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# Technology and Society in the Medieval Centuries: Byzantium, Islam, and the West, 500–1300

By Pamela O. Long

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**Pamela O. Long** is an independent historian who has published extensively on medieval and late medieval/Renaissance cultural history, history of science, and technology. Her fellowships have included a Folger Shakespeare Library NEH long-term fellowship (1994–95), a senior fellowship at the Dibner Institute for the History of Science and Technology at the Massachusetts Institue of Technology (2000–01), the Andrew W. Mellon Foundation Post-Doctoral Rome Prize Fellowship from the American Academy in Rome (2003–04), and grants from the National Science Foundation. Her publications include *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance* (Baltimore, Md.: Johns Hopkins University Press, 2001), awarded the Morris D. Forkosch Prize by the *Journal of the History of Ideas* for the best first book in intellectual history published in 2001, and one of the previous booklets in the AHA/SHOT series—*Technology, Society, and Culture in Late Medieval/Renaissance Europe, 1300–1600.*

**Cover Illustration:** *Building the Tower of Babel.* Drawing from Herrad of Landsberg, Hortus deliciarum, twelfth century (original destroyed). Equipment seen here includes a hoe, at left; a hod (second figure from left) for carrying mortar; a pick, chisel, and mallet used by the stone-cutters on the right; a plumbline held by the man on the top; and a mason's trowel and mason's square held by the man standing at right-center. From *Das Lustgärtlein der Herrad von Landsberg,* ed. Maria Heinsius (Kolmar im Elass: Alsatia Verlag, n.d.), plate 7.

**Author's Note:** For the sake of simplicity I have avoided special characters in Arabic words and used the Gregorian calendar rather than the lunar calendar used by Muslims. I would like to warmly thank the readers of the manuscript who have saved me from many infelicities and errors—Glenn Bugh, Thomas F. Glick, Bert S. Hall, Richard W. Bulliet, and Steven A. Walton. I also thank Bob Post for heroic editing and Bob Korn for creating the maps and for extensive assistance with the illustrations. Any remaining errors are my own.

**Layout:** Christian A. Hale

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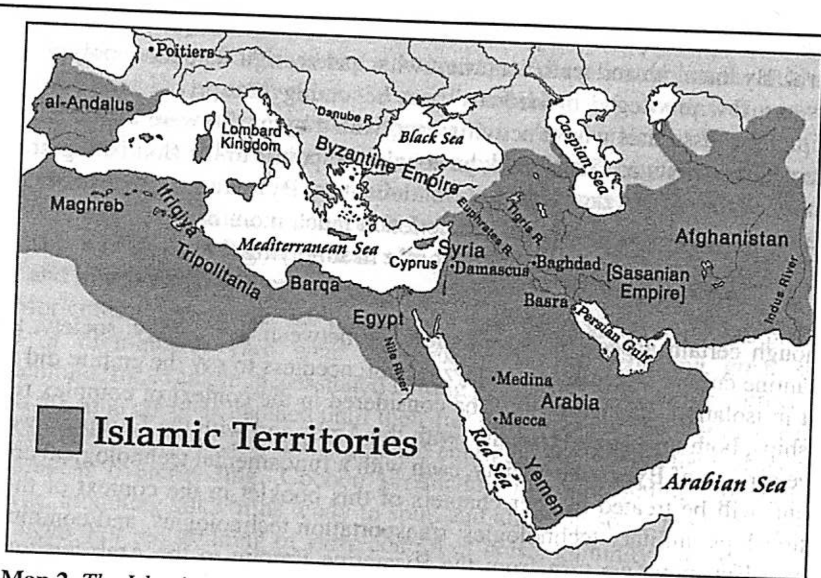


**Map 2.** *The Islamic territories, mid-tenth century.*



# 2

# Technology in the Islamic States

The rise of Islam and the Arab conquests of the seventh and early eighth centuries were remarkable historical events. In the hundred years after the death of the prophet Muhammad in 632, Islamic power was extended from India to Spain, while the extent of Byzantine power was severely curtailed. The Arab advance was stopped only in southern France by the Battle of Poitiers in 732. Historians have long debated the significance of the early Islamic conquests, but, as Fred McGraw Donner points out, expansion entailed two separate phenomena—first the conquests, namely the extension of Islamic power over new territories, and second, Arab migration, the movement of Arabic-speaking peoples from the Arabian peninsula into the new territories.[1]

## Pre-Islamic Arabia

More than anything else, the availability of water shaped the life and technologies of the Arab peoples. Yemen, in Southwest Arabia, received enough rainfall to support farming with the aid of extensive irrigation—that is, the artificial distribution of water by means of dams, cisterns, channels, and ditches. This agriculture allowed a fairly dense population and enabled the development of towns, crafts, and commerce. Elsewhere on the peninsula the rainfall was too sparse for irrigation agriculture, but the desert was interspersed with places that contained springs or aquifers that could be tapped by wells. These oases, as they were called, supported small settlements of people who cultivated date palms. There were also a few large oases that supported larger populations including artisans and merchants, with water sufficient for the cultivation of thousands of date palms.[2]

Outside of the oases, camel nomads lived in "tenting groups" numbering five to twenty people and joined with other groups of near-kinsmen at various times during the year. They survived, often at subsistence levels, on milk from their camels and foodstuffs that they could obtain in trade with oasis settlements. They also acquired weapons and took great pride in their martial skills, attacking rival nomadic groups and raiding settlements, taking goods or exacting tribute. In *The Camel and the Wheel*, Richard Bulliet analyzed the historical context in which camel nomads acquired political, military, and economic power. He argued that their ascendancy had a crucial technological element—the invention of the north Arabian camel saddle, which enabled them to become effective fighters and thereby shift the balance of political power in their own favor. Eventually, this led to their social and economic integration with settled communities. The rising power of camel nomads had a striking ramification in the medieval centuries, namely the abandonment of wheeled vehicles in Arabia and eventually throughout an immense area from the eastern Mediterranean across northern Africa. Instead of wheeled vehicles, the camel became the essential mode of transport.[3]

While nomads controlled the deserts, religious aristocracies controlled towns and settlements, empowered by the respect of tribal groups for the sanctuaries they maintained for the honor and worship of the gods. Those who entered sacred places were bound by rules of conduct which included the prohibition of killing. Towns with major sanctuaries often became important trading centers because of their relative safety. In the sixth century, Mecca was such a religious sanctuary, its shrine, the Ka'aba, attracting pilgrims from all over the peninsula. The fairs at Mecca also made it a significant destination for caravans. Meccans carried goods that had come from Africa or the Far East—including cloth, leather, and slaves—to Syria. Back from Syria to Mecca they carried wine, grains, and weapons. Mecca became a cosmopolitan city where tribal loyalties were weakened as many sorts of people congregated, including exiles and foreigners. Muhammad was born into one of the clans of Mecca, a family of traders. As a young man he worked as a caravaner.[4]

The rise of Islam and the Islamic conquests transformed Arab tribal society even as it profoundly influenced conquered lands. Islam allowed the inclusion of individuals who had been marginalized by tribal hierarchies, and substituted a universalizing, monotheistic religion for tribal loyalties. Religion and politics went hand in hand; for the first time, the Arabian peninsula as a whole became a state. Although the new religion had only a tenuous hold at the time of Muhammad's death in 632, it was soon consolidated by men who called themselves his successors or *caliphs*. Subsequent Islamic conquests did not involve proselytizing efforts by the Arabs. Rather, Arabic military elites conquered opposing armies and then established control over indigenous peoples. While these peoples were often forced to pay tribute, their administrative, economic, and political institutions frequently remained intact, and many of them converted to Islam only gradually over several centuries. The Arabs assimilated into the cultures into which they had moved, as they also changed those cultures. Islamic hegemony was accompanied by the Arab adoption of numerous crafts and technologies originally unknown to them.[5]

### Agriculture and Irrigation

As the Arabs conquered new lands, they adopted and sometimes changed existing patterns of land tenure. An example is the Sasanian Empire where, in the fifth and sixth centuries, land transfers increasingly involved large village estates bought and sold by members of a landed aristocracy. By the late Sasanian period most of the peasant-cultivators were losing title to the land that they worked, and the Islamic conquest did not immediately change this situation. By the second half of the seventh century, numerous Arabic aristocrats held village estates as absentee landlords.[6]



Agricultural labor was performed by tenants. Most tenancy took the form of sharecropping or renting. Renters leased the land for a fixed annual amount, measured either in cash or in produce. Sharecropping was an arrangement whereby peasants held a permanent lease on the land and could decide what crops to grow, could sublet the land to others, and could pass on these rights to successors. In return, they were obliged to give between a quarter and a third of the crop to their landlord. In addition to tenancy, there is evidence for the widespread use of slaves on large estates. Most were Greeks, probably from Syria, captured by the Sasanians in their wars with the Byzantines and then acquired (along with the land itself) by the new Islamic rulers.[7]

The Sasanians had maintained irrigation systems throughout much of the land. On the large rivers they had built substantial dams. On the plateau they had constructed *qanats* (Figure 7). A *qanat* is an underground canal which slopes downward from the surface until it reaches under the aquifer—the underground layer of soil, stone, and gravel commonly known as the water table. Water would seep from the aquifer into the canal and then flow out into an above-ground irrigation channel. To ventilate the tunnel and to enable the excavation of soil, vertical airshafts were sunk every 20 to 150 yards.[8]

The Arab conquerors used the existing Sasanian infrastructure, including *qanats* and other irrigation structures, as they built new garrisons. Some of these sites developed into cities, such as Basra and Baghdad, which attracted traders and visitors from throughout the Islamic lands. An expanding urbanism resulted in the growth of cities serving the Arab elite that required reliable supplies of food and water. To this end, the Arabs granted large expanses of swampland to individuals—usually clients of Arab governors—who drained and developed them for cultivation. They built extensive canal systems that changed swamps

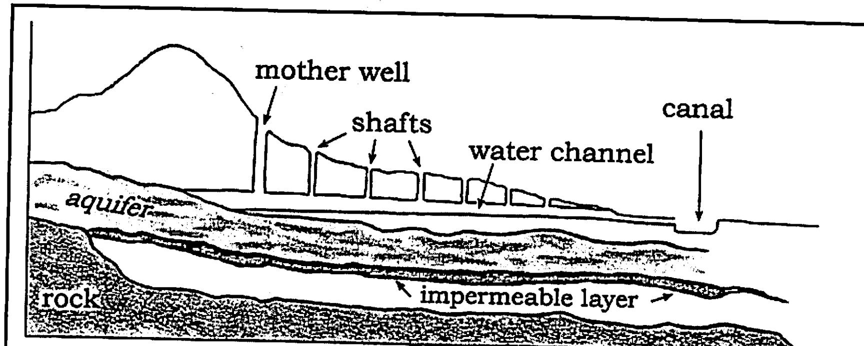


**Figure 7.** *A Sasanian* qanat, *or underground canal. To make a* qanat, *workers dug a trial shaft to make sure of the presence and depth of the groundwater table. When they reached water, they determined whether it had a constant flow and was located in an impermeable stratum. If so, they ascertained the correct slope to ensure the proper rate of flow from that point to the surface. Actual work usually began at the surface end and proceeded backwards. Great care had to be taken when the water-bearing section was entered to prevent breakage by a rush of water.*

into farms, thereby providing foodstuffs for the new cities. Sometimes Arab rulers themselves built new canals to provide water for urban populations and to irrigate fields.[9]

In most of their new lands, the Arabs encouraged the continued use of technologies already established. For example, Egyptian agricultural technologies were dominated by the annual flooding of the Nile. The height reached by the annual flooding was a matter of intense concern. If the river failed to rise to "sixteen arms," the amount of land inundated would be insufficient and famine would result. Floodwaters were controlled to some extent by dams and canals that dated to pre-Islamic and early Islamic centuries. Sultans built and maintained the main canals, while village headmen took charge of small dams and canals that diverted water from one field to the next. The peasants (called *fellaheen*) participated in the ongoing labor of dredging the canals with teams of oxen and removing weeds and debris with pickaxes and hoes. Winter crops such as wheat, barley, lentils, beans, bitter vetch (a plant used for fodder), and flax were irrigated by the Nile floodwaters alone. Summer crops, including cotton, melons, sesame, and sugarcane, were cultivated with the aid of water-lifting devices such as the *shaduf* (see Figure 8) and the waterwheel, the general term for which is the *noria*.[10]

**Figure 8.** *Drawing water from the Nile for irrigation with a* shaduf. *The* shaduf *consists of a long beam that rests on a horizontal crossbar in a lever arrangement. On one end of the beam hangs another long beam or a rope to which is attached a bucket. At the other end is a counterweight. The worker pulls down the vertical pole or rope until the bucket goes into the water and fills it. Then the worker pushes it up, and with the help of the counterweight, turns it, and dumps the water into the irrigation canal. Photo credit: ErichLessing/Art Resource.*



One type of wheel, often called a *saqiya*, was turned by an animal. Goaded by a peasant, the animal—ox, donkey, or camel hitched to a shaft—turned a horizontal "lantern" pinion which engaged the cogs of a vertical wheel, the lower part of which was immersed in a source of water. Pots were attached to the rim of the vertical wheel, called a potgarland wheel. (See Figures 9 and 10.) As the pots turned on the wheel, they reached the water upside down, scooped up the water and then, as they reached the top again, dumped it into a canal or trough.[11]

With variations, these water-lifting technologies came to be used throughout all Islamic lands, including the Iberian Peninsula. The peninsula was called al-Andalus after it was conquered by Arabs leading a Berber horse cavalry in 711. (The Berbers were a people who lived in the area of present-day Morocco.) Thomas Glick describes the region as being influenced by two cultural and ecological systems, one dominated by the Christians in the north and the other by the Muslims. Arab influence on agriculture and technology was particularly notable. Because the entire Mediterranean basin is similar, the Arabs were familiar with the environment of their new lands and could readily import agricultural technologies to al-Andalus that they had used elsewhere. Glick points to the "extensive Syrianization of the landscape that took place in the eighth century," including the migration of Syrian people and the importation of Syrian agricultural systems, hydraulic machinery, and plants.[12]

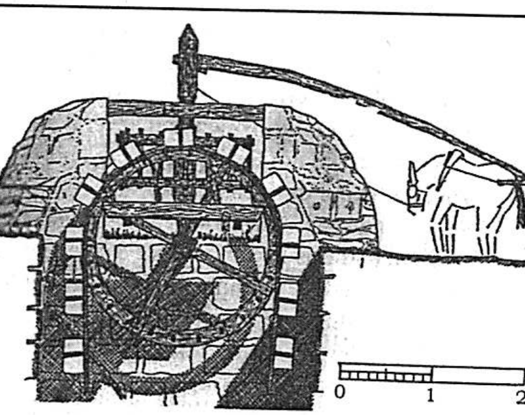


**Figure 9.** *A* saqiya *as depicted in 1955 at Ibiza in the Balearic Islands, Spain. The wheel with pots is called a potgarland wheel. As it turned, pots on the bottom entered the water mouth first, scooped it up, arrived at the top of the wheel, and then dumped the water into an irrigation channel or trough. A device called a pawl acted on the cogs of the potgarland wheel to prevent it from going into reverse when the animal was unhitched. From Thorkild Schiøler,* **Roman and Islamic Water-Lifting Wheels** *(Odense: Odense Universitets Forlag, 1973), 17. Courtesy Thorkild Schiøler.*

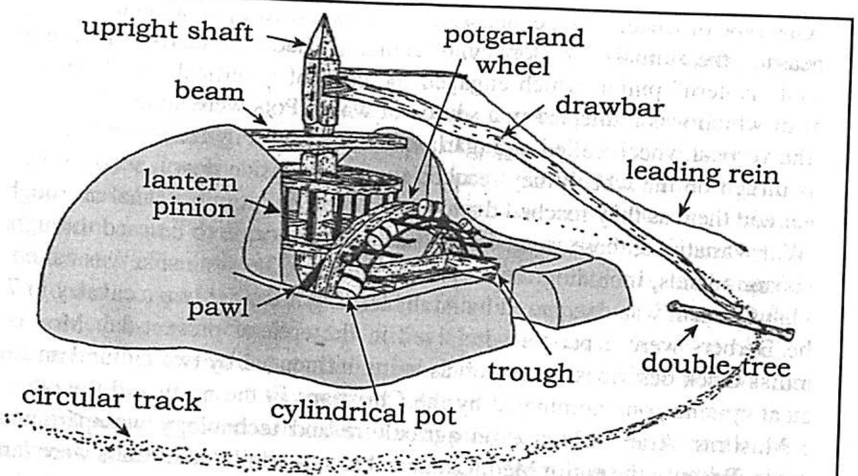


**Figure 10.** *In this detail of a saqiya mechanism, the lantern pinion is seen engaging the cogs of the vertical wheel. From Thorkild Schiøler,* **Roman and Islamic Water-Lifting Wheels** *(Odense: Odense Universitets, 1973), 16. Courtesy Thorkild Schiøler.*

Particularly important in al-Andalus was the animal-powered *noria*, which probably originated in Persia and moved with the Arabs across northern Africa to the Iberian Peninsula by the eighth century. Because the *noria* was a highly efficient device that cost little to construct and operate, it allowed small landholders to exploit their holdings effectively. A second important hydraulic technology in al-Andalus was the *qanat,* which had several advantages over surface canals; it required less slope, did not lose water by evaporation, and obviated the necessity of constructing lifting devices.[13]

After the Islamic conquests, migration and travel were relatively easy throughout a vast region, and this had important consequences for the transmission of new technologies and new knowledge. In agriculture, it enabled the establishment of new crops throughout Islamic lands, a phenomenon that historians have called the Arab "green revolution." These included rice, sorghum (a cereal grass used as fodder and for making molasses or syrup), sugarcane, cotton, watermelons, eggplants, spinach, artichokes, colocasia (the tubers and leaves of which are cooked and eaten), sour oranges, lemons, limes, bananas, plantains, mangoes, and coconut palms. Many of these crops were originally from India or from further east. Most were summertime crops. Their successful cultivation required numerous plantings, meticulous irrigation, and plowing techniques that conserved the water in the soil.[14]

The westward movement of many of these plants began in pre-Islamic times but did not get far. Increased travel and migration across Islamic lands encouraged plant diffusion, however, since people going from east to west would naturally have brought their eating habits with them, and peasants may well have carried the seeds and cuttings, along with the knowledge necessary for establishing new crops. Establishing a new crop involved innovations in both cultivation and patterns of consumption. Often it required the extension and improvement of irrigation, and improved irrigation techniques were widespread in the medieval Islamic world. New summer plantings greatly increased the productivity of the land. Sometimes a number of plantings on the same plot of land could be made in one summer. Careful attention to the suitability of particular soils to particular plants, fertilization with human and animal waste and other materials, and even the development of new varieties of plants that were more suitable to the new conditions—all played a part in this "green revolution." The result was an increased food supply leading to population growth and growing urbanization.[15]



## Architecture and Building Construction

Ernst J. Grube described some general characteristics of Islamic architecture, whether religious or secular, public or private—mosques, tombs, dwellings. First is the emphasis on enclosed spaces. The traditional Muslim house presents the street with high windowless walls, and some structures are completely hidden by other buildings. If a building displays a visible facade, it often reveals little about the interior. Accompanying the idea of a "hidden architecture" is the absence of any correlation between architectural forms and function. An example is the four-*iwan* courtyard structure that was common in the Sasanian Empire and subsequently adopted by Islamic architects (Figure 11). The *iwan* is a vaulted hall that is walled on three sides. In a four-*iwan* structure, four such halls surround a square, making a central courtyard. This structure was (and is) used throughout the Islamic world in mosques, palaces, *madrasas* (schools attached to mosques), and caravansaries (overnight shelters for caravans).[16]

A second major type of architectural plan is the hypostyle or arcaded plan, of which the Great Mosque of Cordoba is an example (Figure 12). In this plan there is a courtyard in the center and "a forest of columns" that form arcades or colonnades, all covered by a wood-beam roof. It has the advantage of simplicity, and only necessitates repetitions of a post-and-lintel structures (horizontal beams on vertical supports). Domes projecting up from flat roofs were later added to many such buildings.[17]

With the exception of the *iwan* court plan, as Grube explains, Islamic architecture rarely consisted of a focused unit in which the form of the building reflected the functions of its parts. For example, the center of a mosque—the prayer niche or *mihrab*—while always oriented in the direction of Mecca, did not have any particular set position that was indicated by the interior space of the building. This is sharply different from western European practice, where the altar of a church was always built in a predetermined space. In contrast, Islamic buildings were often designed with a deliberate disconnect between form and function. Because many of the buildings did not have a set orientation, it was easy to construct additions facing in any direction without destroying any preexisting balance. Interior decoration was highly significant. In Grube's words, the decoration of interior spaces was "a true negation of architecture as conceived in Europe, that is, of structure; it

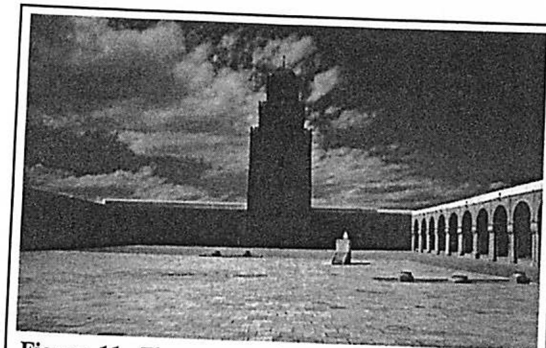

**Figure 11.** *The courtyard of the Great Mosque of Kairouan (Qayrawan) in Tunisia, founded by Prince Ziyada Allah in 836. The minaret dates from that year, the courtyard and arcades from 862–75. This is an example of the* Iwan *structure. Photo credit: Erich Lessing/Art Resource, New York.*

aims at a visual negation of the reality of weight and the necessity of support." For example, heavy, weight-bearing piers might be made to look ephemeral with lace-like ornamentation. Such effects were achieved with surface decorations made of tiles, mosaics, painted designs, molded plaster, and open cut work in walls and vaults. (See Figure 13.) All of these motifs were applied with a rich repertory of geometric and floral designs, inscriptions, and calligraphy.[18]

Most surviving Muslim buildings from the medieval centuries are mosques. Building styles and materials depended upon the location and the availability of materials. In Syria, for example, traditional ashlar masonry persisted in Islamic times because of the availability of Syrian limestone that was extremely durable but at the same time easy to work. Building walls of pounded clay (to be discussed below) occurred in areas where fieldstone was lacking. The building trades were highly specialized. Stoneworkers were divided into quarrymen and masons. Masons were separated into those who prepared rough blocks for inner walls and foundations, those who produced finished ashlar, and skilled carvers. Woodworkers included sawyers who cut rough timber to the correct dimensions, carpenters who did woodwork inside buildings, turners who made wooden screens for windows and other ornamental woodwork, and craftsmen who fabricated chests and door locks. Specialization facilitated the rapid completion of building projects. Standards of workman-

**Figure 12.** *The Great Mosque, Cordoba, Spain, built in the hypostyle or arcaded architectural style. Photo credit: Art Resource, New York.*



ship were guaranteed by craft and market laws administered by an urban and market magistrate called a *muhtasib*, whose modus operandi—as we know from surviving market manuals—was similar to that of the Byzantine *eparch*.[19]

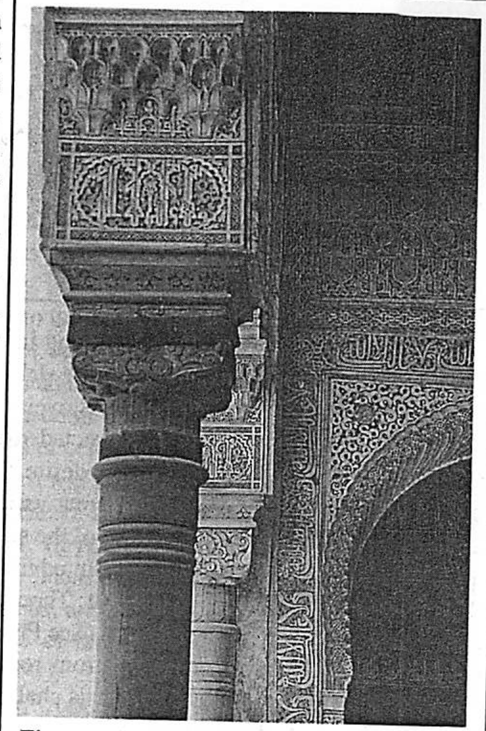

**Figure 13.** *Decorated surfaces in the Alhambra, Grenada, Spain, built between 1338 and 1390. Photo credit: Steven A. Walton.*

Masons often used granite or basalt for the foundations of buildings. Workers prepared mortar from either gypsum (plaster of Paris) or lime. Often they constructed buildings with the ground floor and perhaps a second floor of stone and the higher stories of brick. They might use columns and capitals from old buildings, but not in their original function; for example, they would invert a capital and use it as the base for a shaft. Often they reinforced columns and shafts with iron rods. They made buildings with intricately patterned and colored stonework, and marble carved into complex shapes.[20]

A second major building material was brick. Brick-making had reached a high level of refinement by the Sasanids in Iran, and many Sasanid techniques were adopted in the Islamic era. Builders used baked bricks for permanent buildings, but also used unbaked bricks at the building site, mixing clay with water and straw and tramping on it with bare feet before putting it in wooden molds; they turned the bricks at set intervals until they dried. Making baked bricks entailed more care in mixing clay and sand with water. These were also dried in the sun, but afterwards they were packed into a kiln and fired for three days. Fuel included shrubs and dried camel dung. Brick-makers used gypsum mortar for baked bricks except in exposed areas, where they used a lime-sand mortar. For ornamental work, bricks were cut into molds shaped as polygons or stars, the surfaces polished with a hard stone, and then they were put into a wood frame in a decorative design and covered with gypsum plaster. When this dried, workers lifted the panel from the frame and placed it into position in the building.[21]

A third building technique consisted of clay walling or *tapia*, constructed without the use of bricks. In one method two wooden walls were set on a foundation with space between them, and rope or twine holding them in position. Workers then

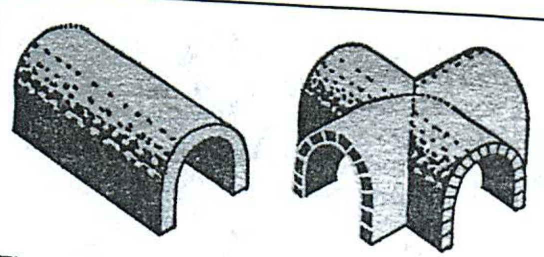

**Figure 14.** *A barrel vault and groined vault.*

put earth mixed with quicklime into this form and pounded it. When one course was finished they moved the form up for the next. In another method, walls were constructed layer by layer without forms. As they reached higher, walls got thinner and leaned slightly inward. Then, when cracking occurred, a building in effect consolidated itself. Doorways and windows were reinforced with stone slabs or timber. Walls were waterproofed by capping them with lime, sometimes over a layer of poles.[22]

Initially, Islamic architects constructed rounded arches adopted from Roman and Byzantine precedents. But their desire for novelty led them to develop the pointed arch and other arches in a great variety of shapes. They often reinforced arches with timber tie-rods. Because of the scarcity of timber, they also developed a variety of vaults and domes that required little or no wooden centering to support the structure as they were building it. These included barrel vaults and an intersecting variant called groined vaults. (See Figure 14.) They also developed diverse methods for making the transition from rectangular or square walls to a dome. Byzantine and Sasanid solutions to this challenge included the pendentive used in Hagia Sophia, but Muslim architects also developed domes with ribbed vaulting and double-shell construction, making domes lighter and thereby allowing a larger structure.[23]

A scholar who has investigated the development of the medieval Islamic town and city, Hugh Kennedy, outlined the profound changes that occurred in Syrian cities under Islamic rule. The wide streets and colonnades, theaters and baths, and market squares (the *agora*) that characterized the ancient city slowly disappeared in a process that had begun even before the rise of Islam. In the Islamic city, commercial establishments were located in linear fashion along narrow streets. As a public meeting place, the mosque superseded the *agora* and theater. Roman law had emphasized the distinction between the state and private property, the state protecting public domains from private incursions. In Islamic law, by contrast, the family and the house were of central importance. Owners of houses could build out, just so long as the construction did not disturb the neighbors. Streets were only wide enough for two pack animals to pass. Richard Bulliet has suggested that the form of the Islamic city, with its narrow winding streets, is one result of the disappearance of wheeled transport between the fourth and eighth centuries.[24]





The textile industry was basic to the economy of the Islamic world, as it was in the Byzantine Empire and in western Europe. Especially in Islamic regions, textiles were used not only for clothing but also for tents, rugs, and wall hangings. The scarcity of wood in the eastern Mediterranean was conducive to the use of rugs and wall hangings in place of wooden furniture. Rugs were portable and could be moved around in order to change part of a dwelling from a sitting area to a dining area to sleeping quarters. Nomads used textiles for bags in which to carry goods and also for their tents. Clothing was made according to the customs of particular locations and norms of gender, class, and status. The four primary fibers used for textiles were wool and linen, native to the Mediterranean, and silk and cotton, both originating in Asia. Secondary fibers such as hemp also were used, as well as a variety of mixed fibers such as linen and silk blends.[25]

In pre-Islamic times, linen was made in Egypt and valued by the Arabs as well as by the Byzantine rulers of Egypt. For centuries, it was the staple cloth of Islamic lands. Linen is made from flax, which was grown in upper Egypt. When the Arabs conquered Egyptian lands they inherited a flourishing linen industry located in the towns and villages of lower Egypt. Egyptian weavers produced both ordinary linens in white and colors, and fine linens, including rich brocades. The Persian town of Fars also produced fine linens, and particularly in the tenth and eleventh centuries linen factories in this area of the old Sasanian Empire produced and exported cloth of very high quality.[26]

To derive usable fibers from flax, workers dried the stalks, fermented them in water, dried them again, and then placed them on stone or wooden blocks and pounded them with mallets. They then combed the stalks to remove any remaining woody material and separate the bundles of fibers. They spun the fibers into long threads and wove them into cloth, usually on stationary vertical looms that were used by settled Islamic populations. Linen is a versatile cloth, fine enough for veils and strong enough for ropes. Its gray-brown fibers must be bleached and it is difficult to dye, however. So, when decorative colors were desired, workers often mixed the linen with another kind of fiber, such as cotton or silk.[27]

Cotton is native to India but had spread westward to some extent before the Islamic conquests. During Islamic rule, Iraq, Syria, and Yemen in southwest Arabia became major centers of cotton production. Cotton was used for making cloth, but also for stuffing quilts, mattresses, and pillows. Like linen, cotton is a plant product. Textile workers began cotton processing by beating the "bolls" to remove the seeds, after which they proceeded to the processes of carding, spinning, weaving, dyeing, and finishing. Cotton was versatile and could be used for a variety of cloth from fine gauze to thick fabrics similar to wool. The availability of both linen and cotton cloth (and therefore rags) provided the raw materials for the production of paper, an important product of medieval Islamic lands, as will be discussed in chapter six.[28]

Silk was used as a luxury fabric. As we have seen, silk was a highly developed Byzantine industry. When the Arabs conquered Syria, they took over the industry there and expanded it. Sericulture gradually spread throughout Islamic lands and into western Europe. Weaving intricate patterns in silk was made possible by the development of the drawloom, with which workers used fine strings instead of wooden heddles to raise and lower the warp threads to create the shed. Several thousand drawstrings could be used, each one controlling a single warp thread. A drawloom required two workers, a weaver and a drawboy who sat on a platform on top of the loom, watched the pattern the weaver was creating, and drew up the correct strings in succession, making the sheds through which the weaver passed the shuttle. Around the year 1000, a new technique was developed called *lampas*, which speeded the process of making highly decorated weaves by using two sets of warps and wefts and enabling the creation of patterns and ground weaves that were separate.[29]

The relationship of political power and textiles was highly significant in the medieval Islamic world. This is especially evident in the *tiraz* system initiated in the late seventh century. (*Tiraz* is an Arabic word derived from a Persian word for embroidery.) In this system state workshops first produced long, beautifully worked strips embroidered with the ruler's name and other information, and later all manner of cloth and clothing. The ruler distributed coats, shirts, tunics, caftans, pants, turbans, and other items of clothing to individuals who were members of his court. Thus did an individual's apparel signify his or her close connection to the highest power.[30]

In addition to textiles, artisans produced artifacts out of pottery, glass, and metal, crafts that entailed transforming materials from the earth—clay, sand, and ores. Specialists fabricated many kinds of containers from these materials, as well as armor, weapons, tools, utensils, precision instruments, coins, and jewelry.[31]

Potters collected clay from riverbanks. By the twelfth century, they were also making a potting material by grinding together sand, quartz, and other substances, and then mixing them with water to make a stone-paste or frit ware. Potting techniques included modeling slabs and coils of clay by hand, pressing clay into preformed molds, and throwing—shaping the clay on a potter's wheel. Shaped objects were left to dry in the sun and then fired in a kiln. Particularly important in the dry climates of the eastern Mediterranean were earthenware vessels for the storage of water. One special type, called *gadus*, was the pot used for the potgarland wheel of the *saqiya*. Pots for water were porous, causing evaporation on the surface, thereby cooling the vessel and its contents. But such pots were unsuitable for olive oil, which turns rancid with long exposure to air. A glaze applied to an earthenware vessel or tile functions as a seal, and potters made glazes by adding red lead, which lowers the temperature at which the glaze mixture turns into glass. In the twelfth century, an alkaline glaze similar to glass was developed; it was made from a mixture of soda or potash, to which salt sometimes was added. Glazes could be colored and decorated, a technique leading to the development of fine ceramic wares. Abbasid rulers of the eighth and ninth centuries particularly admired such wares from China, and Islamic potters refined their own craft partly in response to these wares from the east, developing stone-paste as part of their art.[32]

Metal was worked by specialists who made utensils and vessels, arms and armor, jewelry, tools, and scientific instruments, each of which involved different



traditions, workshops, and techniques. They created objects from silver, gold, and copper alloys, primarily an alloy of copper and zinc called brass. Bronze, an alloy of copper and tin, was rare and expensive in the Islamic world because of the high cost of tin, which had to be imported from England or Asia. Metalworkers used two general techniques. In casting, they poured molten metal into a form. They also worked metal by hammering, forging, or spinning on a lathe, a device developed in the early thirteenth century. Brass objects such as incense burners and ewers for water were often highly decorated, and metalworkers were ultimately able to transform brass objects into luxury goods by pressing wires into them and creating inlays that made them resemble those made of gold and silver.[33]

### Work and Gender

Around 1890, a vast collection of documents relating to the medieval Islamic world was found in Fustat (now called Old Cairo), in a *geniza* connected to a synagogue. *Geniza* is a Hebrew word meaning a storehouse or treasure. The Jews believed that writings in which the name of God appeared (or even documents written in Hebrew) should be buried in a cemetery. As a result, a Jewish community in medieval Fustat placed thousands of documents intended for later burial in a lumber-room connected to their synagogue. Long afterward, a renovation of the synagogue revealed the sealed room containing—as it was gradually realized—a priceless collection of documents concerning work, marriage, and commerce; letters; wills; and literary materials. These documents provide detailed accounts of daily life, work, and commerce as it pertained to this Egyptian Jewish community, especially from the eleventh to the thirteenth centuries.[34]

From the Geniza documents, scholars have learned that the typical workplace was a shop headed by "a single craftsman, a family, a clan, or a number of partners, usually not more than five." Two new industries—sugar-making and paper-making—that used techniques of Chinese origin involved a greater concentration of manpower than was the case in older craft industries. In Islamic lands, both industries used vertical waterwheels and cams to macerate the fibers and cane respectively. While the crafts in Islamic lands had not yet been organized into guilds (this occurred only in the fourteenth century), the practitioners of particular crafts were concentrated together in the same locality. Thus streets or quarters were named after "clothiers, tailors, perfumers, coppersmiths, turners, chest makers, woolworkers, manufacturers of leather bottles, makers of almond sweetmeats, oil makers." Often the same worker who made a product also sold it.[35]

Although craft-workers were from the lower strata of society, skilled artisans were respected and manual work was not considered degrading. The Geniza documents reveal a high degree of specialization. The most important industries concerned textiles, dyeing, and clothing; metals, glass, and pottery; and building construction and food processing. There were specialists in numerous small trades: makers of kohl sticks used to apply eyelid powder; makers of writing cases, mirrors, mats, fans, spindles, sieves, combs for hair and flax; makers of beads; perforators of pearls; persons who processed corals. In every household, at least one woman worked as a spinner.[36]

In a comprehensive study in which she analyzed sources including S. D. Goitein's work on the Geniza documents, Maya Schatzmiller investigated occupations in the medieval Islamic world. She listed hundreds of occupations that include "extractive" work such as agriculture, mining, and fishing, and trades ranging from dye makers, soap makers, brick makers, and textile workers to food processors such as bakers and sausage makers. This study provides a much-needed foundation for understanding the high degree of work specialization that developed over the medieval centuries. It also provides at least a small window into the elusive but important subject of the trade groups to which various workers belonged and attitudes toward manual and skilled labor in general.[37]

A particularly difficult problem in the study of work in the medieval Islamic world concerns the nature of women's work. For rural women, there is a critical lack of evidence. Shatzmiller suggested that "taking families as a production unit in agricultural pursuits provides too small a group to allow any significant division of labor on the basis of gender to be seen." It is certain that both men and women fully participated in agricultural production. Certainly, however, as in the Byzantine Empire and in the west, there was some division of labor by gender. In other arenas, women's work is well documented. Women took care of silkworms, a labor-intensive task, as we have seen. Women produced and sold radish and linseed oils, and brought chickens, eggs, and wool into towns to sell. Indeed, there is much evidence to show that women were often involved in commercial transactions and also active in investing in rural property. Documents reveal female purchases of irrigation rights, of an orchard, of a date plantation, of a silo, of residential properties, and of slaves.[38]

Documentation for urban female work is more extensive than for rural. In manufacturing, women's basic household skills were expanded to a commercial scale in two fundamental areas, textiles and food. The spinning of flax, wool, cotton, and silk were female monopolies. Women worked as embroiderers, weavers of brocades, and carpet-makers, often with their children working alongside. They also made lace, though commercial weaving was a male occupation. Both men and women worked as dyers. Female trades were transmitted within informal apprenticeship systems in which women trained young girls, including their own daughters.[39]

Women were particularly involved in food processing and food production. Documents attest to female millers, vinegar makers, and makers and sellers of sweets, sweetmeats, and cooked beans. Women were also active in health care, working as physicians, midwives, and wet nurses. Women washed the dead and worked as professional wailers. They worked as launderers and as "combers" and "henna applicators." Educated women acted as court secretaries. There were women calligraphers, poets, and scholars.[40]

Beyond the question of who did what kind of work is the more general question of how labor was perceived in the medieval Islamic world. In pre-Islamic nomadic Arab culture, manual labor—"the work of the blacksmith, the peasant, the goldsmith and the sword maker"—was held in contempt. To some extent, this attitude carried over into Islamic times. In the ninth century, the



activity of building construction and the development of skilled crafts brought about a literature in which manual labor was a focus of interest and respect. Nevertheless, labor in general was viewed negatively, while commerce was much more highly regarded. In the ninth and tenth centuries, a form of Sufi mysticism developed in reaction to the luxurious lifestyle of court circles in Basra. It adopted the doctrine of *zuhd*, the renunciation of worldly goods and also the work involved in acquiring them, instead relying on God's favor for basic necessities. This mysticism generated a reaction in the form of a literature that advocated work and extolled its value. A conflict of values concerning work continued to the fourteenth century and beyond.[41]

### Mechanical Devices and Scientific Instruments

During the eighth and ninth centuries, Arab scholars undertook a remarkable quest to master the learning of the foreign cultures with which they had come into contact, namely in the Byzantine and Sasanian (Persian) empires and India. Scholars and translators sought out classical Greek and Hellenistic writings as well as texts in Syriac and other languages, making them available to the Islamic world by means of translation into Arabic and extensive commentary. They eventually incorporated the entire corpus of Greek classical learning and wrote original works that extended that learning. Translations included Greek and Hellenistic writings on mechanics and mechanical devices—the pseudo-Aristotelian *Mechanical Problems*, and the writings on mechanical devices by Philo of Alexandria (third century B.C.E.) and Hero of Alexandria (second century C.E.). The *Mechanical Problems*, probably written by a follower of Aristotle in the fourth century B.C.E., defined mechanics as a discipline combining mathematics with physics, or—put in another way—theory (meaning the mathematics of mechanical motion) and practice (actual machines and devices). All such writings had been translated into Arabic by the ninth century.[42]

The Arabic word *hiyal* describes the whole range of topics entailing mechanics and machinery. Based on the Greek sources, an Islamic tradition of writing on such topics emerged during the ninth century. The three Musa brothers—Muhammed, Ahmad, and al-Hasan, known as the Banu Musa—were famous for their engineering works in Baghdad and Samarra, and they also wrote *The Book of Ingenious Devices*. The sons of a noted astronomer, they traveled to the Byzantine Empire to bring back books for translation from Greek or Syriac into Arabic.[43]

The Banu Musa wrote books on mathematics and astronomy as well as on mechanics. *The Book of Ingenious Devices* described six fountains and eighty-three trick vessels: pitchers that do not continue to pour after an interruption, vessels that replenish themselves after a small amount of liquid is removed, vessels from which a mixture of liquids would pour from separate spouts. As Donald Hill explained, such vessels were effected by different combinations of siphons, valves, pulleys, gears, cranks, miniature waterwheels, floats, and balances. Each machine was a kind of automata.[44]

A later book devoted to machines, Ibn al-Razzaz al-Jazari's *The Book of Knowledge of Ingenious Mechanical Devices* was completed in 1206. Al-Jazari was the most important and original author on mechanics in medieval Islamic lands. Most of the devices he described are automata, water clocks, and water-raising machines (Figure 15). These were significant for the development of mechanical technologies; for example, one of them embodies the first known instance of a crank that works as part of a machine (in distinction from hand-operated cranks). Al-Jazari's clocks also embody numerous mechanical concepts and technologies, including "accurate calibration of small orifices; feedback control methods; the use of paper models to establish intricate designs; the use of wooden templates; the static balancing of wheels, the use of laminated timber to minimize warping; one-way hinges; and tipping buckets." None of these machines, however, was conceived solely as a practical device. As George Saliba explained, one objective of those who wrote about machines was to address the Aristotelian problem of how to move from potentiality to actuality by means of mechanical devices.[45] Al-Jazari's interest in both theory and practice was characteristic of the Islamic traditions of mechanics.

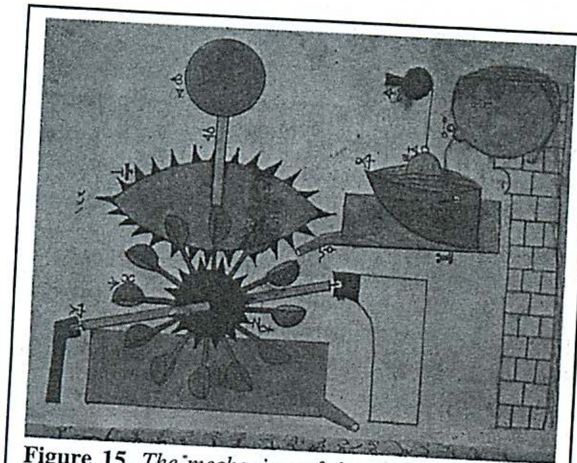

**Figure 15.** *The mechanism of the "water-clock of the peacocks." Al-Jazari instructs that the water-clock is to be built behind a fountain. The action of the clock causes peacocks to come out and squabble every half hour. Al-Jazari,* **Book of Knowledge of Mechanical Processes,** *Saljuq dynasty, 1206. Topkapi Palace Museum, Istanbul, Turkey, thirteenth century. Ms. No. 3472. Photo credit: Giraudon/Art Resource, New York.*

Interest in mechanical devices extended to precision instruments, including the balance and, most importantly, astronomical instruments. Such instruments were described in treatises and they were also fabricated and used in practice. A twelfth-century philosopher, Abul Fath al-Khazini, in his treatise on physics titled *The Book of the Balance of Wisdom* (1121–22) described in detail methods of constructing and using balances to determine weights, including the proportions of weights of specific substances in alloys. His descriptions of instruments include dsmall clepsydras (water clocks) that measured short intervals of time and were used in the study of astronomy.[46]



Islamic technologists and astronomers designed intricate astronomical instruments used in the observatories that were built throughout Islamic lands. One example was a planispheric astrolabe (Figure 16). This instrument consists of "a two-dimensional model of the celestial sphere in relation to the earth, based on the assumption that the earth is the center of the universe." It was constructed by stereographic projection, a geometric method whereby points on the celestial sphere were placed on the flat surface of the instrument. The astrolabe functioned as an observational instrument which enabled astronomers to determine the time of sunrise and sunset and the positions of celestial bodies.[47]

**Figure 16.** *Hispano-Moorish astrolabe, c. 1260, made of brass and copper. Each part of the astrolabe has a central hole so the parts can be held together with a pin and wedge. Parts include plates engraved to indicate the inhabitable regions of the earth; the rete, the celestial part indicating important stars; and the mater, a brass plate with rim. Inventory no. 43504, Museum of the History of Science, Oxford. Courtesy Museum of the History of Science, Oxford.*

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Islamic conquests and migrations had important consequences for the history of technology. The Arabs permitted established modes of production and their associated technologies to continue in the territories they conquered, adopting and developing them futher. Rather than destroying the Byzantine silk industry in Syria, for example, they expanded it. They learned about new crops in the east and adapted them to new locales in the west. They developed many different kinds of arches and domes; they developed new glazes for pottery. They were receptive to the learned cultures they came upon, translating and assimilating Greek, Syriac, and other ancient writings, and composing original works on the basis of this foundation. Islamic powers, although by no means a single, unified entity, spanned both eastern and western lands. Ultimately, Islamic culture would exert a profound influence on western European Christian culture, to which we now turn.