West. In a treatise on clocks prepared for Alfonso the Wise, Isaac ibn Sîd first describes the construction of a main wheel, by fashioning four arms to be assembled in the form of a cross, "just like *norias* are made." The equalizing and bell wheels are then to be constructed in the manner of an *aceña*, the paradigm of a dentate wheel.⁽⁴⁴⁾ For similar reasons, the *noria* pot (*qâdûs*) came to be the universal pot (see below).

(b) Deep wells. Experience with *qânâts* seems to have exercised an undeniable influence of well-digging, the mastery of which was a prerequisite to the diffusion of the *noria*. The Andalusí aeronomical writers provide practical advice on well-digging. Ibn al-'Awwâm notes that the volume of well water can be doubled by digging four wells in the same vein, adjacent to each other in stepped depths, with the last three, progressively shallower wells, providing additional water to the main well -- a kind of miniature *qânât* system. Ibn Bassâl advises the emplacement of wells near to rivers so that water continuously filters in and the level remains constant. If not, the water will fall below the level at which the *noria*'s chain of pots can reach it. Moreover, wells should be dug in August, when the flow of water is most sluggish. For deep wells, ibn Bassâl recommends a counterbalance device which had the advantage over the *noria*, for that would have required a chain of pots of excessive length. It is possible

that deep-drilling techniques also had an Islamic diffusion, to judge by the interval between its mention by al-Bîrûnî, writing in Damascus in the early eleventh century, and its first European documentation, at Artois in 1176. ⁽⁴⁵⁾

(c) Pottery. The early history of pottery techniques in the Iberian peninsula cannot be described with any certainty. The Romans introduced the use of the kick-wheel throughout Europe, but its universality cannot be assumed. What is likely is the simultaneous practice of a variety of techniques, from hand-building, to the use of a turntable without the [239] application of centrifugal force, to the kick wheel. Nor is ethnographic evidence of contemporary folk pottery historically unequivocal, since pottery techniques do not necessarily stabilize at the most advanced technological level; rather, there is frequently a tendency towards regression from the kick wheel to a turntable or hand-building, if market demand declines or if urban styles cease to dominate the rural market. Medieval Christian documentation distinguished between the *ollero* (the potter who used a wheel) and other ceramic workers, who worked with molds. ⁽⁴⁶⁾

Medieval unglazed pottery falls broadly within three categories, according to archeological evidence studied by Juan Zozaya. South of the central cordillera, there was a Berber type, with red or brown vertical stripes on a whitish buff, with characteristic sharp undulations caused by the action of the wheel, resembling northern Moroccan pots. To the north of the central range is found a Germanic type with thin stripes and round undulations; it appears in the Duero Valley *before* Alfonso I's repopulation of the Tierra del Campo. Finally, there was a primitive northern ware with no slip, found in Asturias. ⁽⁴⁷⁾ Non-archeological evidence provides some indication that eastern Islamic styles also affected the form of unglazed ware. It suffices to mention that because of the widespread diffusion of the *noria*, its pot, the *qâdûs*, became the universal unglazed pot in al-Andalus and it must have been the mainstay of the rural pottery industry until relatively recent times, when tin replaced earthenware. The most representative pot, with a waisted middle and a knob on the bottom to facilitate the lashing of the pot to the *noria* rope, is related to Syrian prototypes. Just as common were flat-bottomed vessels with a hole in the bottom. This latter was an all-purpose vessel: it was used as a casserole, according to an Andalusî-Magribî cookbook of the thirteenth century; as a flower pot, according to Ibn Bassâl; and, in irrigated areas where delivery of water was timed, as an outflow clepsydra, or hanging water clock, through the vent of which water issued in a determinate time. The shape of the *qâdûs*, bell-like, even lent its name to a flower, the *qâdûsî* narcissus. ⁽⁴⁸⁾

The diffusion of glazed wares, introduced from the East by the Arabs, can be traced with greater precision, owing to the chemical specificity of glaze recipes. Thus we know that blue glaze of cobalt oxide was introduced from the East to Málaga during the Taifa period, whence it was diffused to Murcia and then to Christian Spain, to Valencia (beginning of the fourteenth century) and Barcelona (at the end of the century). Also of eastern, specifically Persian provenance, were tin enamel glazes, [240] producing an opaque white, used by Malagan and Mallorcan potters of the eleventh century. The most commented glazed pottery was that called lustreware, with golden metallic glaze on a white ground, a Persian style known in Spain from at least the twelfth century, when Idrisî mentions its production in Christian Calatayud. Persian lustreware potters fled to Málaga in the late thirteenth century, fleeing the Mongols, and it is probable that they chose this destination because of its reputation as a lustreware center. In the later middle ages, lustreware (called *malica*, after Málaga) was produced by Muslim potters at Manises. ⁽⁴⁹⁾

The introduction of Persian glazes meant that Persian kilns would also have to be imported. Indeed, both lustre kilns (which were small updraft kilns) and the larger, standard, high-vaulted updraft kiln were of Persian inspiration. The Persian kiln became the standard Spanish kiln; this is the *horno árabe*, still used by traditional earthenware potters today. The firing chamber is located above the hearth, from

which it is separated by a perforated floor. Besides ethnographic evidence, there is scant documentary material regarding medieval kilns. The foundation of an Andalusí kiln has been excavated in Almería, and there are citations of kilns in medieval Christian documentation. These latter are so vague that it is impossible to tell what they might represent (e.g., a *furnum antiquum* in Ardón, 952; *furnum de cantaria* in Lérida, 1193). Some clues regarding kilns may be forthcoming from medieval chemical lore. Interestingly, temperatures requisite for common alchemical operations were indicated in recipes by specifying the kind of oven needed. Thus for slow-heating operations, the low-temperature *tanûr* (medieval Castilian or Latin *athanor*; *actanor*) was used; the next lowest, according to Gerard of Cremona's twelfth-century translation of *De aluminibus et salibus* attributed to al-Râzî, but with obvious Andalusí interpolations, was the *furnum panis*, the baker's oven; then, the potter's furnace (*furnum figuli*); and finally the glassmaker's oven (*furnum vitrearum* or *fusionis*). The diffusion of certain kinds of eastern kilns may well have been encouraged by the spread of apposite chemical processes. - (50)

In the wake of the Christian conquest, the northward migration of Muslim potters, particularly from Murcia, was common. The potters (*moros olleros*) were the recipients of a privilege allowing them to dig clay in the thirteenth century; their position declined, and many migrated to Manises in the following century. It will be noted that the process of the westward diffusion of glazed pottery was quite slow, [241] especially the adoption of the technique by Spanish Christians. (51) This is doubtless explained by the function of al-Andalus as an emporium: so long as Christians could import the wares, they did not produce them at home. The techniques were transferred only upon conquest of towns, where they were being practiced by resident Muslim craftsmen who, subsequent to the conquest, became very mobile and diffused glazing throughout the Christian kingdoms.

(d) Glass. Glass-making is a good example of a technique imported into al-Andalus in its Chinese form, essentially unchanged. Throughout the Islamic world, glass was either cut from crystal or blown in molds. The technique of cutting crystal was said to have been introduced in al-Andalus by 'Abbâs ibn Firnas, poet and astrologer in the courts of 'Abd al-Rahmân II and Muhammad I. ('Abbâs had other technological interests: he built a clock, a planetarium, and an armillary sphere, and made an unsuccessful attempt to fly by donning a feather-covered silk suit.) (52)

Glass vessels were blown in Islamic Almería, Málaga, and Murcia, doubtless in imitation of eastern wares, such as the *irakes* -- glass goblets - so favored on the noble tables of tenth-century León. It is known that Islamic styles, and therefore presumably Islamic techniques, were imitated by Catalan glassmakers, who must, however, also have had access to western European styles and techniques as well. In 1189 the monastery of Poblet granted to the glassblower Guillem the right to gather glasswort in return for tithe and two hundred pounds of sheet glass paid annually. (The site of these glassworks, at Narola, was excavated in 1935.) In the later middle ages there is ample documentation indicative of a flourishing glass industry in Barcelona (where glass furnaces were regarded as a fire hazard as early as 1324) and other Catalan towns. It is in the fourteenth century that imitation of eastern styles becomes explicit, e.g., frequent citations of "glass of Damascus" (referring to Syrian, or Syrian-style, enamelled glass), or a 1396 citation of a rose-water sprinkler (called by an Arabism, *almorratxa*, from *mirashsha*, watering can) "of blue glass decorated with the work of Damascus." In 1387, the council of Tortosa ordered the purchase of a glass lamp, either made in Damascus or an imitation thereof. Formulas of eastern inspiration designed to strengthen or to color glass also circulated: several are given in the *Lapidario* of Alfonso X. (53)

(e) Paper. Paper, one of a number of Chinese techniques whose westward passage was eased by the inclusion of Turkestan within the Islamic [242] orbit, was known in al-Andalus by the mid-tenth century, as evidenced by the appearance around this time of the surname al-Warrâq, "the papermaker."

Because it was a completely new technique without local precedent, it was able to break with the pattern of traditional craft organization and was typically mass-produced in large water-powered mills. The scale of production was a response to the burgeoning of Islamic scholarship with which the diffusion of this technique coincided.⁽⁵⁴⁾

When Andalusí scholars went east, they made copies of books on paper and then, upon returning home, transferred their drafts to parchment, which was thought more durable. Early papermakers thus attempted to imitate parchment (thus it is called "rag parchment"-- *pergamino de paño* -in the *Siete Partidas*), an effect achieved by sizing it with wheat starch, a Persian innovation which rendered the paper's surface more suitable for writing with ink. Other sizings were also used: the *Lapidario* of Alfonso the Wise recommends a substance called *omna* to make the paper whiter and glossier. In the Islamic West paper was made from flax fibers (generally in the form of old cloth scraps), which were soaked in quicklime, washed, pounded, and dried in molds. In Christian Spain, the gathering of rags for the paper industry was a profession in itself, as evidenced by a grant by the King of Aragón in 1287, empowering two citizens of Menorca to search for cloth scraps with which to make paper.⁽⁵⁵⁾

The paper-making center of al-Andalus was Játiva, which produced a distinctive product still known as *shâtibî* in Morocco. It is assumed, but not proved, that the water-driven mill was used in Islamic Játiva; documentation shows Muslims of Játiva operating a paper mill (*almerxampapiri*; note the Arabism, from *mi'sara*, "press"). Since the texture and composition of the oldest surviving specimens of medieval Catalan paper are identical to the Andalusí product, the techniques of paper making in both societies can be presumed to have been identical. References to paper mills abound in Catalan documents of the twelfth century, and, by the thirteenth, paper was exported to Sicily from both Barcelona and Valencia. The Valencian exports doubtless originated in Játiva, where the Muslim community received royal support for the continued production of paper; not only were the Muslims of Játiva granted a virtual monopoly in the kingdom of Valencia, but a prohibition against Valencian Muslims producing paper anywhere but in Játiva probably is indicative of the deliberate concentration of that industry there.⁽⁵⁶⁾

(f) Textiles. Of the various medieval textile technologies, that of silk [243] weaving is best documented. Because of the regional specialization typical of medieval craft organization and the demand in international commerce for high-quality silken cloth, this industry was characterized by a relatively high degree of diffusion and imitation of styles and techniques. Certain wares, such as *tirâz* (silken cloth embroidered with lettering), were so stylized that the paths of their diffusion were noted by contemporaries and are therefore quite easy to trace. In al-Andalus, the production of eastern-style cloth was concentrated in the towns of Málaga and Almería, which, as ports, were the first to receive the new techniques or styles. Almería's role in this process was particularly salient in the twelfth century: "In the industry of *tirâz* and of silk there were eight hundred workshops and one thousand for excellent tunics and brocade, and as many more for *ciclato*; the same for *jurjanî* and *isfahanî* cloth; the material called *'attabî*, the surprising *mi'jar* and tapestries embroidered with flowers for saddles."⁽⁵⁷⁾ *Jurjanî* and *isfahanî* refer specifically to the types of ware distinctive of the Persian cities of Jurjan and Isfahan; *'attabi* is a silk and cotton fabric named after a quarter of Baghdad where it was originally produced. (Baghdadi wares were imitated as a matter of state policy: Andalusí emirs of the ninth century encouraged the duplication of Iraqi styles and techniques. In the early tenth century, Muhammad ibn 'Ubayd learned how to make brocade in Baghdad according to techniques which he continued to use in Córdoba. Baghdad silks were so popular that Andalusí weavers falsified the place of origin in the decorative inscriptions on the cloth.) Also imitated were *tustarî* (Persian), *dabiqî* (Egyptian), *irmînî* (Armenian), and *siqillî* (Sicilian) cloths.⁽⁵⁸⁾ *Tirâz* was typically a state monopoly and was produced by specially trained weavers in royally financed establishments (e.g., the *dâr al-tirâz* of the Umayyad emirs). According to ibn Khaldûn, the Party Kings continued the Umayyad style and

diffused it to North Africa. It was also copied in Christian Spain. We have noted the settlement in León of a group of *tiraceros de rey*. Tenth-century documents refer to *tirâz*, probably imported, and later documents mention *manteles letrados*.⁽⁵⁹⁾

The diffusion of Persian-style cloth with complex geometric designs implies as well the concomitant diffusion of the Persian draw loom with enough heddles (four for the twill binding and at least four for the pattern) to produce such patterns. The *hisba* treatise of al-Saqatî provides locations for looms, regulating the minimum dimensions required for the weaving of fine silk. Similar regulations occur in the municipal [244] ordinances of Christian Seville and Toledo, indicating continuity in silk-weaving procedures.⁽⁶⁰⁾

Other weaving techniques, such as the making of esparto mats, were likewise continued by Christians in substantially the same form as developed by Andalusí Muslims.⁽⁶¹⁾

(g) Net fishing. The terminology of net fishing along the Mediterranean coasts of southern Spain is so heavily laced with Arabisms that one must assume an Islamic origin. Along with elements of navigational, shipbuilding (for example, the sternpost rudder) and other maritime technologies, fishing techniques made their way from the Red Sea and Arabian Gulf to al-Andalus as Arab mariners migrated westward or participated in maritime commerce. The drag net, *aljerife (jarîf)*, is a common south Arabian net with two arms, operated from the shore. Other nets of apparent Arab influence or origin are the tuna trap (*almadraba*, from *madraba*); the conical net (*atarraya*, from *tarrâha*); the purse seine (*jareta*, from *sharît*); and the pocket seine (*jabega*, from *shabbak*).⁽⁶²⁾

(h) Clocks. A variety of non-mechanical techniques and devices were used for timing irrigation water. Two of these, the sinking bowl and the outflow clepsydra, although ancient, probably had, by medieval times, come to be wholly associated with Andalusí irrigation practices. The use of both was widely diffused and quite homogeneous throughout the Andalusí-Magribi orbit.⁽⁶³⁾

In the *Libros de saber de astronomia*, Isaac ibn Sîd described five time-measuring devices, more or less of ancient provenance but filtered through the prism of Arabic science. The clocks described were (1) a sundial divided into quadrants, to be used with a table of declination of the sun; (2) the "Palace of Hours," a cupola on the interior walls of which the hours of daylight were marked by sunlight shining through a progression of windows; (3) a clepsydra, wherein water whose flow is regulated by a siphon turns an astrolabe; (4) a candle clock whose indicator is moved by a counterweight regulated by the candle; and (5) a compartmented cylindrical mercury clock (also a clepsydra). The mercury and water clocks were conceptually the most important because they had astrolabes for dials and were therefore true chronometers rather than devices which illustrated the movement of the heavenly spheres. The mercury clock was said by Isaac to have been built two hundred years before by "Iran," an anachronistic reference to Hero of Alexandria, which nonetheless indicates that the Arabs had known the principle of weight-driven [245] mechanical clocks two centuries before it was appreciated in the Latin West. This clock was a perpetual motion machine which, as the mercury flowed from compartment to compartment, rotated an astrolabe dial, set for Toledo, where Alfonso the Wise maintained his observatory, once every twenty-four hours. The clepsydra had an eleventh-century antecedent in the water clock built in Toledo by al-Zarqâl.⁽⁶⁴⁾

A host of other techniques reveal the same pattern of diffusion from east to west within the Islamic world, and thence to the Latin West. The case of sugar refining, a Chinese factory-scale technique which diffused westward with the crop itself, is obvious, although the Christians did not acquire the technique until the early fourteenth century. Of eastern provenance also were the tanning techniques that produced a number of soft leathers: *guadameci* (after the oasis of Ghadames), which was sheepskin tawed with alum, and Cordoban, which was vegetable-tanned goatskin. These methods were developed

in al-Andalus, probably on eastern or North African models, and subsequently diffused in the Christian West. A more inferential case is the snow well, a rudimentary but effective method of preserving snow for use in cooling in summertime. The similarity of snow wells in Spain and in the Islamic East, as well as the citation by Spanish authors (e.g., Monardes) of Arabic pharmacological prescriptions, including snow as an ingredient, lead to an assumption of cultural continuity.⁽⁶⁵⁾

Techniques of ivory decoration provide an example of the variegated responses to Islamic art on the frontier. The carving of has reliefs in ivory was an Islamic technique (initially of Persian inspiration) highly valued by Christian Spaniards, who prized carved ivory coffers or reliquaries as booty and as objects of trade. In the Islamic world, ivory-carving was related to the technology of gold and silver working and also to the carving of wood, which, owing to its scarcity, was treated with higher regard by Muslim artisans than by their European counterparts. Ivory was carved in various Andalusí towns, particularly Cuenca, and Mozarabs established an ivory workshop at San Millán de la Cogolla in imitation of those of Córdoba. But ivories *painted* with Arabic inscriptions also appeared in medieval Spain, ostensibly produced for the Christian market, more western than Islamic stylistically. Pinder-Wilson identifies this kind of interaction of artistic tastes as characteristic of areas on the fringe of the Islamic world.⁽⁶⁶⁾

It is clear that the tremendous flow of techniques from east to west - [246] in part a result of the international trading system of the medieval Islamic world, and in part a cause of it -- was at the heart of the economic dynamism of al-Andalus and of that society's ability to remain economically viable even in the face of political disorganization at home and the pressure of enemy attack. The kinds of techniques diffused were to a great extent determined by the environmental constraints of the resource-poor Mediterranean basin, as Maurice Lombard reiterates, pointing to the probable cause of the late medieval Islamic decline.

In regard to the role of technological diffusion in Christian Spain, the processes were similar, although retarded by socio-political factors unfavorable to urbanization, on the one hand, and by the overweening dominance of Andalusí manufactures in the marketplace, on the other. Once the southern emporium was destroyed, a more normative pattern of technological diffusion was instated. Castro's argument that Spaniards have always been importers of foreign technologies, only that in the middle ages (after 1085) the "exporters" (i.e., Jews and Mudéjars) were enclaves of technological expertise geographically inside the country, but ethnically outside, is misleading.⁽⁶⁷⁾ It is true that, in an ethnically plural society, economic division of labor often follows along lines of ethnic cleavage; but such lines of cleavage do not necessarily act as barriers to technological diffusion. They may have the opposite effect.

Castro must have assumed (as does Sánchez-Albornoz) that some peoples are naturally endowed with certain technologies, and that these technologies therefore diffuse across cultural boundaries with great difficulty. That this is not the case, and that receptivity to technological innovation is governed by a variety of extrinsic social and economic factors, can be appreciated by turning the equation around and noting that in the fifteenth and sixteenth centuries Jews bore Spanish technology with them to the Balkans and, moreover, these technologies (e.g., textile weaving, glass blowing) were not identifiably "Jewish." The same is true of the Moriscos, who bore generalized technological information (e.g., firearms, New World crops) to North Africa.

In the middle ages, Jews were prominent in certain crafts (dyeing, metal working) and Mudéjars in the building trades. Both groups undoubtedly played a role in the transmission of technological elements after 1085, in the first phase of cultural adjustment subsequent to conquest, during which Christians acquired many of the trappings of the subject population. After this early phase of contact, Muslims, in particular, [247] suffered tremendous technological loss, as the most talented and successful artisans

migrated and those who remained were forced into increasingly restricted roles, both economically and creatively.

Moreover, the diffusion of techniques across cultural borders is a normative process, whether those borders are political or simply define an ethnic entity. Ethnic boundaries are not hermetically sealed, any more than is the border between France and Spain. Elements were constantly being exchanged across those borders. Then too, the diffusion of Frankish techniques to Christian Spain was a process identical to that governing diffusion of techniques from the Islamic world. The identification, therefore, of Jews and Muslims as the sole repositories of technological innovation or expertise is inexact.

One could, in fact, make the case that Christians of the high middle ages had a rather high value for technological expertise, to judge by the number of technologists who were canonized. Best known is Santo Domingo de la Calzada, who built the bridge over the Oja River with a timber framework and pillars of stone, as well as constructing hostels for pilgrims and repairing roadbeds along the pilgrimage route. His disciple, San Juan de Ortega, was also a builder of roads and bridges. The patron saint of Burgos, San Adelelmo or Lesmes, was best remembered for devising a sewage system for the town by diverting water from the Pico and Vena streams (affluents of the Arlanzón) through canals which he constructed down the centers of the streets. With an adequate drop, the water carried the sewage off. These conduits were called *esquevas* and were imitated in Valladolid and other towns.⁽⁶⁸⁾

The implantation of new techniques in Christian towns of the middle ages, whether through the migration of artisans (San Adelelmo was French; the other two saints were Spanish), utilization of the skills of ethnic enclaves, or imitation of foreign wares, was a function of the growth and mobilization of indigenous Christian capital. Castro's view of a Christian economy colonized, in effect, by its own ethnic subordinates, is simply not believable.

Notes for Chapter 7

1. Needham, "Central Asia in the History of Science and Technology," p. 137; Juan Verner, "La ciencia en el Islam y Occidente," *Occidente e l'Islam nell'altomedioevo*, II: 549-550.
2. On regional specialization, see Goitein, *Studies in Islamic History*, p. 265; Lombard, *L'Islam*, p. 185. On commerce as a stimulus to the transfer of technology, Bonnassie, *La Catalogne*, I: 485. On imitation as a stimulus for technological change, see Keith Nicklin, "Stability and Innovation in Pottery Manufacture," *World Archaeology*, 3 (1971-1972), 20.
3. Goitein, *Letters of Medieval Jewish Traders*, p. 266 n. 17; Hans E. Wulff, *The Traditional Crafts of Persia* (Cambridge, Mass.: M.I.T. Press, 1966), p. 62. Goitein perhaps underestimates the training of scales-makers; a *mawâzînî* of Toledo made astrolabes in mid-eleventh century; J. M. Millás Vallicrosa, *Assaig d'història de les idees físiques i matemàtiques a la Catalunya medieval* (Barcelona: Institució Patxot, 1931), p. 69.
4. See discussion in section 2, below, and also Gual Camarena, "Para un mapa de la industria textil," p. 110.
5. On resource constraints on technology, see Lombard, *Espaces et réseaux*, p. 169, and *L'Islam*, p. 176. On Arab dependence on others for iron-forging, Bulliet, *The Camel and the Wheel*, p. 94.
6. Bertran Gille, "Technological Developments in Europe: 1100 to 1400," in *The Evolution of Science*, Guy S. Métraux and François Crouzet, eds. (New York: Mentor, 1963), p. 201.
7. Lynn White, Jr., "Cultural Climates and Technical Advance in the Middle Ages," *Viator*, 2 (1971), p. 181.

8. Foster, *Culture and Conquest*; Juan F. Riaño, *The Industrial Arts in Spain* (London:Chapman and Hall, 1879), pp. 149-151.
9. On familial adscription to trades, see Goitein, *Studies in Islamic History*, pp. 261, 269; *idem*, *Mediterranean Society*, I: 79; Horace M. Miner, "Traditional Mobility among the Weavers of Fez," *Proceedings of the American Philosophical Society*, 117 (1973), 17-36. On the French *urbanistes*, *ibid.*, p. 19, citing Roger Le Tourneau, *Fès avant le protectorat* (Casablanca: SMLE, 1949), p. 2, and Torres Balbás, *Ciudades hispanomusulmanas*, I: 131, citing Louis Massignon. On the conservatism of traditional artisans, see George M. Foster, "The Sociology of Pottery: Questions and Hypotheses Arising from Contemporary Mexican Work," in *Ceramics and Man*, Frederick R. Matson, ed. (Chicago: Aldine, 1965), p. 49. On the small scale of industry, Goitein, *Mediterranean Society*, I: 80-81 (small workshop with single craftsman), whose conclusions are supported by documentary and archeological evidence in Torres Balbás, *Ciudades hispanomusulmanas*, I: 317-320 (on *operatoria*).
10. On the migration of artisans, see Karl W. Deutsch, "Medieval Unity and the Economic Conditions for an International Civilization," in *Early Medieval Society*, Thrupp, ed., p. 248; Richard Ettinghausen, "Interaction and Integration in Islamic Art," in *Unity and Variety in Muslim Civilization*, G. E. von Grunebaum, ed. (Chicago: University of Chicago Press, 1955), pp. 110, 113; Goitein, *Mediterranean Society*, I: 49, 51.
11. Lombard, *Espaces et réseaux*, p. 105; Ettinghausen, "Interaction and Integration in Islamic Art," p. 113; Luis M. Llubiá, *Cerámica medieval española*, 2nd ed. (Barcelona: Labor, 1973), p. 90; Torres Balbás, "Gibraltar, llave y guarda de España," *Al-Andalus*, 7 (1942), 174; Georges S. Colin, "L'Origine des norias de Fès," *Hespéris*, 16 (1933), 156-157; Goitein, *Studies in Islamic History*, p. 265.
12. Al-Khushanî, *Historia de los jueces de Córdoba*, Julián Ribera, ed. and trans. (Madrid: Centro de Estudios Históricos, 1914), pp. 137 (text), 169-170 (trans.). Note that the term for oven is *furn*, a Latinism, while that for tube is Arabic *unbûb*.
13. Lacarra, "Aspectos económicos de la sumisión de los reinos de Taifas," pp. 270, 273; Represa, "Genesis y evolución urbana de Zamora," p. 526; Sánchez-Albornoz, *Investigaciones y documentos*, pp. 173-174; Yáñez, *Monasterio de Santiago de León*, p. 246; Vázquez de Parga, *Peregrinaciones a Santiago*, II: 472 n. 20; González García, *Salamanca*, p. 82; Luis Rubio García, "Los documentos del Pilar (s. XII)," *VII Congreso de Historia de la Corona de Aragón*, II: 322-323; Lladonosa Pujol, "Proyección urbana de Lérida," p. 197; Agustí Altsient, "Una societât mercantîl a Catalunya a darrerîes del segle XII," *Boletín de la Academia de Buenas Letras de Barcelona*, 32 (1967-1968), 59; Marcelin Defourneaux, *Les français en Espagne au XIe et XIIe siècles* (Paris: Presses Universitaires de France, 1949); Bonnassie, *La Catalogne*, I, 487; Gual Camarena, "Comercio de telas," p. 88.
14. Ignace Goldziher, "The Spanish Arabs and Islam," *The Muslim World*, 53 (1963), 8 n. 5.
15. Riaño, *Industrial Arts in Spain*, p. 163; Josep M. Madurell i Marimon, *El paper a les terres catalanes. Contribució a la seva història*, 2 vols. (Barcelona: Fundació Vives Casajuana, 1972), II: 968; Torres Fontes, *Repartimiento de la huerta y campo de Murcia*, p. 46; Gual Camarena, "Comercio de telas," p. 93; *idem*, "Para un mapa de la industria textil," p. 150.
16. Mobarec Asfura, "Condición jurídica de los moros," p. 42; Torres Fontes, *Los rnuvéiares murcianos en el siglo XIII*, p. 12; Gual Camarena, "Para un mapa de la industria textil," pp. 136, 142; Llubiá, *Cerámica medieval española*, p. 183; G. J. Osma, *Los maestros alfareros de Manises, Paterna y Valencia*, 2nd ed. (Madrid: Instituto de Valencia de D. Juan, 1923), pp. 18.21; Lombard, *L'Islam*, pp. 187; Robert I. Burns, "Immigrants from Islam: The Crusaders' Use of Muslims as Settlers in Thirteenth-Century Spain," *American Historical Review*, 80 (1975), 30.
17. Thomas F. Glick, "Cob Walls Revisited: The Diffusion of Tabby Construction in the Western

Mediterranean World," in Bert S. Hall and Delno C. West, eds., *On Pre-Modern Technology and Science: Studies in Honor of Lynn White, Jr.* (Los Angeles: Center for Medieval and Renaissance Studies, 1976), pp. 147-159.

18. Glick, *Irrigation and Society in Medieval Valencia*, pp. 176-177; J. A. García-Diego, "The Chapter on Weirs in the Codex of Juanelo Turriano," *Technology and Culture*, 17 (1976), 218-219; Norman Smith, *A History of Dams* (London: Peter Davies, 1971), pp. 87, 92-93, 101, 104-105, 108-109.

19. Glick, *Irrigation and Society in Medieval Valencia*, pp. 182-184; Bolens, "L'Eau et l'irrigation," p. 66; Bonnassie, *La Catalogne*, I: 465; Torres Balbás, *Ciudades hispanomusulmanas*, pp. 49, 152; Vázquez de Parga, *Peregrinaciones a Santiago*, I: 56; Smith, *History of Dams*, pp. 90-91; Oliver Asín, *Historia del nombre "Madrid."*

20. Glick, *Irrigation and Society in Medieval Valencia*, p. 178; Steiger, *Toponimia árabe de Murcia*, p. 12; Torres Fontes, *Repartimiento de la huerta y campo de Murcia*, p. 39; Moreta, *San Pedro de Cardeña*, p. 77.

21. K. D. White, *Roman Farming*, pp. 174-175; Juan Martínez Ruíz, "Notas sobre el arado bereber de Beni Chicar (Marruecos)," *Revista de Dialectología y Tradiciones Populares*, 22 (1966), 323, 327-328; García de Cortázar, *San Millán de la Cogolla*, pp. 91, 269; Bonnassie, *La Catalogne*, p. 478.

22. Smith, *History of Dams*, p. 88; Torres Balbás, *Ciudades hispanomusulmanas*, 51; ibn Bassâl, *Libro de agricultura*, pp. 55 (text), 61-62 (trans.); Millás Vallicrosa, "Sobre la obra de agriculture de ibn Bassâl," p. 140; Bolens, "L'Eau et l'irrigation," pp. 72-73; Torres Fontes, *Repartimiento de la huerta y campo de Murcia*, p. 51; Goitein, *Mediterranean Society*, I: 113; Thomas F. Glick, "Levels and Levelers: Surveying Irrigation Canals in Medieval Valencia," *Technology and Culture*, 9 (1968), 165-180; Millás Vallicrosa, "La introducción del cuadrante con cursor en Europa," *Estudios sobre historia de la ciencia española* (Barcelona: Consejo Superior de Investigaciones Científicas, 1949), pp. 67-69; *idem*, *Assaig d'història de les idees físiques*, pp. 167-168.

23. Oliver Asín, "Quercus en la España musulmana," *passim*; ibn 'Arabî, *Sufis of Andalusia*, p. 126; Goitein, *Mediterranean Society*, I: 111, 422; Chalmeta, "El 'Kitâb fî âdâb al-hisba," *Al-Andalus*, 33 (1968), 397-398; Lévi-Provençal, *Sevillemusulmane*, p. 133.

24. For some indications of medieval iron technology, see Gual Camarena, "El hierro en el medioevo hispano," and L. Salkield, "Ancient Slags," in *La mineria hispana e iberoamericana*, I: 93.

25. For some indications of medieval iron technology, see Gual Camarena, "El hierro en el medioevo hispano," and L. Salkield, "Ancient Slags," in *La mineria hispana e iberoamericana*, I: 93.

26. Needham, *Science and Civilisation in China*, IV, part 2: 405.

27. On rural-urban dichotomies in mill types, see John Muendel, "The Horizontal Mills of Medieval Pistoia," *Technology and Culture*, 15 (1974), 209, 213; and Louis C. Hunter, "The Living Past in the Appalachias of Europe: Water-Mills in Southern Europe," *ibid.*, 8 (1967), 455.

28. Muendel, "Horizontal Mills," pp. 200, 209; Julio González, "Aranceles del portazgo de Sahagún en el siglo XIII," *Anuario de Historia del Derecho Español*, 14 (1942-1943), 577.

29. Represa, "Genesis y evolución de la Zamora medieval," p. 526; Julio Caro Baroja, "Sobre maquinarias de tradición antigua y medieval," *Revista de Dialectología y Tradiciones Populares*, 12 (1956), 150. The term *azenia* is either found alone in Castilian documents or linked with *molendinum*. When the reference is to, e.g., *aceniis et molendinis*, there may be an implicit distinction between vertical and horizontal mills, respectively. When *azenia* appears alone, it might refer either to a vertical, undershot mill, or, conceivably, to a dual-purpose wheel driving the grindstone of a gristmill. On

terminology, see Gautier-Dalché "Moulin à eau," p. 341 n. 30; on dual-purpose *norias*, see Smith, *Man and Water*, p. 142.

30. García de Cortázar, *San Millán de la Cogolla*, p. 250; Wulff, *Traditional Crafts of Persia*, p. 279 (on longevity of stones); González, "Aranceles del portazgo," pp. 577, 578; Rodríguez Fernández, *La judería de la ciudad de León*, p. 97.

31. See descriptions of Catalan horizontal mills in Jean-Pierre Cuvillier, "Les communautés rurales de la plaine de Vich (Catalogne) au XIIIe et XIVE siècles," *Mélanges de la Casa de Velazquez*, 4 (1968), 86, and diagram in appendix III-I; and Bonnassie, *La Catalogne*, I: 461. These systems were identical to those of southern France; see Pierre Gérard and Elisabeth Magnou, eds., *Cartulaires des Templiers de Douzens* (Paris: Bibliothèque Nationale, 1965), xxix-xxxii. Note that the diagram on p. xxx is erroneous, inasmuch as it confuses the *resclausa* (diversion dam) with the *caput rego*, which is the mill's intake channel. On the dressing of millstones, see Caro Baroja, "Maquinarias de tradición antigua," p. 163.

32. *El Fuero de Jaca*, Molho, ed., pp. 49, 108, 390.

33. Lynn White, Jr., *Medieval Technology and Social Change* (Oxford: Clarendon Press, 1962), p. 161; Neuvonen, *Arabismos del español*, pp. 249-250; Jaime Oliver Asín, "El hispanoárabe al-farnât 'los molinos harineros' en la toponimia peninsular," *Al-Andalus*, 23 (1958), 456-459. Note the term *rouet arabe* describing a horizontal wheel with curved blades, in Languedoc; Smith, *Man and Water*, p. 219 n. 7.

34. Undershot wheels run on the impact, from fall, of the water, while overshot wheels are impelled by the weight of the water alone (see Smith, *Man and Water*, p. 147). On the general pattern of massing, see Hunter, "Water-Mills in Southern Europe," pp. 463-464; and Charles F. Gritzner, "Hispano Gristmills in New Mexico," *Annals of the Association of American Geographers*, 64 (1974), 516. For mills in Córdoba, Torres Balbás, *Ciudades hispanomusulmanas*, pp. 140, 142; on *ribulo molendinis*, Pallares and Portela, *Bajo valle del Miño*, p. 27. On the pairing of overshot and undershot mills, Needham, *Science and Civilization in China*, IV: 402. See also al-Saqundî, *Elogio del Islam español*, p. 108, for a reference to "inside" and "outside" mills (*arhâ' al-dâkhila w'al-khârija*), which would seem the equivalent of the Castilian *rueda de dentro*, *rueda de fora* to identify whether the millwheel is within the mill house or outside; see Gautier-Dalché, "Moulin à eau," p. 347 n. 84, on the association of mills with dams and bridges, G. Menéndez Pidal, *Caminos en la historia de España*, p. 65; Smith, *History of Dams*, p. 90; *idem*, *Man and Water*, p. 142.

35. Marc Bloch, "The Advent and Triumph of the Watermill," in *Land and Work in Medieval Europe* (New York: Harper and Row, 1969), pp. 149, 157-159; *Poema de Fernán González*, p. 117 (verse 383). See Wulff, *Traditional Crafts of Persia*, pp. 277 (hand querns), 292 (*tanûrs*).

36. On the fulling mill, Caro Baroja, "Maquinarias de tradición antigua," pp. 145-153; Gual Camarena, "Comercio de telas," p. 92 n. 31. On forges, Caro Baroja, *op.cit.*, p. 116, and Gille, "Technological Developments," pp. 175, 198. On paper mills, Oriol Valls i Subirà, "Caracteristiques del paper de procedència o escola àrab," *VII Congreso de Historia de la Corona de Aragón*, III: 320; Madurell i Marimon, *Paper a terres catalanes*, II: 961-962. On river-driven undershot mills, Smith, *Man and Water*, p. 143.

37. See discussion in White, *Medieval Technology and Social Change*, p. 161 and references; Needham, *Science and Civilisation in China*, I: 245.

38. Needham, *Science and Civilisation in China*, IV, 2: 321-322; see the illustrations in Alvar, *Atlas lingüístico*, I: lámina 127. For *atahorra*, *ataharre*, *ibid.*, Lámina 178, and Julio Fernández-Sevilla, *Formas y estructuras en el léxico agrícola andaluz* (Madrid: Consejo Superior de Investigaciones

Científicas, 1975), p. 367. On the etymology of *jáquima*, J. Corominas, *Diccionario crítico etimológico de la lengua castellana*, 4 vols. (Madrid: Gredos, 1954), II: 1035. Bulliet, *The Camel and the Wheel*, pp. 197, 199, 204-205.

39. Louis Mercier, "Les écoles espagnoles dites de la Brida et de la Gineta (ou Jineta)," *Revue de Cavalerie*, 37 (1927), 301-315; G. Menéndez Pidal, *Caminos en la historia de España*, p. 43; White, *Medieval Technology and Social Change*, pp. 36, 152-153; Emilio García Gómez, "Armas, banderas, tiendas de campaña, monturas y correos en los 'Anales de al-Hakam II' por Isa Razi," *Al-Andalus*, 32 (1967), 163, 165, 167; Neuvonen, *Arabismos del español*, pp. 104-105, 130-131; Riaño, *Industrial Arts in Spain*, pp. 88-89.

40. Bolens, "L'Eau et l'irrigation," p. 66; Castrillo Márquez, "Descripción de al-Andalus," p. 101; Glick, *Irrigation and Society in Medieval Valencia*, p. 178.

41. Schiøler, *Roman and Islamic Water-Lifting Wheels*, pp. 16, 79-83; Bolens, "L'Eau et l'irrigation," pp. 71-72.

42. Torres Balbás, *Ciudades hispanomusulmanas*, pp. 140, 144; Pérès, *Poésie andalouse*, pp. 204-205; Bolens, "L'Eau et l'irrigation," p. 66; Glick, *Irrigation and Society in Medieval Valencia*, p. 180.

43. Bolens, "L'Eau et l'irrigation," p. 72; Schiøler, *Roman and Islamic Water-Lifting Wheels*, pp. 169-170; Glick, *Irrigation and Society in Medieval Valencia*, p. 150; Antoni M. Alcover, *Diccionari català-valencià-balear*, 10 vols. (Palma: M. Alcover, 1930-1962), IX: 825-826 (s.v. *sènia*).

44. Ibn al-Razzâz al-Jazacî, *The Book of Knowledge of Ingenious Mechanical Devices*, Donald R. Hill, trans. (Dordrecht: Reidel, 1974), pp. 182-183; Schiøler, *Roman and Islamic Water-Lifting Wheels*, pp. 67-72; José Augusto Sánchez Pérez, *La personalidad científica y los relojes de Alfonso X el Sabio* (Murcia: Academic Alfonso X el Sabio, 1955), pp. 21-24.

45. Bolens, "L'Eau et l'irrigation," p. 71; ibn Bassâl, *Libro de agricultura*, pp. 223-226 (trans.); Needham, "Central Asia and the History of Science," p. 138.

46. On the evolutionary sequence of potting techniques, see George M. Foster, "The Potter's Wheel: An Analysis of Idea and Artifact in Invention," *Southwestern Journal of Anthropology*, 15 (1959), 99-119; on regression in technique (in Europe and North Africa), see Nicklin, "Stability and Innovation in Pottery Manufacture," p. 43; for terminology in the Fuero de Teruel, Llubiá, *Cerámica medieval española*, p. 128; on turntables and kick wheels in Castile, Natcha Seseña Díaz, "Pucheros de Alcorón," *Revista de Dialectología y Tradiciones Populares*, 22 (1966), 129; "La alfarería de Mota del Cuervo," *ibid.*, 23 (1967), 339-346; and *La cerámica popular en Castilla la Nueva* (Madrid: Editora Nacional, 1975), Pp. 38-44.

47. Juan Zozaya, "Red-Painted and Glazed Pottery in Western Europe: Spain," *Medieval Archaeology*, 13 (1969), 133-136, and comment by Guichard, *Al-Andalus*, p. 306.

48. See references in Thomas F. Glick, "Noria Pots in Spain," *Technology and Culture*, 18 (1977), 646-647. Note also that English, albatross (first pelican, then frigate bird) derived from Portuguese, *alcatraz*, comorant is another derivative of *qâdûs*. See Eric Partridge, *Origins*, 2nd ed. (London: Routledge and Kegan Paul, 1959), p. 11.

49. Llubiá, *Cerámica medieval española*, pp. 37-38, 90, 115; Osma, *Maestros alfareros*, p. 7 n. 2; Wulff, *Traditional Crafts of Persia*, p. 144; Riaño, *Industrial Arts in Spain*, pp. 146, 153.

50. Robert Steele, "Practical Chemistry in the Twelfth Century," *Isis*, 12 (1929), 10-46 *passim*; Wulff, *Traditional Crafts of Persia*, p. 159; Daniel Rhodes, *Kilns: Design, Construction and Operation* (Radnor, Pa.: Chilton, 1968), pp. 36-37, 40 (especially figures 39 and 41); Llubiá, *Cerámica medieval*

- española*, pp. 77, 183; Mut, *Vida económica en Lérida*, p. 101; Rodríguez Fernández, *Monasterio de Ardón*, p.215; Seseña, *Cerámica popular*, p. 50.
51. Torres Fontes, *Mudéjares murcianos*, p. 20; Juan Zozaya, "Cerámicas medievales del Museo Provincial de Soria," *Celtiberia*, 21 (1971), 217.
52. Elias Terés, "Abbâs ibn Firnas," *Al-Andalus*, 25 (1960), 241-242; Juan Vernet, "Abbâs ibn Firnas," *DSB*, I: 5.
53. Alice Wilson Frothingham, *Spanish Glass* (New York: Thomas Yoseloff, 1964), pp. 13, 20-24; Alfonso X, *Lapidario*, Maria Brey Marñio, ed. (Madrid: Castalia, 1968), pp. 204-205 (chaps. 259, 269).
54. Lombard, *L'Islam*, p. 191; Goitein, *Mediterranean Society*, I: 81, 91; Vernet, "Ciencia en el Islam y occidente," p. 550.
55. Mones, "Hommes de religion," p. 75; Martin Levey, *Mediaeval Arabic Bookmaking and its Relation to Early Chemistry and Pharmacology* (Philadelphia: American Philosophical Society, 1962), p. 10; Valls i Subirà, "Caracteristiques del paper," p. 321; Wulff, *Traditional Crafts of Persia*, p. 237; Alfonso X, *Lapidario*, p.106 (chap. 118); Madurell y Marimon, *Paper a terres catalanes*, I: 27; II: 967.
56. Lombard, *L'Islam*, p. 191; Madurell, *Paper a terres catalanes*, II: 963-968; Valls i Subirà, "Caracteristiques del paper," pp. 319-321; Burns, *Islam under the Crusaders*, p. 94; *idem*, *Medieval Colonialism*, pp. 238-239.
57. Castrillo Márquez, "Descripción de al-Andalus," p. 97.
58. Ettinghausen, "Interaction and Integration in Islamic Art," p. 110; *idem*, "Impact of Arts on the Arts of Europe," in *Legacy of Islam*, Joseph Schacht, ed., second ed. (Oxford: Clarendon Press, 1974), p. 298; Sánchez-Albornoz, *España: Un enigma histórico*, II: 108; Goitein, *Mediterranean Society*, I: 50; Lombard, *L'Islam*, p. 185.
59. Ibn Khaldûn, *The Muqaddimah*, II: 66-67; Gómez-Moreno, *Iglesias mozárabes*, pp. 123 (*tiracero*), 128 (*tiraz*); Jesusa Alfau de Solalinde, *Nomenclatura de los tejidos españoles del siglo XIII* (Madrid: Real Academia Española, 1969), p. 27; note the fame of Almería cloth in medieval French poetry (*ibid.*, pp. 22-25).
60. See Wulff, *Traditional Crafts of Persia*, p. 174; and Chalmeta, "El 'Kitâb fî âdâb al-hisba,'" *Al-Andalus*, 33 (1968), 398-399. The Castilian term *palacio*, meaning section of a comb, is a literal translation of Arabic *bayt* (house), the technical term for this implement.
61. Chalmeta, "El 'Kitâb fî âdâb al-hisba,'" *Al-Andalus*, 33 (1968), 405 n. 2.
62. Foster, *Culture and Conquest*, pp. 77-81; R. B. Serjeant, "Fisher-Folk and Fish Traps in al-Bahrain," *Bulletin of the School of Oriental and Asian Studies*, 31 (1968), 489; Braudel, *The Mediterranean*, II: 763; Juan Vernet, *Historia de la ciencia española* (Madrid: Instituto de España, 1975), p. 86.
63. Glick, "Medieval Irrigation Clocks," pp. 425-427; Steiger, *Toponimia árabede Murcia*, p. 16 (similarity of Berber and Murcian sinking bowls).
64. Sánchez Pérez, *Personalidad científica de Alfonso X*; Silvio A. Bedini, "The Compartmented Cylindrical Clepsydra," *Technology and Culture*, 3 (1962), 116-117; White, *Medieval Technology and Social Change*, p. 122; J. M. Millás Vallicrosa, *Estudios sobre Azarquiel* (Madrid-Granada: C.S.I.C., 1943-1950), pp. 6-9.
65. On sugar, see Gual Camarena, "Peaje fluvial del Ebro," pp. 171-172; on tanning, John Waterer, *Spanish Leather* (London: Faber and Faber, 1971), pp. 15-16; on snow wells, Vernet, "Ciencia en el

Islam y occidente," pp. 560-562.

66. On ivory, see R. Pinder-Wilson, "Adj," *El²*, I, 200-203; *Poema de Fernán González*, p. 83 (*arquetas de marfil*); Riaño, *Industrial Arts in Spain*, pp. 12, 133, 138, 141; J. Ferrandis, *Marfiles árabes de occidente*, 2 vols. (Madrid, 1935-1940), I, 47.

67. Castro, *The Spaniards*, p. 298.

68. Vázquez de Parga, *Peregrinaciones a Santiago de Compostela*, II, 162-173 (Santo Domingo), 173-175 (Juan de Ortega); Francisco Grandmontagne, "Un santo hidráulico," *El Sol*, August 29, 1925 (on San Adelelmo, following Albarellos, *Efemérides burgalesas*).