9: Achievements and Contributions of al-Andalus: Exploration of Material Culture and Science

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Overview:

During the more than 700 years of Muslim rule in the Iberian Peninsula, Muslim culture was both a center for receiving influences from other Muslim lands, and a center of innovation and adaptation in material culture and the sciences. Through an interface either on the *Cities of Light* web pages at < www.islamicspain.tv/the-science-and-culture-of-islamic-spain/25-subjects-of-science-and-culture >, or the handouts printed from these lesson plans and made available to the class for study, students will use select readings and images that introduce them to a range of arts, sciences and technologies that contributed to the material culture of al-Andalus and its dissemination to other cultures. Through the collective learning activity, students can become "experts" in a number of fields they will present to the class from what they learned, and through the shared classroom experience, they will also be exposed to many other fields. An assessment activity aims to create a lasting impression of this information to round out the students' understanding of the contributions of al-Andalus to civilization.

Objectives:

Students will be able to

- identify numerous areas of achievement in material culture and the sciences in medieval al-Andalus.
- describe a selection of contributing fields of knowledge and activity from al-Andalus during the centuries of Muslim rule in the Iberian Peninsula.
- list individuals who contributed as scientists, artists and writers in the area of material culture and the sciences.
- assess the importance of al-Andalus as a center of activity and contributing culture in the areas of material culture and the sciences.

Materials:

"Magic Squares" game board, Student Handout 9a for note-taking on the topics and print-outs of the 1-2 page text and image information texts and images that correspond to the topic named in each square on the grid, **Student Handouts 9.1 to 9.25**.

Time:

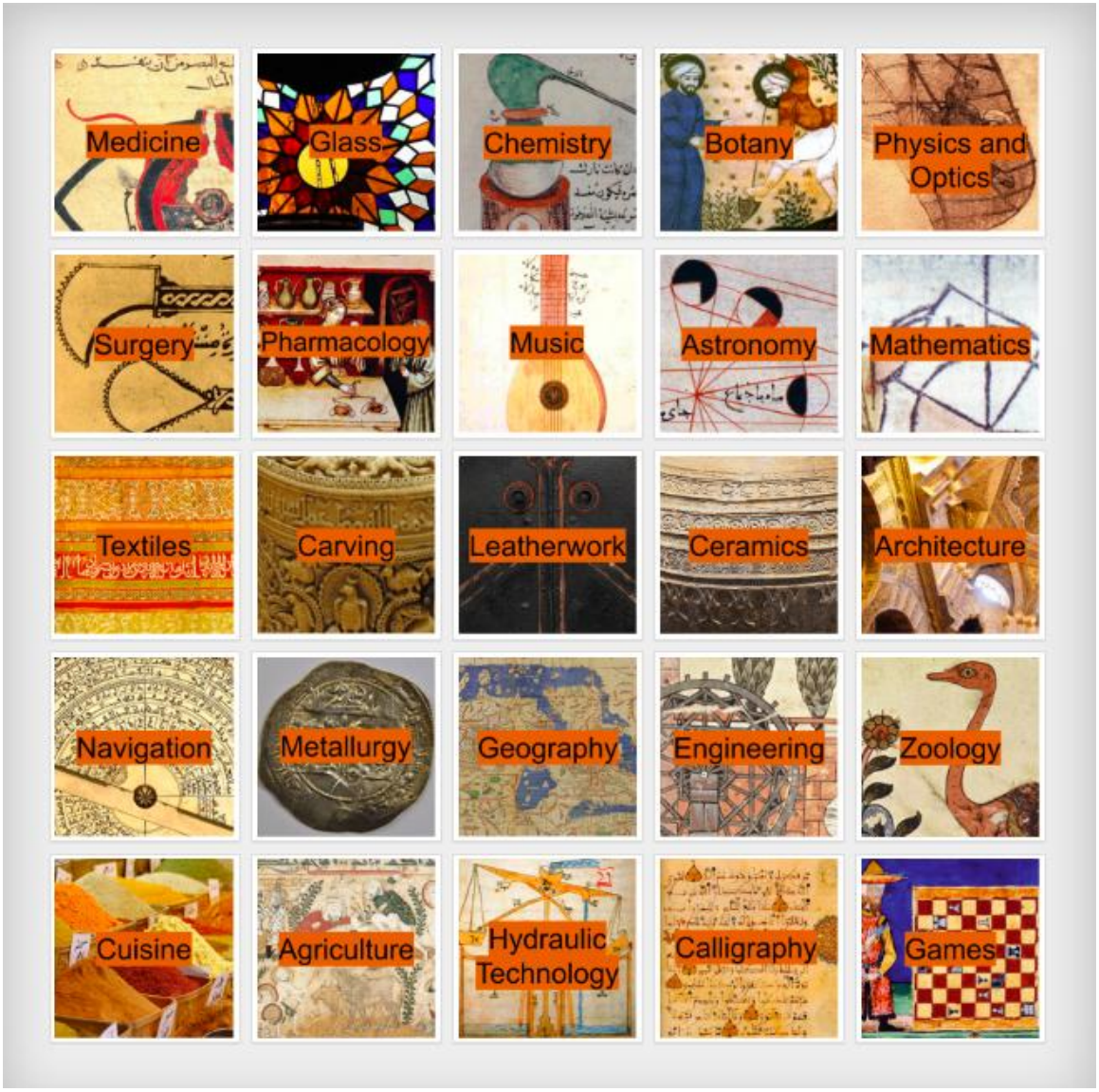
1-2 class periods and/or option of a homework assignment for preparation

Procedure:

Teachers can assign the students to choose a given number of rows up or across, complete a diagonal row or rows, or a pattern of numbers that add up to a certain sum. They will be responsible for presenting the material to the rest of the class. When the class is de-briefed on their exploration, they will gain an overall idea of the cultural and scientific ideas that took place in al-Andalus during the eight centuries of Muslim rule and its aftermath in the translation

effort, and the effects of the diffusion of this knowledge.

Students can also be assigned to freely choose a square (corresponding to the labels on the chart on the next page), and select the handout that corresponds to the topic. Teachers can assign the students to choose a given number of rows up or across, complete a diagonal row or rows, or a pattern of numbers that add up to a certain sum. Users will be able to acquire a broad overview of the cultural and scientific ideas that took place in al-Andalus during the eight centuries of Muslim rule and its aftermath in the translation effort, and the effects of the diffusion of this knowledge in a short period of time by surveying the images and following the links according to their interest.



Student Handout 9a: Magic Squares for Exploring Material Culture and Sciences in al-Andalus

The labels on this set of "Magic Squares" refer to contributions to the arts, sciences, and technologies that al-Andalus contributed to the world. Select any vertical, horizontal, or diagonal row and ask the teacher for the readings that correspond to the numbers in the table, or at < www.islamicspain.tv/the-science-and-culture-of-islamic-spain/25-subjects-of-science-and-culture>.You will become a class expert in the information contained in those readings. Be ready to briefly summarize the knowledge you have gained and share it with the class. You will learn about the areas you did not choose from your classmates. Use the note-taking organizer in Handout 9b to take notes.

1 Medicine	2 Glass	3 Chemistry	4 Botany	5 Physics & Optics
6 Surgery	7 Pharmacology	8 Music	9 Astronomy	10 Mathematics
11 Textiles	12 Carving	13 Leatherwork	14 Ceramics	15 Architecture
16 Navigation	17 Metallurgy	18 Geography	19 Engineering	20 Zoology
21 Cuisine	22 Agriculture	23 Hydraulic Technology	24 Calligraphy	25 Games

Student Handout 9b: Notes Organizer for the Magic Squares Activity

CONTRIBUTION	NOTES ON INFORMATION	DRAWING OR SYMBOL THAT REPRESENTS THIS CONTRIBUTION
1 Medicine		
2 Glass		
3 Chemistry		
4 Botany		
5 Physics & Optics		
6 Surgery		
7 Pharmacology		
8 Music		

9 Astronomy		
10 Mathematics		
11 Textiles		
12 Carving		
13 Leatherwork		
14 Ceramics		
15 Architecture		
16 Navigation		
17 Metallurgy		

18 Geography		
19 Engineering		
20 Zoology		
21 Cuisine		
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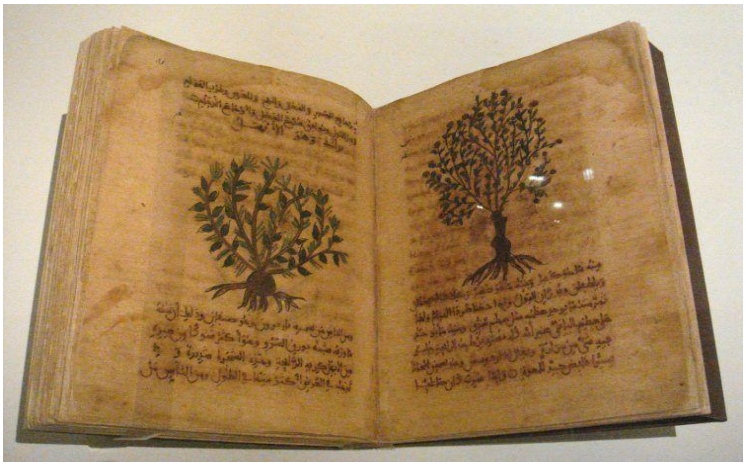
23 Hydraulic Technology		
24 Calligraphy		
25 Games		

1. Medicine

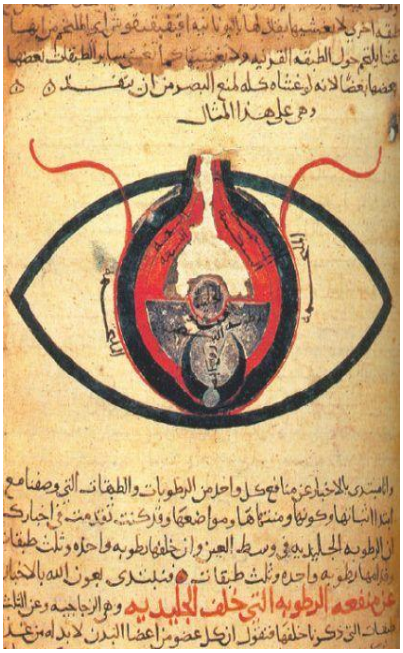
With the growth of Muslim territory and civilization, knowledge of medicine, which had accumulated in the classical civilizations over time, became available to those living in Muslim lands. With the spread of Arabic language and the effort to translate important works from other languages of learning, this heritage was concentrated in the Muslim libraries. Knowledge of diseases and diagnoses, and ways of curing them with medicines, surgery, and other treatments were published, along with advice on staying healthy.



A 13th Century Arabic translation of "On Medical Material", a Greek book on Pharmacology written in 50 CE (PHGCOM from Wikimedia Commons).

In Muslim cities, hospitals were founded and became centers of learning — the teaching hospitals of today. Rulers and wealthy people consulted physicians to help them overcome diseases, and supported their work in advancing medical studies.

Among the sciences that flourished in Muslim civilization, medicine is one that perhaps most represented a multi-religious, multi-ethnic effort. The number of physicians of different religions working in the institutions of learning and serving as court physicians includes Jewish, Christian, and Indian physicians and researchers. This is true in the eastern Muslim lands as well as the western.



The human eye according to Hunayn ibn Ishaq, circa 1200CE (Zereshk on

For example, the first head of the House of Wisdom in the 8th century, and a physician who contributed knowledge about the anatomy of the eye, was al-Hunayn, a Nestorian Christian mathematician and physician. His co-religionists, the Bakhtishu family, served the Abbasid in Baghdad court as physicians for generations.

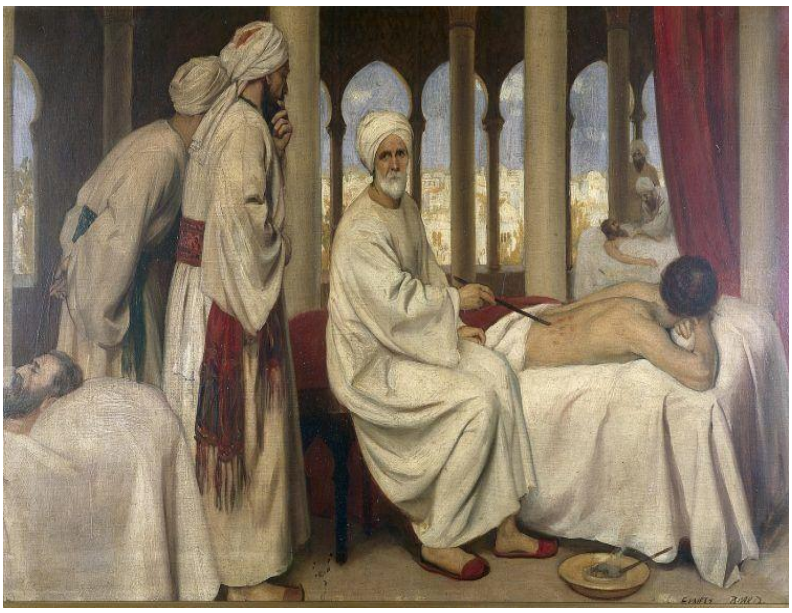
Translations of Greek, Indian, and Persian medical works were available in Al-Andalus. Medicinal substances were imported through trade networks across Africa, Asia, and Europe. New medical knowledge accumulated through practice and research in hospitals and medical colleges.

A famous Andalusian physician was Hasdai Ibn Shaprut (915-970 CE), a Jewish physician who served Abdul Rahman III (912-961 CE) at Córdoba, and translated an important work on pharmacy, using his knowledge of Arabic, Hebrew and Latin.

Famous Muslim physicians in Al-Andalus were many. Ibn Juljul (Córdoba, b. 943 CE) wrote a commentary on Dioscorides' work of pharmacology *De Materia Medica*, and

wrote *Categories of Physicians*, a history of medicine from the Greeks to his time. Abul Qasim al-Zahrawi (Córdoba, d. 1013 CE) is best known as a surgeon, and served al-Hakam II as court physician. Al-Zahrawi wrote about other diseases and treatments in his *Tasrif* — a leading medical text in European universities after its translation into Latin in Toledo, in which al-Zahrawi is called Albucacis.

Physician Ibn Zuhr (d. 1162 CE in Seville), known as Avenzoar in Latin, was the first to describe pericardial abscesses (of the heart) and to recommend tracheotomy when necessary. Ibn Zuhr's *Taysir* was a standard medical work in Europe, translated into Latin in 1280 CE. In addition to his work in philosophy, Ibn Rushd (Córdoba, b. 1126) was both an accomplished physician and an astronomer. His famous medical book, *Kitab al-Kulyat fi al-Tibb* (known as the *Colliget* in Latin) discussed various diagnoses and cures for diseases, as well as their prevention. He was the personal physician to several Almoravid caliphs in Spain and Morocco. His friend Ibn Tufayl (d. 1186 CE) had been physician and medical author before him.



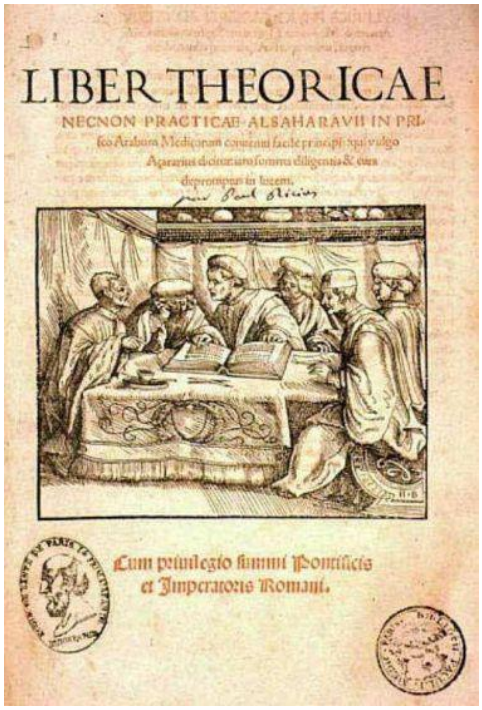
Medical students looking upon Andalusian physician al-Zahrawī blistering a patient in Cordova in 1100 CE (Painted by Ernest Board, hosted on Welcome Images).

The great Andalusian physician Ibn al-Khatib of 14th century Granada wrote an important book during the time of the Black Death. On the theory of contagious diseases, he wrote, "The fact of infection becomes clear to the investigator, whereas he who is not in contact remains safe." He described how transmission happens through clothing, vessels, and earrings, at a time when nothing was known about viruses and bacteria.

Andalusian doctors made contributions to medical ethics and hygiene. The jurist and philosopher Ibn Hazm wrote about the qualities that a physician should have: kindness, understanding, friendliness, dignity, and the ability to accept criticism. He wrote about the clothing and hygiene necessary for doctors. This cleanliness carried over into the hospitals, which had running water, gardens, and different wards for different diseases. The poor were treated there for free, and hospitals were open to all, supported by the government and private charities. They were also important institutions for training doctors.

Lasting impact: European medicine benefited from the knowledge and experience of Muslim and Jewish physicians in Spain and Sicily in many ways. Muslim medical science contributed knowledge of sedatives, the use of antiseptics to clean wounds, and use of

sutures made of gut and silk thread to close wounds. Techniques for curing disease with drugs, for assisting childbirth, setting bones and curing eye and skin diseases, as well as knowledge of contagious diseases, were just a few contributions.



An example of a Latin printing of a medical manuscript developed by Andalusian physician al-Zahrawī (courtesy of World Digital Library).

Visiting scholars in Islamic Spain were also exposed to the practice of medicine there, which was far advanced over that in other parts of Europe. The first European colleges of medicine developed at Palermo, Sicily, and at Salerno, Italy. During the 11th century CE, medical books by important Muslim physicians like Ibn Sina (980-1037 CE) and al-Razi (864-930 CE) were translated into Latin and brought into European universities, where they were used for centuries.

With the invention of the printing press in Europe, these books became widespread. The famous English writer Chaucer shows how well known this medical knowledge from the Arabs was in Europe. In the beginning of the *Canterbury Tales*, Chaucer names physicians from the Medieval Islamic tradition: Ibn Sarabiyun or Serapion as he was known to Europe, a 9th century Syrian physician; "Razis" the great 10th century al-Razi; and "Avicen," or Avicenna (Ibn Sina), whose early 11th-century medical encyclopedia was a basic work for physicians. Arabic medical literature gave rise to European medical advancements.

2. Glass

The story of glass-making involves many centuries and many peoples, over thousands of years. It is not always possible to discover the exact origins of specific techniques. A legend with origins in 7th century Spain, in the writings of Isidore of Seville, describes its invention as a historical accident by Phoenician merchants:

… in a part of Syria which is called Phoenicia, there is a swamp…from which the Bellus River arises . . . whose sands are purified from contamination by the torrent's flow. The story is that here a ship of natron [sodium carbonate] merchants had been shipwrecked; when they were scattered about on the shore preparing food and no stones were at hand for propping up their pots, they brought lumps of natron from the ship. The sand of the shore became mixed with the burning natron and translucent streams of a new liquid flowed forth: and this was the origin of glass."

1Stained glass wall inside Nasir al Molk Mosque in Shiraz City, Iran (MohammadReza Domiri Ganji on Wikimedia).

~ Isidore of Seville, Etymologies XVI.16. Translation by Charles Witke

According to archaeologists, however, true glass originated in Mesopotamia in about 2500 BCE, where beads, seals, and glazed decoration on buildings have been found. About a thousand years later, glass artisans learned how to make glass containers, and the technology spread to Egypt and Greece. Perhaps Isidore of Seville thought Syria and Palestine were the source, because the major glassmaking center of his time was there, and in Egypt. Isidore could not have known that his own homeland would become a center for skilled glassmaking just a century or two after he lived, when the area came under Muslim rule as Al-Andalus.

Glass is a mixture of sand, soda, and lime melted together in a very hot furnace. Colored glass can be made by adding metal oxides to the glass (rust, for example, is iron oxide.) Metal compounds that make beautiful colors are cobalt for dark blue, iron for green, tin for opaque white, antimony and manganese for colorless glass, and many others. These formulas were closely guarded secrets among glassmakers, but some scientists, such as the Muslim writer al-Biruni (d. 1048 CE), recorded this kind of information.

There are several ways to make glass containers. The earliest technique was to form it by winding hot glass around a clay core. After cooling, the core was removed and the glass polished with sand. Later, artisans learned to make containers by pouring fused glass into a clay mold, then polishing and grinding it. Around 50 BCE, glass-blowing was invented. A blob of glass heated in a furnace was placed on the end of an iron pipe, and the artisan blew into it, forming a bubble of glass. This achievement happened in the area of Syria and Palestine. Beautiful glass objects could now be formed into large or tiny bottles, pitchers, and vases. Hot glass trails and dots were added to the surface to make handles and other decorations.

The Romans, Egyptians, and Persians used this technique, and it was transmitted to the Arabs and carried to Spain. In cities of Al-Andalus like Almeria, Murcia, and Malaga, artisans made delicate glassware like this 8-handled green glass bottle from Almeria, which is in the Hermitage Museum at Leningrad along with almost 100 other glass objects from southern Spain that are made in the Islamic tradition. Experts say that this region kept strong connections with Syrian glass-making centers. Syrian and Andalusian glass also influenced Italian glass-makers at Murano, who made pilgrim flasks and large glass vases similar to enameled mosque lamps.

An ornate eight-handled vase from Andalusia manufactured in the 16th century (courtesy of The Russian State Heritage Museum).

Colored glass windows, and especially the spectacular stained-glass windows in cathedrals, have a long and uncertain history. Like other glass technologies, there is most likely more than one line tracing its origins. We know that the Romans made glass into windows during the first century CE. This glass let in light, but it was very thick and not transparent. They may have done this in the colder, northern cities of their European empire, because the technology seems to have survived into the early middle ages. Archaeologists have found pieces of colored glass used in a window in a monastery founded in 686 CE in England. Other European locations of Roman glass-making have also been found.

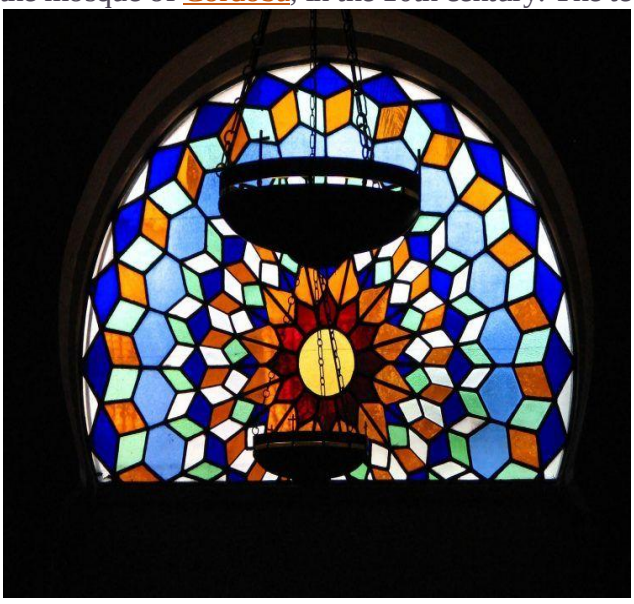
The idea of using colored glass to create geometric and floral designs also has multiple origins. In 1937, in Syria, archaeologists named Jean LaFond and David Schlumberger discovered an 8th century Islamic city in the desert near Palmyra.

They found 115 colored glass fragments in colors like “greenish white, bluish white, moss green … tobacco yellows … burnt sienna, smokey, three purples (one near wine, one more brown), a garnet [red] of great beauty and two violet purples …” Schlumberger found evidence that they had been mounted in a framework of stucco in arabesque designs, so that light would show through the glass. This technique has also been found in Yemen, where instead of glass, thin pieces of alabaster let a golden light through the design into the room between the stucco. Here, in an 8th century Umayyad city, was an early stained-glass window.

Stained glass windows in buildings in Sana’a, Yemen (Rod Waddington on Flickr)

Experts believe that Arabian “filigree” windows moved into Europe when the Muslims entered Spain, and that these windows were cemented into marble, plaster, or stone, with iron ribs used to make the windows stronger. These early stained-glass window designs may have appeared there as early as the 10th century, or as late as the 13th century.

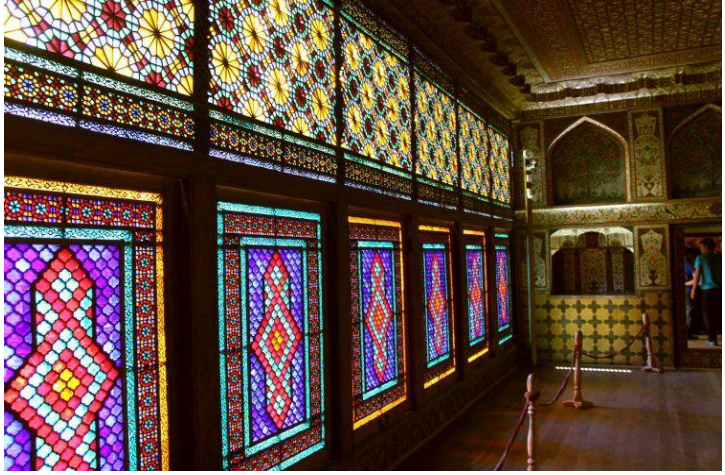
Colored glass mosaics had appeared in Spain, imported by Byzantine architects building the mosque of Córdoba, in the 10th century. The technology was certainly present for making colored ceramic glazes, which use many of the same substances, and glaze for pottery is also a kind of glass.



A stained-glass window in the Mosque-Cathedral of Cordoba (Conan on Flickr).

In northern Europe, development of stained glass may have another thread of origin based on Romanesque ideas and techniques, which were also linked to Rome and Syria through the Byzantines. These windows at first had no glass in the decorative openings, but were pierced openings in slabs of lead. Later, small pieces of glass were attached using soldered strings of lead. Romanesque Christian churches built in the 4th and 5th century also have windows that use patterns of thinly-sliced alabaster in wooden frames, like those of Yemen.

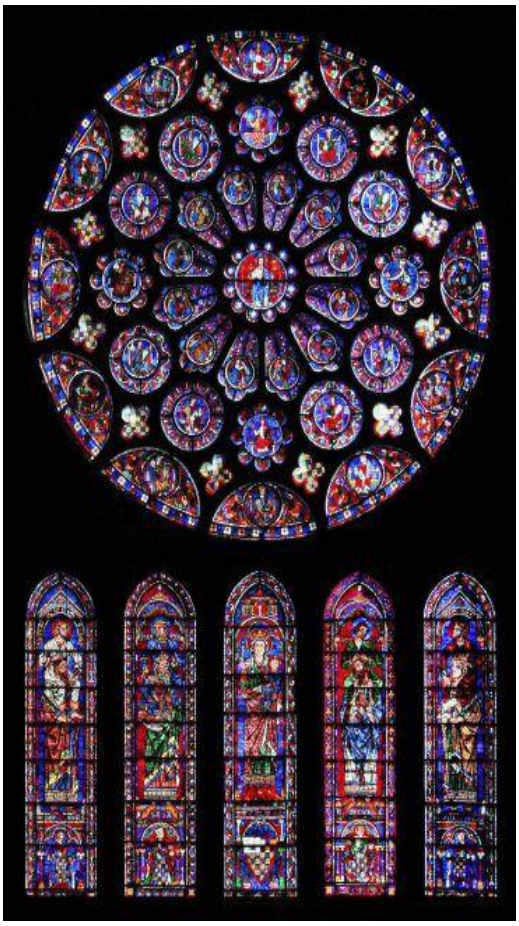
European and Islamic window designs seem at first very different. Muslim artists did not use pictures in mosques. European stained glass in churches tells stories from the Bible and shows pictures of Jesus, Mary, the Apostles, and saints. Examples of painted glass in



The interior of the consulation room from the Khan's Palace of Shaki in Azerbaijan (Urek Meniashvili on Wikimedia).

Europe that may have been used in a window date from 540 CE and 1000 CE , in Italy. As European stained glass artistry reached its height, however, it combined designs using human figures with highly complex geometric designs reminiscent of Islamic art and mathematical skill. Whether or not the ideas can be traced to common origins, there are surely many remarkable connections in space and time.

It is probably no coincidence that European glassmaking and Gothic cathedrals both advanced during the time of the Crusades and after, and that the 12th century was a time of growth in towns and trade in Europe, following centuries of urbanization in Muslim lands. This was also a time when scientific knowledge entered northern Europe from Islamic Spain and Sicily, and when cultural influences came from Spain and from the returning Crusaders. It is widely known that cathedrals owe many architectural and engineering techniques to advances from Muslim lands, such as the pointed arches and vaults that can be traced to North Africa and Al-Andalus.



The Rose Window of the Chartes Cathedral was inspired by Andalusian or Islamic stained glass art (Ludwig Schneider on Wikimedia).

Chartres Cathedral (built 1134-1220 CE) has a beautiful rose window that combines the techniques of leaded stained glass with geometric designs that are very complex, and based on the circle. The designs are set into openings in the stone, perhaps suggesting the stucco or marble designs of Spain or Syria. German art historian Otto von Simson explained the origin of the rose window by comparing the idea to the six-sided rosettes and octagon window on the outside wall of the Umayyad palace Khirbat al-Mafjar, built in the Holy Land in about 750 CE. The theory is that Crusaders saw such windows and brought the idea back to Europe, introducing it into churches.

Is it just a coincidence that many techniques and knowledge, and contact among peoples all intensified at this time? Is it possible that beauty and skill are the result of many hands, minds, and lands—sometimes through conscious contact and sometimes indirect? Some day, perhaps we shall know more.

3. Chemistry

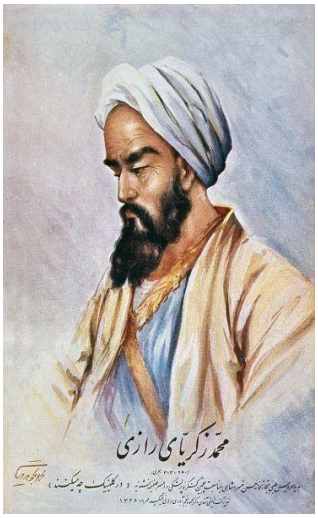
Chemistry is a theoretical and practical science, which is important to many technologies that rely on chemical reactions and useful compounds. Artisans and scientists contributed to theoretical and practical chemistry in Al-Andalus during the time of Muslim rule and after, through translation of books, discovery through experimentation, and by artisans of Al-Andalus, whose traditions were passed on to Spain and Portugal.

A drawing showing the distillation process in a treatise on chemistry (courtesy of The British Library).

The science of chemistry is often described as growing out of a pseudo-science called alchemy. The word for both in Arabic is al-kimya. The goal of alchemy was to transform matter, and especially to make gold out of base metals, to find elixirs (in Arabic al-iksir) that could ensure long life, and even to try and create life. Even though later scientists dismissed these goals as unreachable or forbidden, alchemists learned a great deal about the natural elements by trying to reach these goals.

Alchemy and chemistry in the Muslim tradition built on classical and ancient foundations. The history of knowledge about chemistry runs on a scale from ordinary to mysterious. Al-Kindi distinguished investigation of substances from alchemy, an important step toward science. Physicians al-Razi (864-930 CE) and Ibn Sina (980-1037 CE) also wrote and investigated chemical properties and processes, discouraging alchemy, but encouraging scientific investigation.

Jabir ibn Hayyan (died ca. 808 or 815 CE) was an alchemist, pharmacist, philosopher, astronomer, and physicist who is called "the father of Arab chemistry" for his important writings and discoveries. His works and techniques reached Al-Andalus, where they were translated into Latin under the name Geber. Jabir's treatises on chemistry became standard texts in Europe. The Book of Chemistry, The Balances, and others were translated by Robert of Chester (ca. 1144 CE) and Gerard of Cremona (ca. 1187 CE) at Toledo. A 1545 CE printed edition of Geber calls it "… Arabic chemical knowledge made available to Latin reading people… the best Latin knowledge of chemistry."



2 portrait of al-Razi (courtesy of Wellcome Collection).

Among Jabir ibn Hayyan's achievements were describing the process for making sulfuric acid, hydrochloric acid, and nitric acid (using saltpeter). He invented aqua regia, a substance that dissolves gold. This discovery was important for extracting, purifying and etching gold, but it was also key to alchemists' efforts to transmute metals into gold. He isolated citric acid (what makes lemons sour), acetic acid (the acid in vinegar), and tartaric acid (from fermented grapes). Jabir's work in chemistry resulted in improvements in metallurgy, dyeing and pigments in paints and textiles, waterproof fabrics, leather processing, and glassmaking. He discovered that adding manganese dioxide removed the green tint from glass to make it clear.

A European depiction of "Geber" (courtesy of the Wellcome Collection).

Jabir described how boiling wine released a flammable vapor, or spirit. Al-Razi is credited with identifying ethanol, or grain alcohol. The word alcohol in English derives from the name given to this substance by Muslim chemists. It was thought to come from al-kuhl, black antimony powder. A more logical derivation is the Arabic word al-ghawl, spirit, or intoxicant (Qur'an 37:47), source of the English word ghoul.

Jabir's classification of elements into metals and non-metals laid the foundation for chemical naming systems today. He divided substances into three categories: "spirits" that turn to vapor when heated; "metals," such as iron, copper, silver, gold, zinc, mercury, and lead; and "stones" or minerals that can be pounded into powdery form and used in many chemical reactions. Alkaline substances such as natron (sodium carbonate, or soda) and ash were widely used in manufacturing during that period in glassmaking, textiles, and soap. The Balances describes weights of substances based on a precise scale he designed and built which could accurately weigh amounts 6,480 times smaller than a kilogram.

Al-Majriti (d. 1007 CE) was a chemist from Madrid who built upon the work in chemistry done in eastern Muslim lands, and made his own achievements. His books, such as The Rank of the Wise and De Aluminibus, described his experiments in synthetic chemistry, and formulas for purifying precious metals. Al-Majriti was the first scientist to prove the principle of conservation of mass.

Oil painting by Ernest Board of Al-Razi in his Laboratory in Baghdad (courtesy of Wellcome Collection).

Practical applications of chemistry in Al-Andalus were found in all of the major industries. In mining, chemicals were used to purify and refine metals from ore by heating or mixing with other substances, and to process metal into products. Glassware and ceramic industries in Al-Andalus used sophisticated ovens and chemical substances to make glass and glazes from silica, adding metal oxides to make different colors. Minerals were made into acid and alkali compounds used in manufacturing. Vegetable and animal oils and even petroleum distillates (naptha: al-naft, for example) were used for lighting and solvents. Other artisans in Muslim lands used chemical processes for refining gems, making fixatives for textile and leather dyes, inks, paint, lacquer, and wood varnish.

Al-Andalus was a major center for processing flowers and herbs for medicines and cosmetics, using different chemical processes. Distillation (boiling and condensing) was one process described in Arabic books of chemistry, shown in the illustration. Others are subliming, crystallizing, dissolving substances in the right concentration, and preserving them in alcohol or syrup (both words from Arabic).

Hospitals and pharmacies in Al-Andalus used these skills and recorded them in manuals and books. Perfumes, essential oils, and cosmetics were made out of natural substances that are weak in their natural form, and must be extracted and concentrated. They also

need to be attractive and pleasant to apply to the body. In the cities of Al-Andalus, perfumers' shops were often located in streets near the main mosque.

Traditional Aleppo soaps (Bernardpascal on Wikimedia).

Production of soap was widespread in Muslim lands during the Medieval period. Soap is made by mixing oil or fat with an alkaline substance (the Arabic word al-kali is the origin), made from ashes of certain plants. Emulsified, the mixture turns into solid soap. Castile soap from Spain became famous, and the Crusaders discovered soap-making centers in the eastern Mediterranean lands. Olive oil became the preferred type of oil for soap in Al-Andalus and around the Mediterranean. Castile soap is still sold in stores today.

Gunpowder is a compound made of potassium nitrate, charcoal powder, and other substances. It originated in China, where it was used for fireworks and early types of rockets. Muslim chemists experimented with this Chinese invention and wrote formulas for making gunpowder. The book Liber Ignium of Marcus Graecus, an early source of gunpowder formulas in Europe, was probably translated into Latin from an Arabic work found in Spain.

European scientist Roger Bacon published gunpowder recipes that some historians believe were derived from Arab chemists through these translations. There is evidence that gunpowder weapons and rockets were used by Muslim forces during the Crusades. Archaeological evidence of potassium nitrate has been found in Egypt from the 12th and 13th centuries CE. Syrian scholar Hassan Al-Rammah (d. 1295 CE) wrote a book on military technology that was translated into European languages. It explained how to purify potassium nitrate, and contained recipes for making gunpowder with the correct proportions to achieve an explosion. The first documented rocket is included in the book, of which a model is on exhibit at the National Air and Space Museum in Washington.

A Turkish cannon built in the mid 1460's, based upon a cannon used by the Turkish in the 1453 siege on Constantinople (Gaius Cornelius on Wikimedia).

Both practical and theoretical knowledge of chemistry advanced in Muslim lands, and was transmitted to Al-Andalus, where it was further developed and transferred to those Europeans who built upon the collective knowledge of many cultures to create the science of chemistry as we know it today.

4. Botany

Farms in Southern Andalusia (Max Pixel).

Botany, the study of plants and their characteristics, is closely related to agriculture and pharmacology, which were both fields of achievement in Al-Andalus. Beyond plants used for food and fiber crops, or medicine, gardening was an important contribution during Muslim rule in the Iberian Peninsula. As in so many other cultural and scientific fields, there was a tendency — in the face of huge amounts of evidence to the contrary — to ignore or downplay the achievements of Al-Andalus under Muslim rule. This has recently begun to change, and the influence of Islamic gardens and botanists has begun to find recognition.

Pages from The Herbal of al-Ghafiqi, a botanical manuscript written by Abu Ja'far al-Ghafiqi in the 12th Century CE (Courtesy of Kala Art Institute).

Identification of plants cultivated in Andalusian gardens between the 10th and 15th centuries can be traced to several main works of botany. One such source is the Cordovan Calendar, an almanac of weather, planting and harvesting times, and Christian holy days. This book dates to the reign of al-Hakam II, Umayyad ruler of Al-Andalus, between 961 and 976 CE. The Cordovan Calendar lists over one hundred plants.

The book of Ibn Bassal produced in Toledo (ca. 1075-1080) also lists over 100 ornamental and useful plants. Ibn Awwam wrote a huge encyclopedia of agriculture around 1138 CE at Seville in which he named and described about 160 different plants and their uses. Ibn al-Awwam's book was translated into Spanish and published as late as 1802 at Madrid, and it has helped to restore the botanical history of Al-Andalus to its rightful place.

Another work is the Treatise on Agriculture by Ibn Luyun of 1348 CE, at Seville, which lists about the same number of plants. These rising numbers indicate that new plants were being introduced and successfully grown in gardens of Al-Andalus. If it were true that the Arabic writers were only copying ancient works like those of the Romans or Greeks, the Arabic writers would have been able to name only as many as those works contain, or fewer. In fact, a famous classical work on horticulture or botany was by Palladius (ca. 380 CE), which lists only about 76 different plants. European herbal books of the early

Medieval period list around the same number as Palladius, and even some of these were imported plants. Charlemagne's court records list fewer than 100 plants. Much later, in about 1300, a Master John Gardner of England listed about 100 plants, about a third of which were also grown in Al-Andalus. Another English botanical garden of the period lists over 250 plants, of which 107 were grown in Al-Andalus.

Among the plants introduced to or cultivated in Al-Andalus were banana, date palm, jujube, myrtle, oleander, olive, sweet orange, and watermelon. Sesame, sugar-cane and pistachio, apricot, cherry, and peach were grown in Andalusian gardens. Fruit trees were especially difficult to introduce, because the fruit retains its quality only through grafting of branches onto sturdy root stock or existing trees.

3The gardens of al-Hambra, a fortress located in Granada, Spain, which later became the residence of Ferdinand and Isabella (htomek on pixabay).

Plants grown for their beauty, such as the iris, jasmine, types of lily, morning glory, narcissus, hollyhocks, and marigolds are identified in these Andalusian works. Many fragrant herbs and medicinal plants like anise, caraway, and carob were grown there. Vegetables like spinach, asparagus, cauliflower, artichoke, carrots, and many types of beans were introduced with culinary fashions. They were also very nutritious, and helped to improve people's overall health.

Industrial crops like hemp for rope and sacks, thistle, and dye-plants were also included in these sources. Alfalfa, whose name comes from Arabic, was an important plant for animal feed, and also restored the nitrogen in soil during crop rotation. Andalusian botanists knew about the life cycles of these plants, the soil and water conditions they needed, and how they could be reproduced. They wrote about crossing (by planting together) wild and cultivated varieties of plants to make stronger or better varieties.

Andalusian botanists built on the works of botanists in eastern Muslim lands, and travelers as well as merchants helped to spread these useful plants, while agricultural policies, irrigation, and cultivation of fine gardens in Al-Andalus provided the environment in which these plants could thrive and spread further.

Other works of botany were those of Abul Abbas al-Nabati or Ibn Rumiyya (d. 1239 CE), Ibn Bajja (d. 1138 CE), who wrote about the reproduction of male and female plants, al-Ghafiqi (d. 1166 CE), on medicinal plants, and the botanical-pharmacological encyclopedia of Ibn Baytar (1197-1248 CE). These authors were scientists, not merely describing or cataloging, but developing knowledge and putting it into practical applications that served their societies.

The information collected by these botanists was carried to the farmers who needed it to improve their plants, to the markets where people could purchase seeds and plants for their gardens, or medicinal plants for the health of their families. These scholars knew and compared the popular names for plants in many languages.

The famous Hanging Gardens of Babylon, one of the wonders of the ancient world, may have been here in this area of what is now Iraq (David Stanley on Flickr).

Lasting influences: Ultimately, the knowledge of plants that the botanists of Al-Andalus and other Muslim lands collected, developed, and disseminated served to spread cultivation of many useful, beautiful, nutritious, and health-giving plants. These plants improved the lives of people in other parts of the world, and greatly enriched the gardens of Europeans north of Spain.

5. Physics and Optics

Physics is the science of motion and its laws, but also of sound, and light, and discussion of matter and energy. The modern science of physics grew out of many Medieval disciplines, ranging from philosophy, or speculative thought, to music theory, engineering, and optics — the study of light and vision, including mirrors, lenses, rainbows, shadows and the process of seeing. Experiments in flight and projection of objects in space (such as cannons, catapults and gliders) are also considered part of physics.

Achievements in Islamic Spain include new ideas produced by studies of physical science that were then published in books, and also translations of works from other Muslim lands, that were transferred to Europe and beyond. They include applications of physics to practical life in areas such as use of energy and hydraulic technologies.

Achievements in the physical sciences began at the court of Córdoba during the 9th and 10th centuries CE, where artists and scholars, inventors and writers could find patronage and interest in their ideas. Books from the eastern Muslim lands, especially Baghdad, were eagerly collected in Andalusian libraries of half a million volumes.

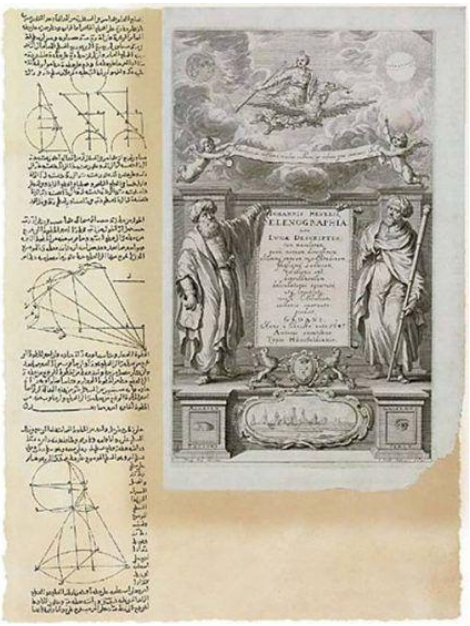
A page from al-Khwarizmi's "The Compendious Book on Calculation by Completion and Balancing", from which the fundamentals of algebra came (John L. Esposito, The Oxford History of Islam).

Among the works brought there were al-Khwarizmi's mathematical writings. Like most other scholars of the time, al-Khwarizmi experimented with many ideas, such as calculating the thickness of earth's atmosphere, and problems with optics, such as magnification. Works on sound and music theory were well known and put to practical use in building complex musical instruments.

A page from al-Haytham's Book of Optics (Delimapagi978 on Wikimedia).

Ibn al-Haytham (died ca. 1040 CE), known in Latin translation as Alhazen, was a scholar in Cairo whose work was widely translated into Latin during the 12th century CE and is still studied by historians of science today. Ibn al-Haytham described his experiments and investigations about light and vision in an innovative work called The Book of Optics. He analyzed the structure of the human eye and described how it sees. He overturned theories held since Aristotle and Ptolemy that either the eye sent out rays that allowed objects to be seen, or objects sent some force toward the eye.

Ibn al-Haytham demonstrated how light enters the eye through the pupil. Using mathematical formulas, he described how light falling on the eye is refracted through its lens, allowing the eye to sense forms of light and color, and the mind to perceive and order the images. Other optical experiments and investigations included projecting the sun's image on a wall through a small opening, which is the camera obscura similar to early photographic cameras of later centuries. (The light-sensitive film to capture the image was a much later invention.) He investigated mirror theory, described spherical and parabolic mirrors, calculated how light is refracted (bent), and how light passing through a lens is broken into the color spectrum — the rainbow. His investigation of glass and water lenses led to the creation of mathematical formulas that allowed advancements in refining the shape of lenses. European scholars studied these ideas, which led to lenses for telescopes, magnifying lenses, and eyeglasses.



Ibn al-Haytham (at left) and Galileo appear on the frontispiece of Selenographia, a 1647 description of the moon by Johannes Hevelius (courtesy of Harvard College Library).

Most surprisingly, his mathematical discussions of the way the eye sees led to the development of perspective drawing, a major aid to realistic painting, but also a great advancement in accurate illustration for scientific and technical books. Combined with the invention of printing, perspective drawing allowed accurate transmission of ideas for machines, architecture and other fields. Ibn Al-Haytham influenced important scientists such as Witelo, Kepler, and Roger Bacon, making Alhazen the most quoted physicist of the Medieval period.

Although the achievements of Ibn al-Haytham, like those of other Muslim scientists, have been neglected, a 17th century engraving in a scientific book shows Galileo, inventor of the telescope and astronomer, dressed as an Arab and posing opposite him as a tribute to his contribution.

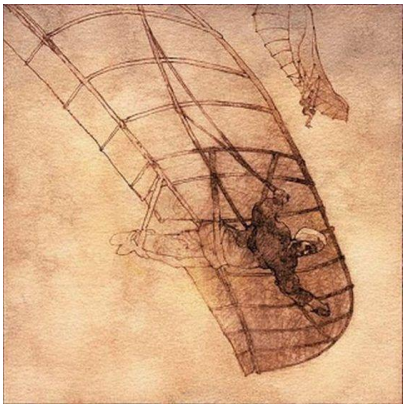
Other applications of physics were being used and developed in Al-Andalus. In hydraulic technology, machines to move water were built on models like those of al-Jazari, who invented the crank-connecting rod system. This was very important to the development of technology, because it involves a way of transforming rotation into linear motion, like the mechanism that moves your bicycle. The same principle is used in car engines.

Al-Jazari's manuscript is full of innovations, such as valves and pistons, one of the first mechanical clocks driven by water and weights, and a combination lock. Andalusian Muslim engineers continued to produce and perfect mechanical clocks, and this knowledge was transmitted to Europe through Latin translations of their books on mechanics. Many of these books have since been lost or destroyed.

Another practical and experimental scientist who worked in Al-Andalus was as Abbas ibn Firnas (810–887 CE), who came to Córdoba from Baghdad to teach music theory at the court of Abd al-Rahman III. Ibn Firnas worked in many fields, including chemistry, physics, astronomy, and as a poet. He designed a water clock, he worked to improve the way glass was made, and is said to have worked on eyeglasses to help those with poor

vision. He devised a way to cut very hard quartz, or rock crystal, and made a mechanical model to show the motions of planets and stars.

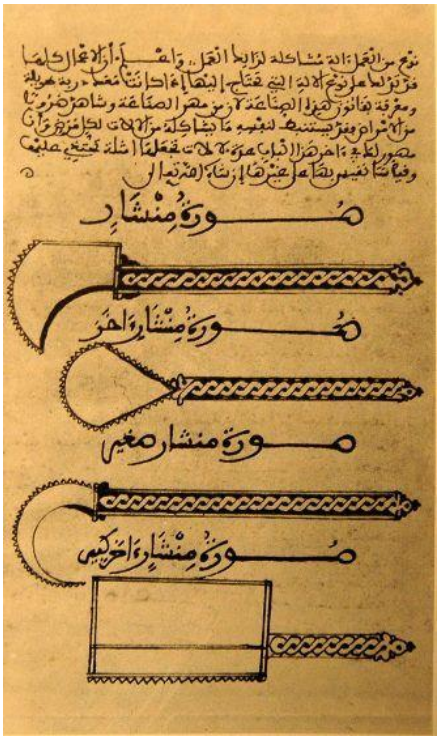
In 875 CE, Ibn Firnas did something that made him famous, but almost ended his career. He constructed a glider, and launched himself into the air. The flight was successful, and was viewed by a crowd of invited guests. As an experimental vehicle, however, the design was not perfected, and it had no tail to help with landing, a fact which he later noted when observing birds. He injured his back upon landing. Historian Philip Hitti wrote, "Ibn Firnas was the first man in history to make a scientific attempt at flying." A crater on the map of the moon is named Ibn Firnas to honor his achievement as one of the first people to fly.



A drawing of Ibn Firnas's glider (Mikhail Zarezin).

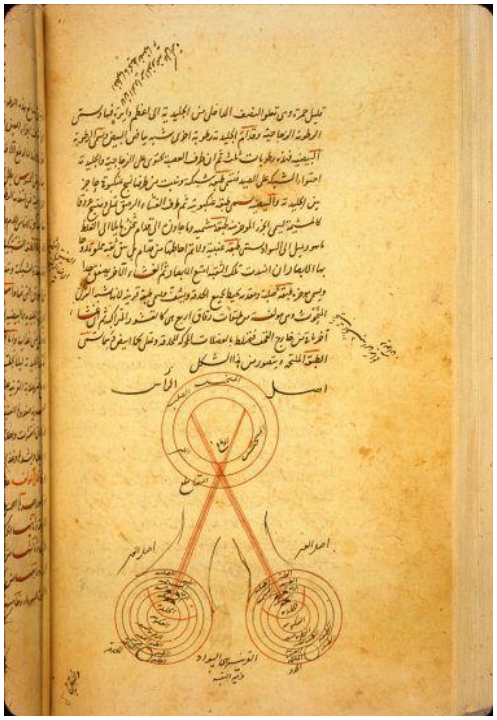
Europeans benefited greatly from the knowledge and research of Muslims in physics. One piece of evidence of this is that many these books were translated into Latin in Spain. Another is that these books were taught in European universities and quoted by scientists as they developed their own work. Finally, they were among the first books printed after Gutenberg invented the printing press in 1453 CE by, and were re-printed many times. These ideas laid the foundation for the Scientific Revolution of the 16th and 17th centuries CE. Even though much of this Muslim legacy was forgotten, historians of science are restoring its rightful place today.

6. Surgery



The most famous surgeon in Al-Andalus was the 10th century physician and author, Abul Qasim Khalaf Ibn Al-Abbas Al-Zahrawi (936-1013 CE). Al-Zahrawi was known to Europeans in Latin as Albucasis, and his surgical work was translated and widely used, being printed and used in medical schools even centuries later. The text at right shows illustrations of metal surgical instruments. It was translated at Toledo by the famous translator Gerard of Cremona.

Al-Zahrawi described many surgical cures for diseases, designed instruments, and wrote about techniques surgeons should use. He discussed cauterization (cleaning and sealing wounds by burning), closing wounds with sutures (stitches), bloodletting and bone-setting, and the proper way to conduct amputations when necessary. He was a pioneer in surgery for the eye, ear, and throat, including a device for cutting out infected tonsils that caught the tonsil in a basket so that it would not fall down the throat of the patient. He also wrote about midwifery and obstetrics — aiding women in childbirth.



A page from Ibn al-Nafis's "The Key to the Mujiz" shows a diagram on the way the eyes function (D.M. Schullian and F.E. Sommer, A Catalogue of Incunabula and Manuscripts in the Army Medical Library).

His instruments were designed to be efficient, specialized for particular types of surgery, and helpful in preventing patients from being frightened. For example, he designed a hidden knife for opening infected wounds so that frightened patients would not see it.

There is evidence that Muslim surgeons used anesthetics, both in the form of pain-killers given by mouth, and a sponge soaked with substances that were placed under the nose of the patient to make him or her less sensitive to pain. Otherwise, surgery was an ordeal that often required the patient to be held steady by more than one person.

7. Pharmacology

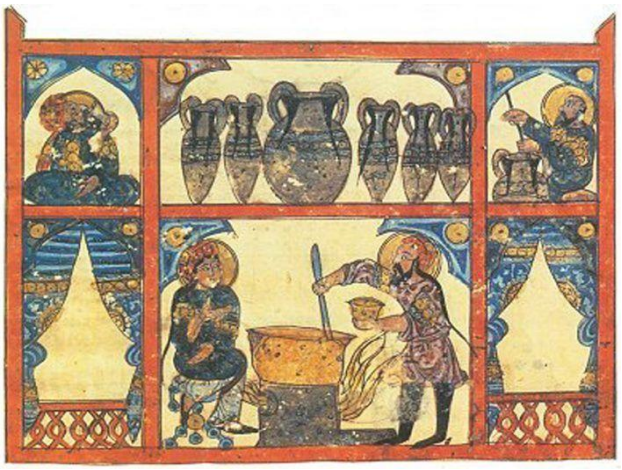


Illustration of a pharmacist preparing drugs, from "De Materia Medica", a Greek manuscript that heavily impacted Arab medicine (Islam and the Arab World, edited by Bernard Lewis).

Pharmacology is the study of plants and other natural substances that cure or prevent diseases. From the very earliest times, people have identified such cures in their local environment. Knowledge of these cures was passed down orally. With the expansion of trade, certain important drugs made of herbs, spices, animal extracts, or minerals became known outside of their native environments. Either the substance was exported in dried or preserved form, or the plant itself was introduced to new places and grown there.

As medical science developed, knowledge about pharmacology was systematically collected in written form. Chinese, Indian, Persian, Greek, and Roman collections of knowledge exist, and information was traded among them. In the Mediterranean and western Asia, several important collections had been passed down, and became part of the legacy of knowledge on which physicians in Muslim lands could draw.

A pharmacist prepares medicines to treat a patient suffering from smallpox in this illustration from a 17th-century Ottoman manuscript of Ibn Sina's Canon of Medicine (courtesy of Istanbul University via Aramco).

Because their geographic reach was so extensive, pharmacologists working in the Islamic tradition were able to include drugs known to a wide variety of peoples since ancient times. Among the important curative substances, or *materia medica* in Latin, the Islamic scientific books included plant and animal camphor, musk, sal ammoniac, and senna, a wide range of herbals and medicines from as far away as China, Southeast Asia, the Himalayas, southern India, and Africa. In addition to drugs, beneficial foods were included.

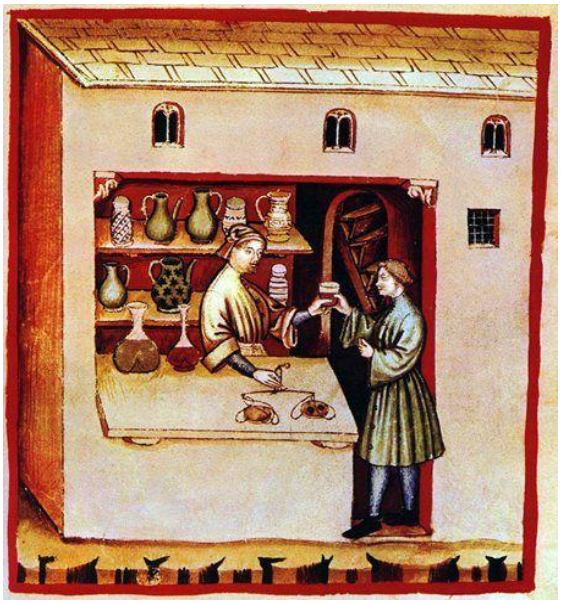
The tradition of medicine in Islam was founded on both good habits of healthful living practiced by Prophet Muhammad, and the tradition attributed to him, "God created a cure for every disease." Taking up this challenge, Muslims and others working in the Islamic tradition traveled to seek knowledge, collected information and specimens, translated important works, and experimented with clinical practice in hospitals.

A pharmacist prepares medicines to treat a patient suffering from smallpox in this illustration from a 17th-century Ottoman manuscript of Ibn Sina's Canon of Medicine (courtesy of Istanbul University via Aramco).

Al-Andalus both absorbed the benefits of this wide-ranging knowledge and added to it with medical and botanical work. Among the important works translated from Greek into

Arabic was Dioscorides, which Hasdai ibn Shaprut (ca. 915-990 CE) helped translate in Córdoba. Another Córdoban, Ibn Juljul (b. 943 CE), wrote a commentary on Dioscorides' work of pharmacology. In the eastern Muslim lands, pharmacists prepared medicines using instructions in directions found in the Treatise on Medicinal Drugs by Abu Raihan Muhammad al-Biruni (973-1048 CE), who shared information with famous physician Ibn Sina (980-1037 CE).

The most valuable and popular work on pharmacology in Al-Andalus, and later in other parts of Europe, was by Granadian botanist Ibn al-Baytar (died in 1248 CE), the Collection of Simple Drugs and Food, an encyclopedia of about 1500 medicinal substances that he collected over his lifetime. The book contains information about the substance, what it can be used for, how to prepare it, and how much to give the patient. As late as 1875 at the famous Bulaq press in Cairo, Ibn al-Baytar's Comprehensive Book on Materia Medica and Foodstuffs was still being printed.



This depiction of an early European pharmacy appeared in a14th century Latin translation of an Arabic pharmaceutical manuscript (courtesy of Pictures from History via Aramco).

These books and the knowledge gained in hospitals, gardening, and pharmacies spread the reputation of medical practice in Spain, which was far advanced over that in the rest of Medieval Europe at that time. The earliest medical colleges grew up in Sicily, southern France, and other places where knowledge from Muslim lands was available. Through translation into Latin, direct teaching, and knowledge of Arabic, Europeans learned this valuable knowledge and founded medical science in the West. Andalusian contributions in preserving and adding to this body of learning are still recognized by scholars today.

9. Astronomy

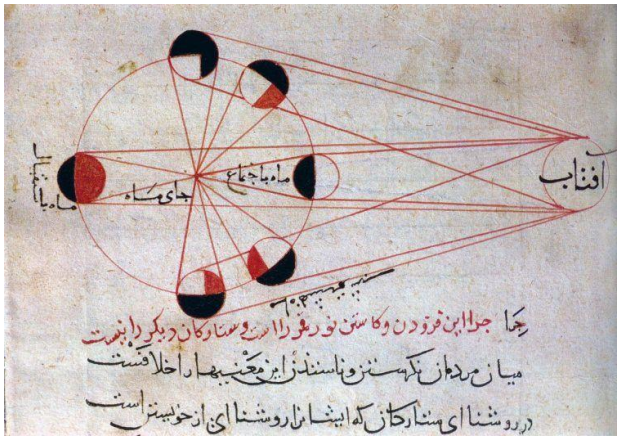


Illustration of different phases of the moon from the manuscript "Kitab al-Tafhim" by Al-Biruni (Roland and Sabrina Michaud on Wikimedia).

Astronomy may not seem so essential today, but that is only because we take accurate calendars and clocks for granted. We scarcely notice the phases of the moon, the sun's passage marked by equinoxes (fall and spring dates of equal daytime and nighttime) and solstices (longest and shortest days of summer and winter), because they no longer seem essential to our lives. To get from one place to another, we use interstate highways and road maps, not devices for navigating by the stars.

In contrast to us, Medieval societies made great efforts to establish accurate calendars for celebration of religious holidays and for plowing, planting, and harvesting. Astronomy was necessary for these practical reasons. Scientists who gathered this knowledge were also curious to know more about the celestial bodies that fill the sky at night, and to understand their relationship to the sun, the moon, and the earth.

An edition of "Kitab al-Qanun al-Mas'udi", another astronomical writing by al-Biruni, which shows the motions of planets (courtesy World History Archive).

Al-Andalus was open to knowledge from eastern Muslim lands, where knowledge from many cultures and religious groups was gathered together during the 800s CE. Early Muslims absorbed Indian, Mesopotamian, Persian, Greek, and Roman knowledge of astronomy.

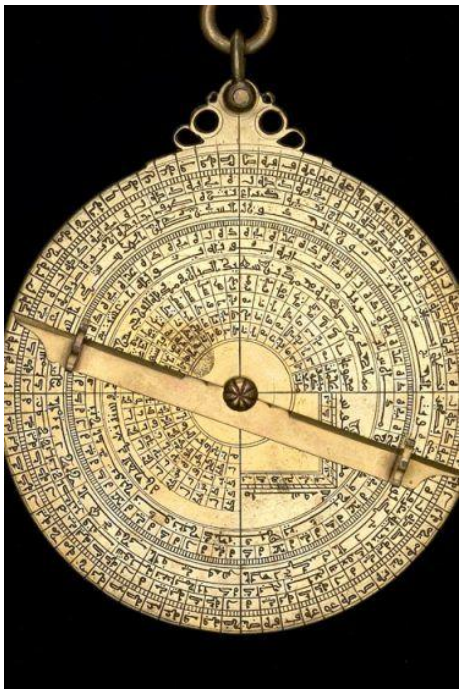
Among earlier works that played a large role was a system of astronomy associated with Ptolemy, a mathematician who lived around 150 CE in Alexandria, Egypt. His system was widely believed, but as observations continued, astronomers found that it couldn't explain the movement of the planets and the sun that astronomers observed, since it placed the earth at the center of the universe.

During the next 1500 years, astronomers continued their observations and developed mathematical and mechanical models to explain this observed movement. Astronomers working in Muslim lands some Muslim, some Jewish and some Christian –wrote books with diagrams and formulas, trying to improve on Ptolemy's system.

Among the earliest Muslim astronomers was al-Faraghani (fl. 863 CE), who summarized but questioned Ptolemy's work and made many important calculations. Columbus used his figures on the earth's circumference, but misunderstood the astronomer's unit of measurement. Al-Khwarizmi (ca. 770-840 CE), the famous Persian mathematician, prepared astronomical charts that were later translated and further developed in Spain.

Al-Battani (d. 929 CE), another critic of Ptolemy, contributed to solving the puzzle of the heavens, and whose work was used for centuries. He calculated astronomical tables (charts on the movement of bodies in the sky), and helped to develop the branch of mathematics called trigonometry, which he used to calculate accurate solar and lunar timekeeping.

Astronomy in Spain built on the work being done in the east. In Córdoba, Spain, al-Zarqali (1029-1087 CE) prepared astronomical charts called the Toledan Tables. He also built and improved on the astrolabe, a tool with hundreds of uses in astronomy, navigation, surveying and timekeeping.

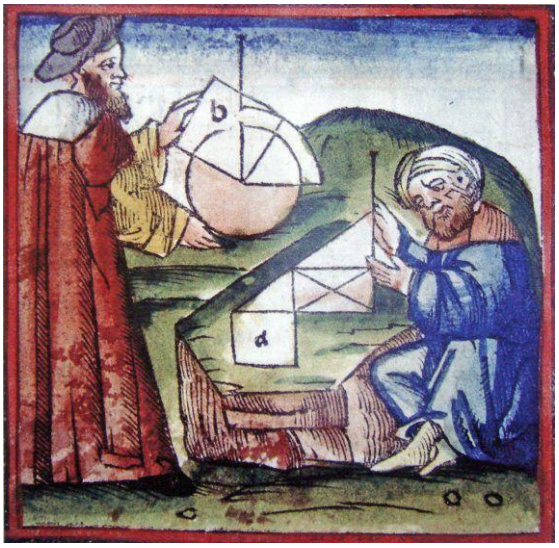


Astrolabe, by Muhammad ibn Sa'id as-Sabban, 1081 CE (courtesy University of Oxford History of Science Museum).

Jaber ibn Aflah (d. 1145 CE) is considered important for his advancements in trigonometry. Using spherical trigonometry, he designed a portable celestial sphere. Al-Bitruji (d. 1204 CE) was a leading astronomer who was born in Morocco and migrated to Seville, where he developed a new theory of the movement of stars.

Translation of books on mathematics and astronomy in Spain from Arabic through Hebrew and Castilian into Latin added to the contributions of Al-Andalus to advancing astronomy in Europe. Historians of science have long known about these translations, where they were published, and which scientists owned these books. Recently, it has become known that some European scientists had direct or indirect knowledge of Arabic, and we are learning that there was more than one path by which learning was exchanged between East and West.

10. Mathematics

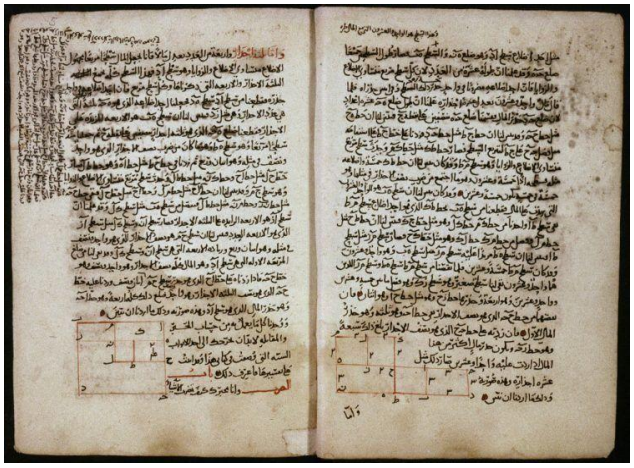


A Westerner and an Arab practicing geometry in the 15th century (Cahiers de Science et Vie No114 via Wikimedia).

Advances in mathematics in Muslim lands have long been recognized. The high degree of skill in mathematics led to advancements in many other fields, such as astronomy, cartography, surveying and engineering, commerce, art, and architecture. The best-known contribution by early Muslim mathematicians was the transfer of Indian numerals, the concept of zero, and its notation.

This transfer was a direct result of the openness of Muslims to new ideas, and the burst of exploration and travel, collection of books and scholarly work from every civilization Muslims encountered. As in other fields of scholarship, the translation and collection of mathematical knowledge from Greek, Persian, Indian and other sources resulted in preserving the highest state of the eastern hemisphere's mathematics up to that time.

Persian mathematician and astronomer Muhammad Ibn Musa al-Khwarizmi (780-850 CE), was appointed court astronomer at Baghdad by the Abbasid Caliph Al-Ma'mun. He is known in Latin as Algoritimi (from which the math and computer term algorithm is derived). He is also known as "the father of algebra," from the title of his work, Hisab Al-Jabr wal Muqabalah, The Book of Calculations, Restoration and Reduction. He gave the name to that branch of mathematics.



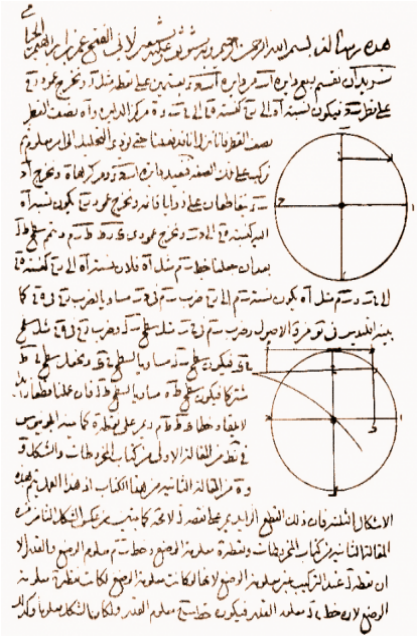
Copied text pages from around 1342 CE from an Algebra manuscript by al-Khwarizmi with geometrical solutions to two quadratic equations (Bodleian Libraries, University of Oxford).

In fact, his algebra was a book of arithmetic featuring Hindi numerals — a huge improvement over Roman numerals and other systems of dots, pictographs, and finger reckoning. His introduction of the Indian concept of zero, along with the other nine digits, meant that mathematicians could express any number. Algebra was a method for moving terms from one side of an equation to the other to find the value of an unknown. He also described how to find the square root of a number, and was the first to demonstrate the concept of exponents for unknown variables. He demonstrated the use of equations, algebraic multiplication and division, and measuring area.

Damascus mathematician Abu al-Hasan Ahmad ibn Ibrahim al-Uqlidisi ("the Euclidian," fl. ca. 953 CE) further advanced the Indian mode of calculation. The Indian system had used a dustboard to perform and erase a series of calculations. Al-Uqlidisi adapted the

Indian system for pen and paper. Mathematicians could now "show their work," sharing problems, equations, and methods for solving them across time and space. Mathematics advanced rapidly as a result of recording and publication.

Al-Battani (850-929 CE) contributed significant work developing trigonometry, computing the first table of cotangents. Al-Biruni (973-1050 CE) also advanced trigonometry, and used it to calculate the coordinates of cities to determine the qibla (direction of Makkah) from any location. Omar Khayyam (b. 1048 CE) classified and solved cubic equations.

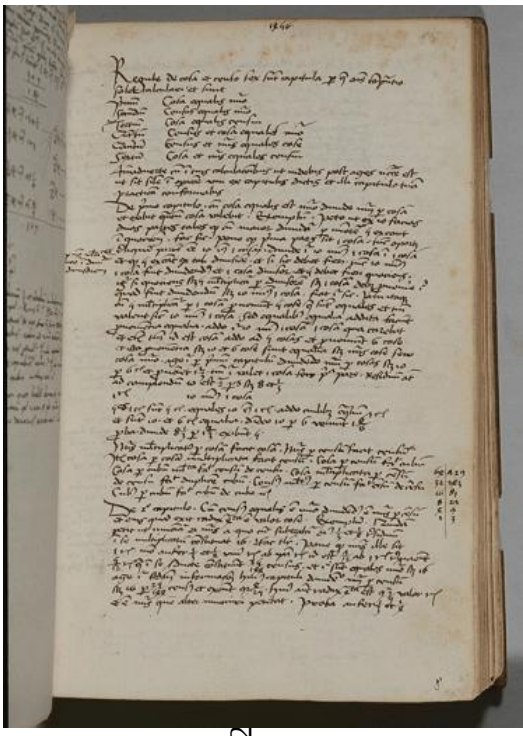


4The first page of an untitled manuscript by Khayyam (Xashaiar on Wikimedia).

By the 10th century, Muslim mathematicians had developed and applied the theory of trigonometric functions — sine, cosine, and tangent — as well as spherical trigonometry. They used symbols to describe the binomial theorem, and used decimals to express fractions that aided accurate solution of complex problems.

Major Arabic mathematical works were brought to Al-Andalus by the 9th century, along with important Greek translations and commentaries. Together with a translation of Euclid's Elements, they became the two foundations of subsequent mathematical developments in Al-Andalus. It is clear from their own achievements that scholars in Al-Andalus followed advancements in other Muslim lands, and contributed their own.

Today, al-Khwarizmi's work exists only as a Latin translation made in Toledo, Spain, by Gerard of Cremona (d. 1187 CE). Europeans did not gain access to the mathematical knowledge found in Spain and North Africa until the 12th and 13th centuries CE. It entered Europe both through scholarly and commercial means. Fibonacci (d. 1250 CE), an Italian mathematician who traveled between Europe and North Africa, transmitted mathematical knowledge from Muslim lands to Europe and made his own discoveries.



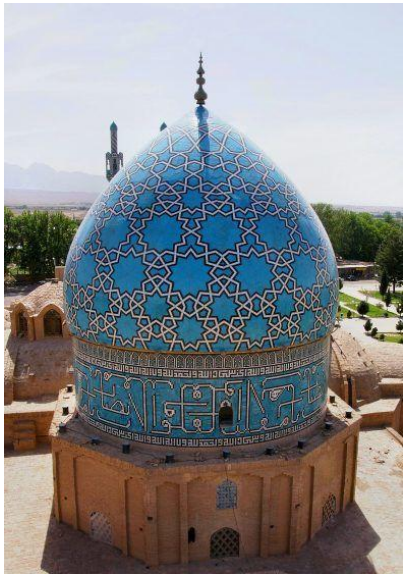
An example of a translation by Gerard of Cremona of al-Khwarizmi's "al-Jebra" (courtesy of The Rare Book and Manuscript Library of the Columbia University

Mathematicians in Al-Andalus also did original work. Maslama al-Majriti (d. 1007 CE) was a mathematician and astronomer who translated Ptolemy's Almagest, and corrected and added to al-Khwarizmi's astronomical tables. Al-Majriti also used advanced techniques of surveying using triangulation.

Al-Zarqali, or Arzachel in Latin, was a mathematician and astronomer who worked in Córdoba during the 11th century. He was skilled at making instruments for the study of astronomy, and built a famous water clock that could tell the hours of the day and night, as well as the days of the lunar month. Al-Zarqali contributed to the famous Toledan Tables of astronomical data, and published an almanac that correlated the days of the month on different calendars such as the Coptic, Roman, lunar and Persian, gave the positions of the planets, and predicted solar and lunar eclipses. He

created tables of latitude and longitude to aid navigation and cartography.

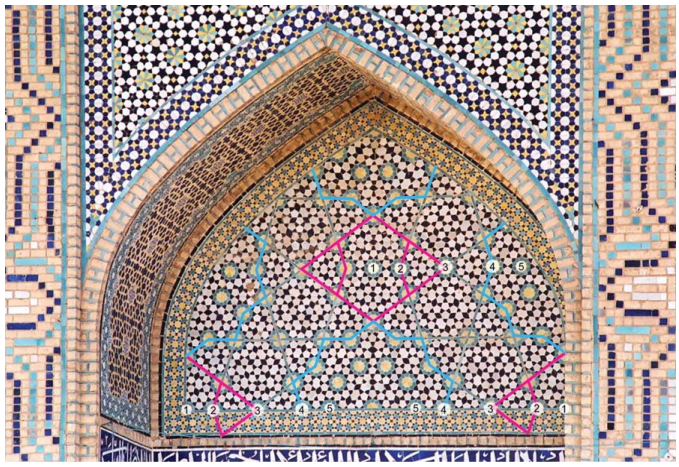
Another prominent Andalusian mathematician and astronomer in Seville was al-Bitruji (d. 1204 CE), known in Europe as Alpetragius. He developed a theory of the movement of stars described in The Book of Form. Ibn Bagunis of Toledo was a mathematician renowned for his work in geometry. Abraham bar Hiyya was a Jewish mathematician who assisted Plato of Tivoli with translation of important mathematical and astronomical works, including his own Liber Embadorum, in 1145 CE. Abu al-Hakam al-Kirmani was a prominent 12th century scholar of Al-Andalus, a scholar of geometry and logic.



Tiled dome and minarets, with cupolas, of the adobe Shrine of Shah Nematollah Vali in southern Iran (anaareh_saaveh on Flickr).

No branch of mathematics is more visible in Muslim culture than geometry. Geometric design reached heights of skill and beauty that was applied to nearly every art form, from textiles to illustration to architectural decoration. Tessellated, or complex, overall patterns were used in Andalusian architecture to cover walls, ceilings, floors and arches. Some scholars of Islamic arts believe that these designs were much more than artisans' work — they consciously expressed the mathematical knowledge of the culture that produced them.

Recently, Paul J. Steinhardt of Princeton and Peter J. Lu of Harvard University discovered Medieval Islamic tessellations designed 500 years ago; they were unusually complex, with polygons of multiple shapes, overlaid by zigzag lines. These designs are known today as quasicrystalline because they have fivefold or tenfold rotational symmetry; that means they can be rotated around a point to five or ten positions and still look the same. Such designs can be infinitely extended without repeating. In the 1970s, Oxford mathematician Roger Penrose calculated the principles behind quasicrystalline symmetry. Steinhardt and Lu discovered that such patterns of stars and polygons have decorated mosques and palaces since the 15th century CE.



Girih tessellation in the Darb-i Imam Mosque Portal, Isfahan (Lu & Steinhardt, Spacetimefactor.wordpress.com)

11. Textiles

Drawing of the garments of the different social classes of Andalusia (Internet Archive Book Images on Flickr)

Fine fabrics made of cotton, wool, linen, and silk were so commonly traded that they were almost a form of currency. Each country produced homespun, ordinary fabrics for clothing from available fibers — in Europe, often wool. Luxury textiles — especially those woven, printed, or embroidered in multiple colors were exactly the type of goods well suited for long-distance trade — light in weight, valuable, and much in demand.

While the ordinary people wore drab colors and coarse materials, the wealthy ruling classes, both religious and political, indulged in "power dressing," purchasing robes, vestments, and decorative fabrics that enhanced their authority.

Fine linens and woolens had been traded for centuries, and the volume of such trade increased during the Medieval period. The luxury fabric of choice, however, was silk brocade, in which different colored threads were woven into complex patterns. Ever since silk production arrived in western Asia from China, brocade weaving had been the technique of choice for luxury fabrics. Sassanian and Byzantine royal workshops produced brocades for palace, royal wardrobes, and religious institutions, as well as gifts of honor.

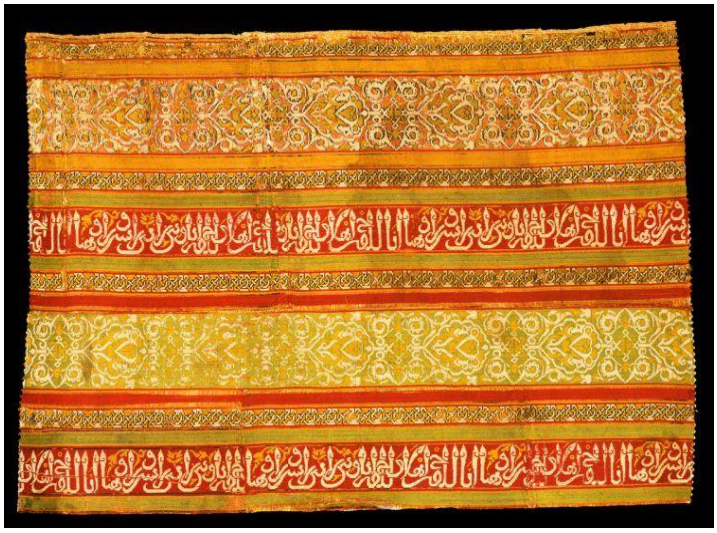
Woven silk textile from 14th/15th century Andalusia (courtesy of The David Collection).

With the expansion of Muslim-ruled territory across western Asia and the Mediterranean, this tradition continued. The typical brocade motif of mythical and symbolic animals and geometric shapes was expanded to include geometric designs and Arabic inscriptions called tiraz. These banded inscriptions, woven or embroidered in colors and often with gold or silver threads, were highly prized for garments. Moving beyond the caliphal workshops, they became prized articles of trade.

Al-Andalus became a center of silk production, including both import of silk thread and cultivation of silkworms. Styles and technologies from eastern Muslim lands kept pace with Andalusian fashions at the court and among the wealthy. Silk textiles became important articles of the export trade. Andalusian silks at first had similar design motifs like those of Persian, Byzantine, and Mesopotamian origin. Andalusian weavers also copied styles popular in Baghdad.

Brocade silks were one of those articles that crossed cultural and religious lines with ease. Brocades with Arabic inscriptions and eastern patterns are found as altar cloths, church vestments and even funeral shrouds in Christian possession. Muslims used them as wall coverings, robes, and over-garments, despite the prohibition against men wearing silks. People unable to afford the complete silk regalia employed woven bands on the edges of clothing or draped neck cloths (taylasan).

Among the silk designs were fanciful animals like griffins, lions, eagles, serpents, birds, and exotic plants of the east, arranged in symmetrical patterns, medallions, and alternating bands. The inscriptions sometimes attributed the qualities of these creatures to the wearer, or represented blessings and praises.



Woven silk textile from 14th/15th century Andalusia, with Arabic script (Adèle Coulin Weibel via The David Collection).

Córdoba was an early textile manufacturing center, where as many as 13,000 looms were active at one time. From the 10th century CE, it was producing silk fabrics, and in later centuries Almería also became an important export center.

The Almoravids developed textile production during the 12th century CE. Spanish weavers became especially skilled at weaving complex designs with fine lines between the colors, and very densely woven threads. The surviving examples of these textiles are still brilliant in color.

They appear in Church treasuries, and in early Renaissance Italy, they are carefully depicted in paintings, often with religious subjects. Almohad period silk textiles are simpler in design, reflecting their rejection of the animal motifs in favor of Islamically acceptable geometric motifs much like the tiles, bookbindings, woodcarvings, and architectural patterns of the time. Wealthy buyers in Christian territories highly prized these textiles, even with Arabic inscriptions. From Spain, Sicily, and Egypt, the techniques and styles of brocade weaving later spread into France and Italy, and then into northern Europe.

A famous example of an Almohad textile is the wall hanging known as the Las Navas de Tolosa Banner, dated between 1212 and 1250 CE, believed to be a battle trophy won by the Castilians. It has an elaborate geometric design with bands of Arabic inscriptions and Qur'anic quotations.

The rich agricultural land of Al-Andalus was able to meet demand for textiles with its domestic production in linen and wool. Both were grown there in Visigothic times, but production increased with the prosperity of farming under Muslim rule. Cotton was a new introduction to Al-Andalus from eastern Muslim lands. The crop was grown in irrigated areas. It was well suited to the need for cool, washable clothing in summer and for household fabrics.

Long-fibered cottons were an innovation in agriculture and textile production, being one of the important crops that moved across Muslim lands during the Medieval period. Cotton textiles were traded regularly between North Africa and Al-Andalus. Historians have found evidence that linen, wool, and cotton were also imported into Al-Andalus for weaving and dyeing for export, which speaks for the skill of Andalusian textile artisans.

The Las Navas de Tolosa Banner (AndalusiArt on Creative Commons).

In the later period of Muslim rule in Spain, Merino sheep, whose fine wool is still prized for textiles, were probably introduced from Morocco. Wool, linen and cotton were also combined to produce specialized fabrics that gave the textiles certain qualities, including combinations with silk thread.

Al-Andalus produced and exported fabric dyes that were an important aspect of high quality silks, linens, cottons, and woolens, giving them vibrant and lasting colors. Yellows were made from saffron — though it was very expensive, since it was extracted from the stamen of a crocus flower. Reds came from qirmiz (kermes), an insect that produced a brilliant red color from its body. Cochineal, a similar intense red produced by insects, was imported from the New World after 1500 CE.

Another red was produced by the madder plant, whose roots were crushed and processed, or red from brazilwood. Woad is a plant similar to indigo that was used throughout Europe for blue dye. It had to be crushed and fermented to release the blue color. This blue dye

A Spanish rug from the late 15th century (Pernille Klemp via The David Collection).

was colorfast when mixed with alum — a product of mining that fixed the color onto the cloth fibers. Alum was an essential export for Iberia and the Middle East in Medieval times, when Europe began to export textiles. Indigo was also imported into Spain for the textile industry from eastern Muslim lands. Andalusian agricultural books mention dye plants like safflower, saffron, wild madder and sumac.

12. Carving

Top of a column in the Alhambra Palace, Granada, Andalusia, Spain (Yves Remedios on Flickr)

To carve means to cut away a solid material with a sharp tool to create a design. Carved designs can be nearly flat or deeply three-dimensional. They can depict geometric designs, plants, animals and people.

Andalusian artists and artisans used many different forms and materials for carving. Among the most famous Andalusian work are carved and molded plasterwork that made solid walls and domes into surfaces like lace. The illustration shows molded and carved plaster from the Alhambra, built under the Nasrid rulers of Granada in the 14th century CE. Solid walls and domes seem to float with delicate, deeply carved plaster designs. Wall surfaces come alive with painted geometric designs.

Carved stone columns like the ruins of the Umayyad palace Madinat al-Zahra at Córdoba show a mixture of styles from ancient and classical times, with leaves and flowers, scrolls, braids, and arabesques that are typical of the light and abstract designs of Islamic Spain.

Ivory boxes made from elephant tusks imported from Africa were carved as deeply and delicately as plastic is molded today. Boxes and small chests like this one from Madinat al-Zahra in the year 966 CE have delicate patterns of leaves, vines, and flowers, with bands of calligraphy in Arabic around the rim of the lid.

This ivory box was carved for the daughter of Abd al-Rahman III (courtesy of Arts of Islam, Victoria and Albert Museum).

These chests and boxes have carved inscriptions that blessed their owners or praise their own beauty. These special boxes were made for members of the ruling groups, for whom they might have held gold coins, jewels, perfumes or medicines, like the Metropolitan Museum of Art's pyxis (cylindrical, domed container).

Pyxid bearing the name of Prince Al-Mughira (Marie-Lan Nguyen on Wikimedia).

Wood carving on furniture, boxes, buildings and bookshelves or bookstands was made from oak and other hardwood trees that grew in Spain. Leafy designs, geometric patterns and animal motifs were carved into the wood with sharp steel tools that were also manufactured at places like Toledo, where these woodcarvings were found.

13. Leatherwork

A cordovan leather chair from the late 17th century.

Al-Andalus' prosperous economy was based on agriculture and industries. According to historian of Islam Philip K. Hitti, "Spain under the Caliphate was one of the wealthiest and most thickly populated lands of Europe." Some of its industries were based on mineral resources, such as pottery, glass, and metalwork. Other industries, such as textiles and leatherwork, were also based on the products of agriculture.

Córdoba had a flourishing leather industry, and cordovan leather became famous all over the world. Cordovan leather was richly dyed and polished to a finish that would last a lifetime. It was so strong that it was used to make armor breastplates for soldiers, and famous "Islamic" shields called adarga, or targa, from the Arabic word for "shield," al-daraqa. Saddles, bridles, and other leather equipment for horses — both in the Old and New World — owe much to this Andalusian heritage.

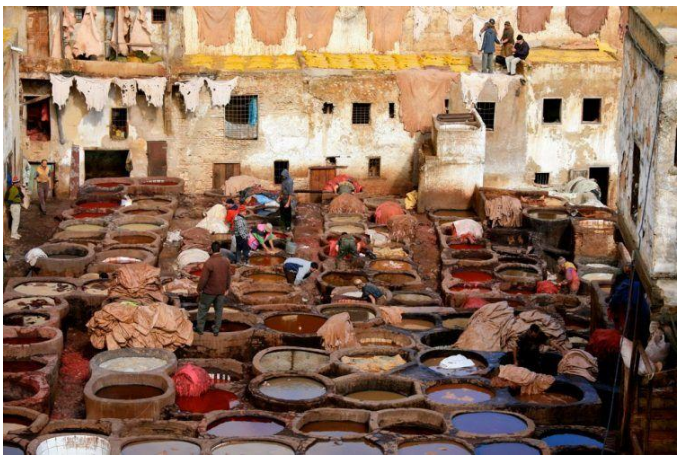
Bookbinding with leather — stamped and gilded — has become the standard for fine books. Gold-tooling techniques for decorating books were introduced from the Muslim Al-Andalus in the 15th century, so that the art of beautiful books entered Europe along with the knowledge of Muslim civilization, and the technique of paper-making that made owning books accessible to more people.

A Spanish adarga leather shield from around 1500 CE (Metropolitan Museum of Art on Wikimedia).

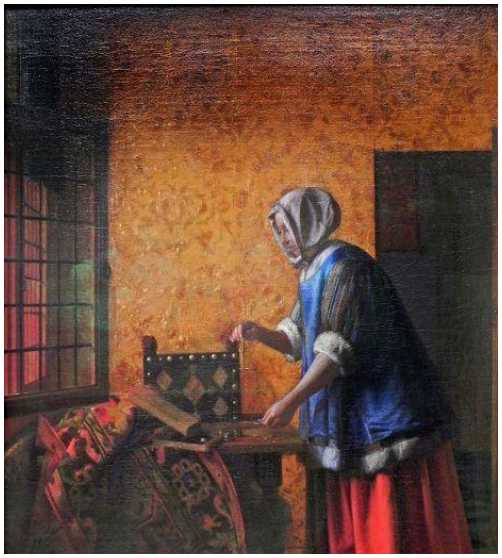
Specialized tools made of brass for tooling, stamping and gilding spread along with the technique, with designs, based on flowers, leaves, animals, crests, and various lines — straight, broken and curved — were stamped or pressed into the leather using tools with a wheel or a handle.

Craft production reached such a high level of artistry that the heritage of these crafts passed into the languages of Europe, and the crafts even outlasted the expulsion of Muslims and Jews from Spain in the 15th and 16th centuries. Some even persist today. One example is the term "cordovan" — luxurious reddish leather used for boots and shoes, belts, bags and saddles. The word for a shoemaker that was used with pride by the guilds through the 19th century was "cordwainer." The art of tanning and embossing leather reached a high degree of perfection in Córdoba. The process of making it is still basically as it was in Al-Andalus, and is still practiced in the traditional manner in Fez, Morocco, today.

The wealth of Spain after the Age of Exploration, and the connections between the Spanish and Habsburg royal families, led to the spread of cultural forms and the export of specific luxury goods and techniques in Europe. For example, Dutch painters of the 16th century illustrated the homes of wealthy merchants of the rising middle class, who displayed goods imported from China, Africa, the Americas, and also from Spain. Leather goods in these paintings provide evidence of these goods in the growing towns and cities of the period. Leather is shown in these paintings as it was used to cover the surfaces and cushions of furniture.



A tannery in Fez, Morocco (Alex Proimos on Wikimedia)



Courtesy of the Berlin Gemäldegalerie on Wikimedia Commons.

One writer says that the Muslims "made huge leather cordovans to cover entire walls" with a surface stamped with rich designs on wooden molds and then gilded like book-covers. The 16th century painting at right by Pieter de Hooch shows these leather wall coverings and a leather chair with brass hobnails and a gilded design. A Turkish carpet is also shown on the table.

In words for leatherworking techniques, in the colors, and styles and traditions, the heritage of Al-Andalus continues to the present day, in the industry itself, and in luxury and everyday items made from leather.

14. Ceramics

A ceramic jar from a Muslim palace in Spain, from the 13th or 14th century CE (José Luis Filpo Cabana on Wikimedia)

The Iberian Peninsula has produced pottery from Neolithic and Roman times to the present. The tradition continued in Al-Andalus, where tiled walls, floors and buildings of all kinds became typical features of the built landscape.

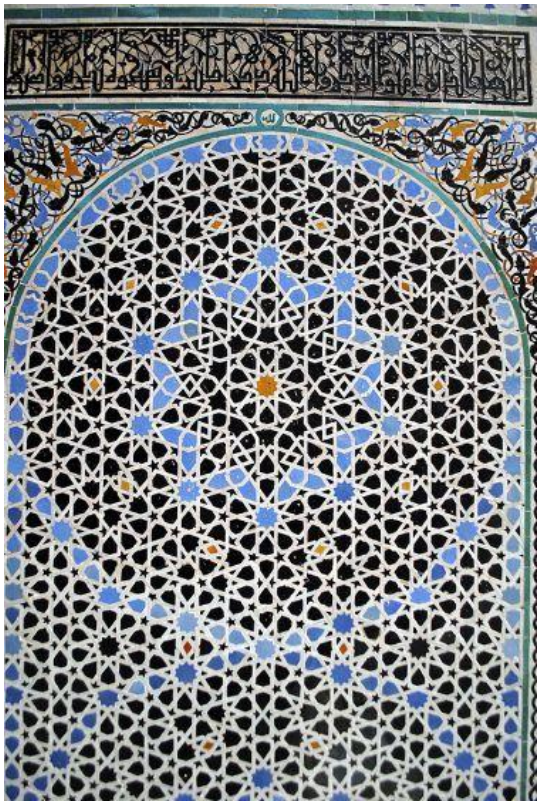
Pottery is made from different types of natural clay or earth, and glazes are made from minerals mixed with sand, which melt at high temperatures to form a waterproof, colorful seal on the pottery. Its distinctive style comes from its shape, color, and decoration. Andalusian ceramic artisans developed many styles and techniques that have strongly influenced ceramic production around the world — probably in your own bath or kitchen.

Production of fine ceramics during Medieval times was a technology that involved the whole continent of Eurasia. The intense network of Muslim trade routes in the eastern hemisphere contributed to the spread of techniques through trade over land and sea.

A dish glazed in blue cobalt featuring a pomegranate from the 8th to 10th centuries CE (Faqscl on Wikimedia)

In early Muslim Iraq, for example, a new type of pottery was made that eventually spread to China, where it became one of the most famous types of ceramic ever made. In Iraq, light brown clay was covered with a white, opaque glaze made from tin. On top of the white glaze, cobalt was painted to make blue designs when fired in the kiln. Arabic lettering, geometric designs and animals were popular on these dishes.

Use of cobalt blue glaze spread along the Silk Roads to China, where it was applied not to brown clay, but to the pure white, thin, bone-hard porcelain that was China's secret. Blue-and-white porcelain was born, and became wildly popular as an export item in east and west. It is still imitated today. Designs for blue-and-white wares included Chinese motifs like clouds and fish scales, and Islamic motifs like arabesques and geometric patterns. Blue-and-white cobalt and tin-glazed ceramics spread to the Mediterranean area, including Al-Andalus.



5A wall of the al-Attarine Madrasa in Fez, Morocco (just_a_cheeseburger on Wikimedia).

Central Asian shaped tile patterns and textures also contributed to the fund of ceramic designs and technologies. Walls, floors and domes were covered with a surface of shaped, cut tiles to form a mosaic surface like the one at left. This technique came to North Africa and Al-Andalus as zillij work.

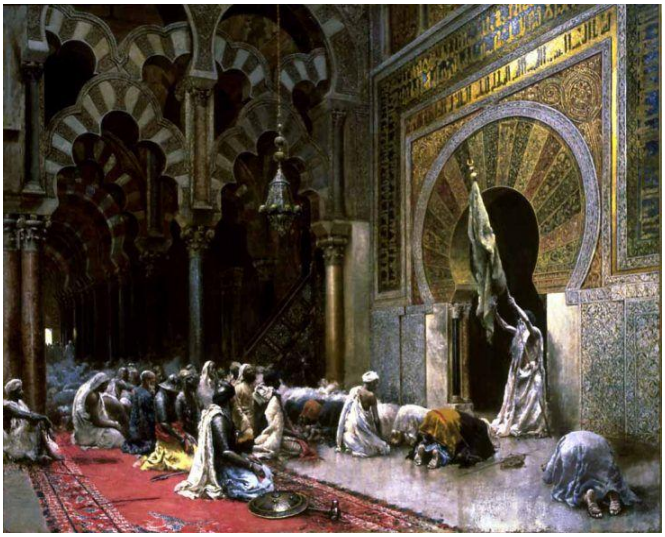
A technique called cuerda seca, or "dry cord," involved drawing the design on fired clay with a crayon made of the mineral manganese mixed with wax or oil. Between these crayoned lines, different colors of glaze could be painted to create a mosaic effect, and the colors would not run together during firing. This was more economical than the method of cutting tiles glazed in different colors into shapes like the one at left. With the cuerda seca technique shown at right, red, green, brown, yellow, and blue glazes could be combined on one object, painted, and glazed in one firing. This technique allowed freedom of design that eventually influenced majolica ware, with its colorful designs in Spain, and later in Italy.

Another important technique used in the Andalusian ceramic industry was lusterware. White, tin-glazed pottery was painted with a metallic overglaze, sometimes together with cobalt blue for contrast, and fired again. This was a difficult and very expensive technique whose pieces were treasured by the wealthy and found their way into palaces like the famous Alhambra in Granada. One Andalusian center of lusterware production was Valencia, which continued to produce objects for wealthy families of Renaissance Italy like the Medici, in the 15th century. Wedding vases with the family coat of arms like the one at right, medicine jars for apothecaries and hospitals, and plates for banquets were among these valuable pieces.

Mudejar ceramic artisans continued to work after they came under Christian rule, and their styles and techniques persisted during the following centuries. One of the legacies of intolerance was the expulsion in the 16th century of some artisan families, and along with it, the turn away from the long tradition of Arabic and Islamic techniques and styles, as well as the denial of their contribution. Scholars, artisans and historians today are working to recover the truth of that cultural heritage.

A lusterware vase with the Medici coat of arms featured, created in 1465 or 1480 in Manises, Spain (courtesy of Trustees of the British Museum).

15. Architecture



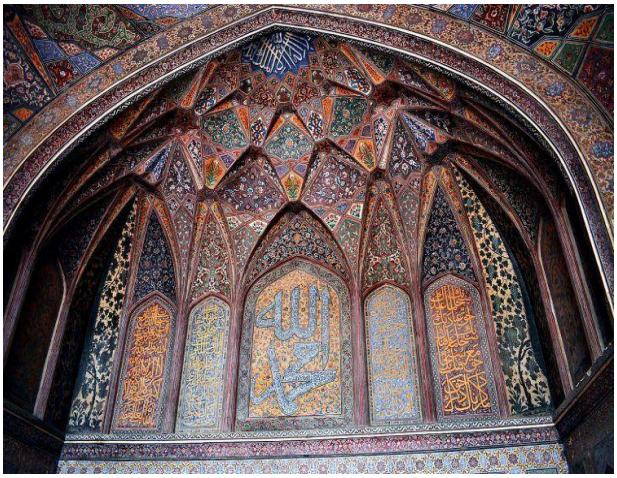
A painting of a 8th Century CE service in the Great Mosque of Cordoba, from the 1870's (courtesy of Walters Art Museum).

The most important building in Islamic Spain and other centers of Muslim civilization is the mosque (called in Arabic masjid), a house of worship. Mosques are almost completely empty inside, without seats or altars. The empty space is a surface for decoration and expression of form.

All mosques are modeled upon the Prophet's Mosque in Madinat al Nabi (a city near Mecca, in today's Saudi Arabia). It was a simple rectangular building with a mihrab, or prayer niche, to show the direction to face during worship. It had columns made of date palm trunks, and a thatched roof held up by palm trunks. The person who called the prayer, the muezzin, climbed to the roof so he could be heard in the neighborhood of the mosque.

Virtually all other mosques have these same features: a prayer hall, a mihrab, and a minaret, a tower the muezzin climbs to project his voice in the call to prayer. Beyond these common characteristics, however, mosques are as varied as the lands and the Muslims living around the world.

Their decoration is equally varied, from plain earthen or white-plastered walls, to fabulously carved and tiled geometric designs. None of these designs — nor any other feature of the mosque — depicts an animal or human being, which might suggest worship of any other being but God. Calligraphy, or beautiful writing from the Qur'an, Islam's holy book, can be found in many mosques as part of the decoration on walls, arches, domes and tiles.



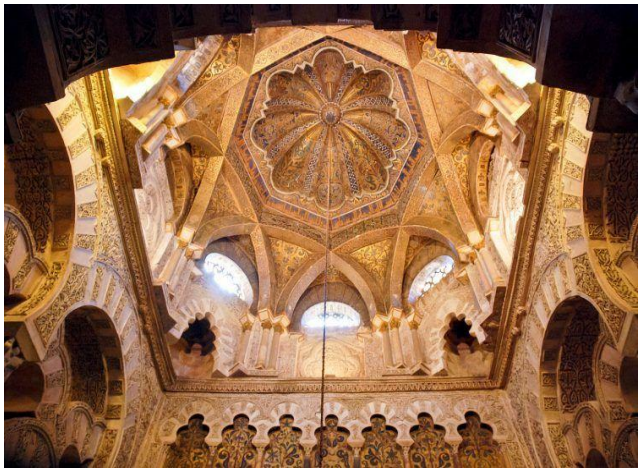
6An example of art in a mosque. This particular piece is in the Wazir Khan mosque in Pakistan from the 17th century (Rizwan Baloch on Wikimedia).

The Great Mosque of Córdoba was designed under Abd al-Rahman I. It began construction in 787 CE, then expanded under later rulers. The building was innovative. The double horseshoe-shaped arches added height and drama to the prayer space, especially with their red-and-white striped decoration on top of simple columns.

Using color in architecture was a design element that traveled widely under Andalusian influence. In 961 CE, a special section of the mosque added "poly-lobed" arches with carved decoration, meaning that the arch was scalloped. The ribbed dome of the mosque gave it strength, but also formed a star pattern that highlights the mosaic designs in the center and between the ribs. The architectural features in the Córdoba mosque spread to

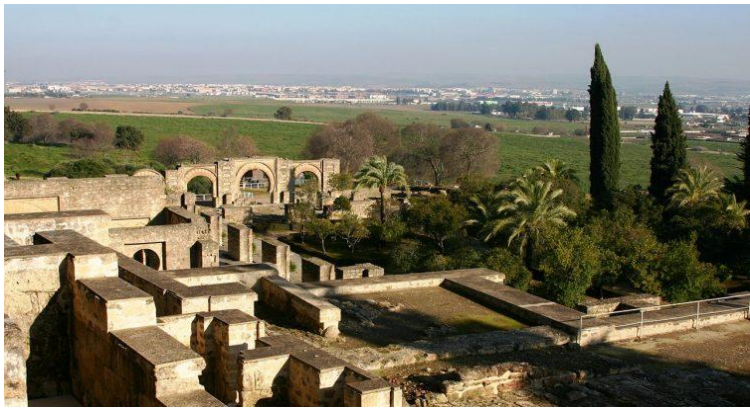
other forms of architecture and became visual symbols of Al-Andalus. The ribbed vault design became a familiar feature in gothic cathedrals of northern Europe.

The minaret is another Islamic form that found many applications in other places, from bell towers in Europe to skyscrapers in the 20th century. Minarets can be very solid, like those built using adobe brick, which have a narrow pyramid shape, or they can be very thin like Ottoman period minarets. In Spain and Morocco, brick towers with a square footprint graced the rectangular mosque layout. The minaret rose to a great height and featured geometric patterns in brick, and symmetrical openings near the slender top.



The dome of the Great Mosque of Cordoba, showing how arches were used for both stability and grandeur (Ruggero Poggianella on Wikimedia).

Palaces for Andalusian rulers were legendary for their influence in the West for centuries to come. Madinat al-Zahra was the first palace to be built in Al-Andalus. Built during the rule of Abd al-Rahman III (961-976 CE), it was a complex of buildings on terraces, and composed of indoor and outdoor spaces intermingled with gardens, pools, fountains, and surrounded by walls. Its walls and pillars were decorated with carving and tilework, and it was filled with fine furniture and decorative pieces made by the best craftsmen. It was a wonder to those who visited it and carried away stories of its grandeur. Madinat al-Zahra was destroyed in 1010 CE during a civil war, and it still remains for archaeologists to learn from its ruins.

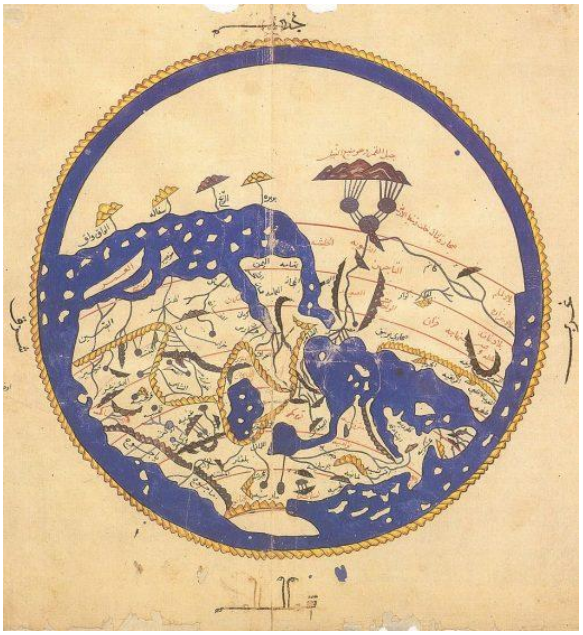


The ruins of Madinat al-Zahra, with red and white arches seen in the middleground, similar in style to those of the Great Mosque of Cordoba (Jose Luiz on Wikimedia)

The second most famous palace was built by the Nasrid rulers of Granada during the 13th century or earlier. It shows the influence of the North African dynasties that ruled in Spain, and brought important ideas in architecture with them. One of these ideas is the decorative muqarnas, plaster stalactites that break up the solidity of domes and arches, placed in geometric patterns and surrounded by carved plaster, calligraphy and tilework. The Alhambra is also a complex of indoor and outdoor spaces that flow into one another, with pools and gardens. The Alhambra has been celebrated by poets, travelers, and artists since it was built.

There are many other architectural monuments in Spain that show the skill and artistic splendor of Andalusian architecture. Cities such as Toledo, Valencia, Almeria, Seville, and others have mosques, bridges, public works, and homes in the Andalusian style. This style also traveled to the New World with the Spanish and Portuguese colonies, and spread to the southwestern United States.

16. Navigation

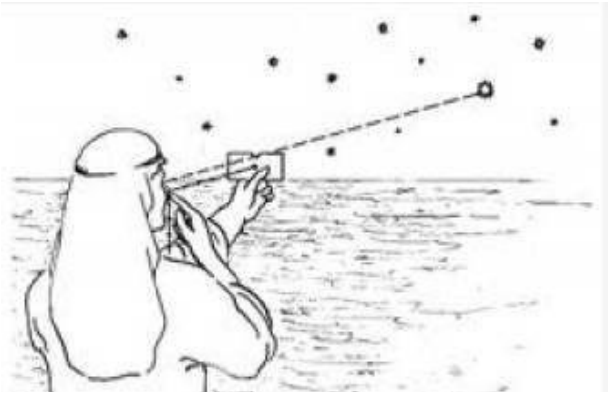


A very simple map of the known world according to Arabs, created by Muhammad al-Idrisi around 1154 CE. Note that the South is at the top of the map (Oxford's Bodleian Library on Wikimedia).

The Iberian Peninsula lies between the Atlantic and the Mediterranean Seas. Muslim rule in Al-Andalus after 711 CE gave the peninsula links to the eastern maritime world beyond the Mediterranean, through trade on the Red Sea, the Persian Gulf, and the Indian Ocean with its link to Indonesia and East Asia through the Strait of Malacca.

With the rapid expansion of territory under Muslim rule in the 7th century, and the expansion of trade and urbanization in the succeeding centuries, the Muslim lands acted as a hinge between east and west, linking the waterways and intercontinental land routes across Afroeurasia, and bringing them to Europe's doorstep.

Across these routes, a wealth of knowledge concerning maritime travel flowed. Navigation is a term that describes shipbuilding and sailing techniques, as well as knowledge of plotting a course at sea, reaching the destination, and passing on the knowledge of the routes. As in many other fields, Arabs and Muslims of the eighth century to the 15th century CE had access to the pre-Islamic knowledge of many civilizations, and accumulated knowledge and technology during the Islamic era. Their constantly renewed contact with mariners in the Mediterranean region and the Indian Ocean provided the opportunity to stay abreast of new inventions.



A drawing depicting the use of a kamal, a wooden rectangle connected to a knotted string.

Knowledge and technology needed for maritime travel belonged to several categories. The first requirement was knowledge that there were lands to which mariners could sail. This is not a minor matter in an age when some thought ships going over the horizon would sail over the edge of an abyss, or into the maw of sea monsters.

Knowing the topography of the lands, their inhabitants (not creatures with dog-like faces in their stomachs, for example, but ordinary human beings), and most important for the motivation to go there — what natural resources and manufactured products could be gained by sailing there. Surveys of geography fulfilled this requirement — detailing the mountain ranges, coastlines, harbors, cities and towns, and products, as well as the languages and customs of the people.
Geographic surveys were compiled by prominent writers from the ancients whose work was translated into Arabic, from the pre-Islamic Arabs of Yemen, Oman and the Persian Gulf lands whose maritime experience was already centuries old, and then early Muslim geographers such as Yaqut, al-Mas'udi, and others picked up the thread with their own, wider exploration.

An Arab astrolabe from 1080 created in al-Andalus (courtesy of The Germanisches Nationalmuseum).

Early explorers of the Muslim lands also laid the groundwork for determining the location of places. Navigation is about getting from one specific location on the globe to another, by determining where the ship is at any given time. The most important technique for determining location is latitude and longitude. Muslims inherited this skill of reckoning using the stars and the sun in conjunction with fixed points on earth from the Greeks and other ancient peoples. The Arabs had relied on astronomical reckoning even traveling through the trackless deserts. Basic techniques, from fingers held up to the horizon to a simple card and string, could determine latitude with fair accuracy, combined with other knowledge of currents and landmarks.

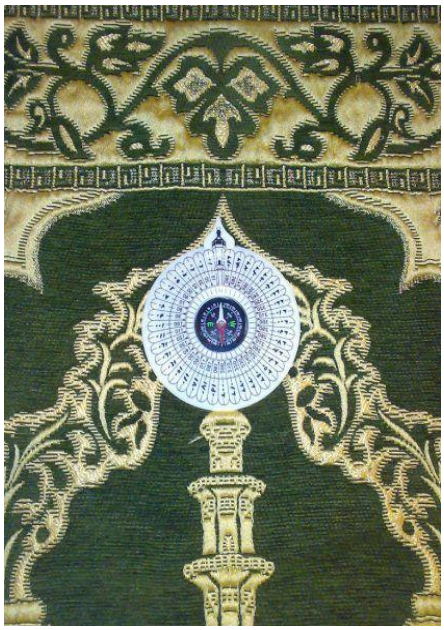
More sophisticated instruments used to triangulate position based on the sun, stars, and horizon were the quadrant, a quarter circle marked with gradations and a dial, and the astrolabe. The Greeks invented the astrolabe, and historians of science agree that the Arabs perfected it, from the 8th century CE on. Advances in astronomy and in mathematics made it possible, including use of Arabic, or Hindi, numerals to represent digits, and trigonometry, formulas dealing with the mathematical relationships of the sides and angles of triangles.

The magnetic compass is an invention whose origin is uncertain, but which seems to have moved from China along the land and sea routes toward the west. It was originally a lodestone or magnetized metal floating in a bowl of liquid used to show direction. The Chinese oriented it toward the south, and Indian Ocean accounts describe a magnetized iron fish floated in a bowl, whose head would point south to show direction at sea. Dry-mounted compasses in which the needle rotates on a pin over a paper or inscribed compass rose to show direction may have originated in Europe, in Spain, Italy, or elsewhere. Historians today must base their ideas on written descriptions, which leave many gaps.

The craft of instrument-making also contributed, as most astrolabes and other instruments are made of brass inscribed with great accuracy. Islamic Spain was the pathway by which astrolabe technology entered Europe from the 12th century, and it became so famous that the French scholar and translator Adelard of Bath named his child Astrolabe! The English

writer Chaucer also wrote a treatise on the astrolabe. The astrolabe could be used for navigation at sea and surveying on land, determining depth or height of distant objects.

Another important aspect of finding location involved recording places in detail using their coordinates. Mathematical geography also used such instruments to plot locations and so to be able to make more accurate maps. Islamic practice required mosques to be oriented toward Mecca (qibla). This led to a science of determining direction on land with great accuracy. There were books written detailing the coordinates of cities, and charts showing the orientation toward the qibla. Just as Muslim scientists made it a priority to determine accurate time for religious observances, direction was equally important. Determining longitude at sea was much more difficult, and awaited the use of mechanical clocks combined with astronomical readings during the 18th century.



A prayer rug with a modern compass which points to Mecca (Maqivi on Wikimedia).

Portolan charts and pilot charts contained valuable knowledge that allowed mariners to navigate to and from their destinations. Pilots, or sea captains, traditionally passed down orally the knowledge of directions needed to get from one place to another by sea. Muslim mariners collected and published this information in nautical manuals called rahmani that scholars study in detail today to identify earlier place names visited and sea routes used to get there. Pilots had knowledge of currents, depths of water, shoals and rocks, and the shape of headlands from sea, very much like Mapquest® driving directions today. This is an example from the 10th century text of mariner Sulaiman ibn Ahmad al-Mahri (ca. 917 CE):

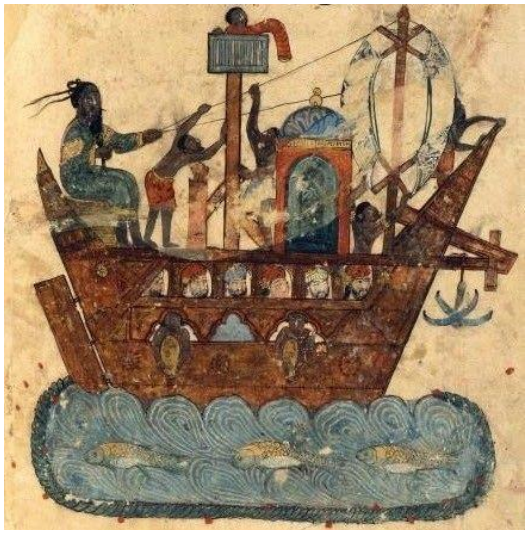
"The journey from Sundib and Farandib to Shati Jam is [made in the direction] ESE; from Shati Jam to the island of Zanjiliya is due south and from Zanjiliya to Najirashi, SSE. From Najirashi to Martaban is ESE. And from Martaban to Tawahi, SSE; and from Martaban also to the island of Fali, due south. From Fali to the island of Buttum is due south and from Buttum to the islands of Pulau Sanbilan Malacca, SSE… and from Malacca to Singapur, and this is the end of Siam to the South, and there the Little Bear is 5 degrees [above the horizon]… and from Ayam to Bab-i-Sin on the coast at 17 ½ P.S. it is NE and from Bab-i-Sin the land turns around to the south as they have told us."

Another famous navigator of a later period was Ahmad ibn Majid (b. 1432 CE), who wrote the Book of Useful Information on the Principles and Rules of Navigation in 1490 CE, whom some writers have associated with personally piloting Vasco da Gama from east Africa to India. What surely accompanied the Portuguese mariner, however, was knowledge of the seas, directions, and navigation that was current in the Indian Ocean, and in the libraries of the Iberian Peninsula where interested Spanish and Portuguese like Henry the Navigator could access it. They had been preceded in the Indian Ocean by the Ming admiral Zheng He, and by generations of indigenous (native) mariners.

Ship design and sailing technology was another important aspect of navigation. This included the design of the hull, the masts and rigging (sails and their control with ropes),

and the steering devices. Among the earliest innovations to reach the Mediterranean Sea from the Indian Ocean was the lateen, or triangular sail. Before its introduction to Europe, ships on the Atlantic and Mediterranean used square sails that needed wind directly behind the ship. Lateen sails allowed tacking, or sailing back and forth with the wind at an angle to the ship.

Combining triangular with square sails was one of the innovations that characterized the Spanish and Portuguese explorers' ships of the 15th century CE and beyond. Another innovation that came from China by way of Muslim mariners was the stern rudder, a hinged steering board at the stern of a ship (shown in the image at right), which replaced an awkward oar lashed to the ship. The system is still used on ships today. Hull design was another innovation introduced through the Muslims' connection with hemispheric waterways. It may have been modeled on the Arab "dhow," a word of Swahili origin that lumps together many different types of seagoing Arab and Indian ships of the Medieval Indian Ocean.



A wooden boat sailing in the Indian ocean. Note the wooden rudder, a feature which quickly spread West to Europe (Chittick 1980, The International Journal of Nautical Archaeology and Underwater Exploration 9(4) ; 297-304)

What came to be called "carvel-built" hulls, in which the boards of the hull were attached side-by-side to the ribs instead of being "clinker-built," or overlapping like the shingles on a roof, made ships sleeker, lighter and more maneuverable. Early modern shipbuilding, like navigation arts as a whole, did not spring fully formed from the minds of any one group, but evolved over centuries and millennia as the achievement of many peoples and many seas, just as the waters of the world were gradually knit together by the human desire to trade, explore, and travel over time.

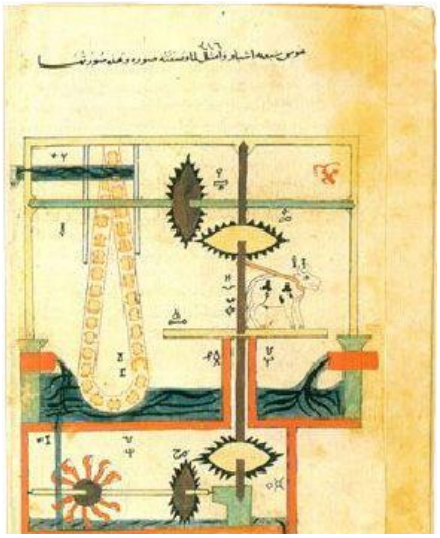
17. Metallurgy

An engraved incense burner created in Syria in the 13th Century CE (courtesy of The Walters Art Museum).

Metallurgy is the science of working with metals. It includes mining, refining and processing the ore (raw rock containing metals), and fashioning metal into useful and beautiful things. Because it is heavy work with special requirements, metallurgy also involves engineering, chemistry, and the control of fire.

The Iberian Peninsula, with its varied Mediterranean landscape, had long been a center of mining. Already during Roman times, silver, gold, iron, lead, copper, tin and other metals were mined in Spain. The revival of these mines for silver, gold, iron, lead, copper, tin, and cinnabar (mercury ore) left them with their Arabic names, such as Almadén and Aljustrel. According to the Andalusian geographers and other records, mining was fully developed, with centers of mining at Jaen and Algrava for gold and silver, Córdoba for its iron and lead, Malaga for rubies, and Toledo and Murcia for iron. Spain was a major source of mercury mining, as noted by the geographer al-Idrisi.

Techniques of mining also required ways of drilling into rock and drawing water out of the mines with the use of pumps, as well as pumping air in and dangerous gases out. Several different models by the 13th century Muslim engineer al-Jazari, like the one at left, used gear and suction systems to safely remove water from underground. The writer al-Qazwini (1203-1283 CE) described such three-stage pumps in use at the silver mines in Morocco.



7A water raising device developed by al-Jazari in 1205 (courtesy The Topkapi Palace Museum).

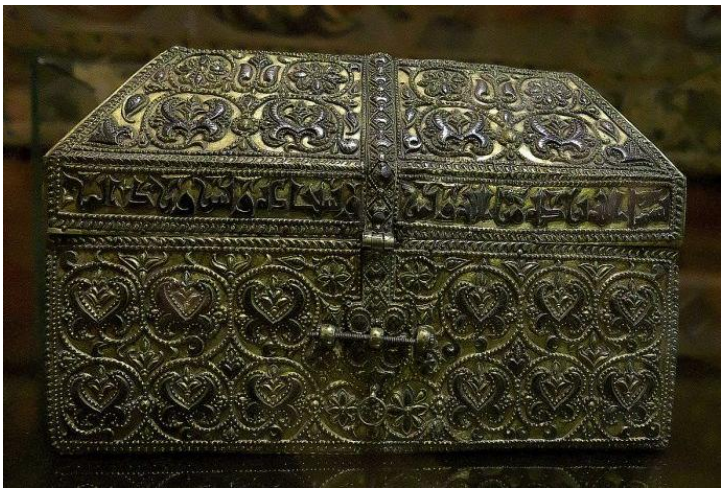
Metal ores require processing to purify, or refine the metal, separating metals that often occur together in rock. This required knowledge and experience of building furnaces that could reach and hold very high temperatures, and of which chemical substances would combine with the unwanted minerals, leaving the pure metal behind when burned or heated in the presence of the metal ore. Some of the most famous writers on this subject were al-Biruni (973-1048 CE), al-Kindi (ca. 801–873 CE), and Jabir ibn Hayyan (d. ca. 815 CE), who worked to gather and record this information from across Afroeurasia. These useful works were available in the libraries of Al-Andalus, and many were translated into Latin. Combined with European knowledge, they laid the foundation for modern industrial metallurgy.

Iron and steel production were carried out at Toledo and other Spanish centers using techniques brought from India, Persia, and Damascus — the famous damascened or watered steel for swords,

armor and tools. Geographer Ibn Hawqal wrote: “Toledo, like Damascus, was known throughout the- world for its swords.”

A historian writes that the art of inlaying steel and other metals with gold and silver decorations flourished in several European and Spanish centers and left such words as “damascene” in the English, French and Latin vocabularies. Armor and cutlery was also decorated using techniques such as gilding, inlay, gold and silver encrusting, as well as setting with jewels and enameling. Brasswork was also produced at many centers such as Almería, where candlesticks, incense burners, plates, lamps, keys and locks, and other ordinary and luxury goods served customers’ needs.

Glazes developed for the ceramics industry, and fixatives for textiles — such as alum — also required chemicals based on metallic oxides. Copper and gold glazes required the pure metal, as in lusterware ceramics, especially the golden luster. Zinc is a metal used in medicines and for other purposes, which was also mined in Spain.



A small ornamental box from the Madīnat al-Zahrā in Cordoba from the 10th century CE (José Luis Filpo Cabin on Wikimedia).

The engineering and chemistry of metallurgy are industrial arts essential to the creation of the modern world. These arts have developed over many centuries in many lands, but the written record of the study of chemistry and the behavior of the elements, along with the experience of artisans in metal provided a sure link from Islamic civilization to Europe during the pre-modern period.

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The legacy of mining by the Spanish in the New World is a story of plunder, but it is also a piece of global economic history. When the Spanish conquered territories where there were mines, they already had access to the technologies of mining and processing the ore that had flourished in Spain. It is thought that Muslim artisans with this knowledge were brought to New Spain, despite the prohibition against their emigration, precisely because their skills were needed. Silver currency using American silver helped globalize currency and trade in the 16th century, and was shipped to the Ottoman Empire, Japan, and China, in addition to Europe.

A silver durham coin issued in Cordoba by the Umayyad dynasty in 873 CE (Jean-Michel Moullec on Wikimedia).

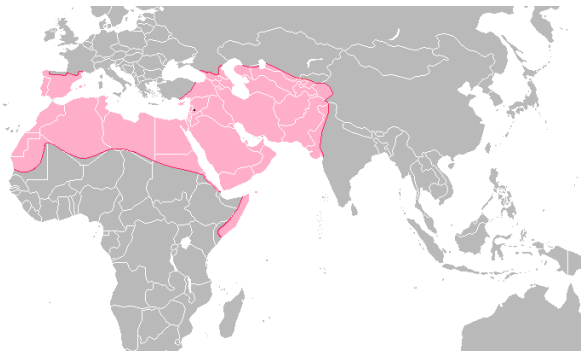
18. Geography

8In 1154 CE, al-Idrisi created the "Tabula Rogeriana" for King Roger II of Sicily. This is a copy by Konrad Miller with Latinicized names.

The rapid expansion of territory under Muslim rule fell in line with Qur'anic recommendations to encourage travel in search of knowledge and other benefits. For example, one passage reads: "Have they not traveled in the land, and have they hearts wherewith to feel and ears wherewith to hear?" (Qur'an 22:46). Another passage states: "And of His signs is this: He sends herald winds to make you taste His mercy, and that the ships may sail at His command, and that you may seek His favor, and that you may be thankful" (Qur'an 30:46).

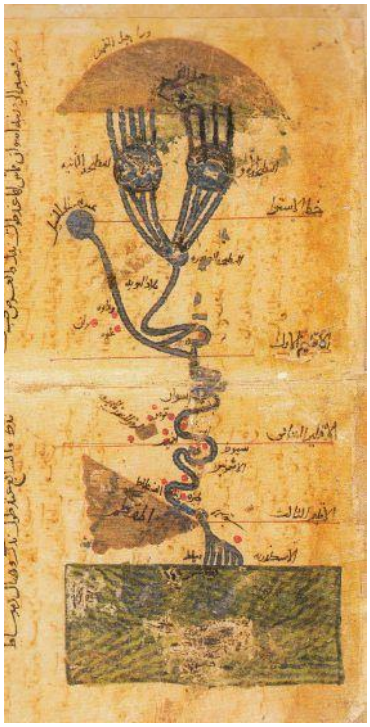
By the 8th century CE, Muslim lands stretched from the Atlantic Ocean to the borders of China, and from the Mediterranean to the Indian Ocean. These lands included a variety of peoples, landscapes, climates, and customs. Among the earliest forms of scholarship were the accounts of travelers and diplomats describing the places where they traveled. A great collection of ideas and knowledge was the result. Among these travelers — which included scientists in mathematics, astronomy, and other fields — were those who compiled geographic works full of information about other places, people, and technologies.

Muslim geographers began their work on the basis of Greek and Roman traditions of geographic writing, especially Ptolemy's *Geographia*. They soon overtook the limited knowledge of their predecessors, however, both because of the huge Muslim territory and expanding trade networks, and because of technical advances in mathematics and astronomy that allowed more accurate surveying on land and at sea. The earliest geographic works by Muslims are from the 9th and 10th centuries, and the work continued on into Ottoman times in the 16th century and beyond.



Map of the Ummayad Caliphate in 750 CE (Hisham10000 on Wikimedia).

Among the earliest Muslim geographers were al-Khwarizmi, the mathematician, who participated in a project to draw a map of the known earth in the early 9th century CE. Al-Kindi, the philosopher, wrote an account of the inhabited parts of earth as known then. Some of the greatest traveler-geographers were Ibn Hawqal, who traveled for over 30 years and wrote about the places and people he saw, and the famous al-Mas'udi. He traveled, quoted geographic works that have disappeared, and wrote his own encyclopedia of geography and history called Meadows of Gold and Mines of Precious Stones in 956 CE. The Palestinian al-Maqdisi described the different climate zones, languages, towns, traded commodities, soils, and topography during the mid-10 century.



A map of the Nile river drawn by Al-Khwarizmi in 1036-1037 CE (National University Library of Strasbourg on Wikimedia).

Many of these writers noted that the earth was round. Caliph al-Ma'mun sent a team headed by al-Faraghani to measure a degree of longitude in order to check the Greeks' calculations and measure the circumference of the earth. Al-Biruni (972-1050 CE) wrote The Book of India, in which he described the sciences of Indian civilization, the topography of the sub-continent, and even made many geological observations, such as noticing that an ancient sea must have covered the Indus Valley at one time. He studied the seas, and believed there was a passageway through the southern oceans, and related the tides to the phases of the moon. Al-Biruni was a mathematical geographer who accurately plotted the Indian coastline by calculating the longitude and latitude coordinates of cities and ports.

The works of these geographers were available in important libraries of Muslim lands, including Spain. Though many have been lost, some of these works have been translated into European languages, and edited in printed Arabic editions for modern scholars. As proof that this geographic knowledge was available in Al-Andalus, the library at Seville still houses an atlas with Christopher Columbus' handwritten notes in the margins, called Imago Mundi.

Among his notations was one that cited al-Faraghani's calculation of a degree of longitude (56 miles @ 1 Arabic mile = 4000 "black" cubits). Measured by today's understanding of a mile, the correct distance is 69 miles, but al-Faraghani was using a different standard for the cubit. His measurement was only off 2 miles, but Columbus understood it as the standard used in his time and place. Modern historians have sorted this misunderstanding out, but Columbus' error at the time was one of the most famous mistakes in history.

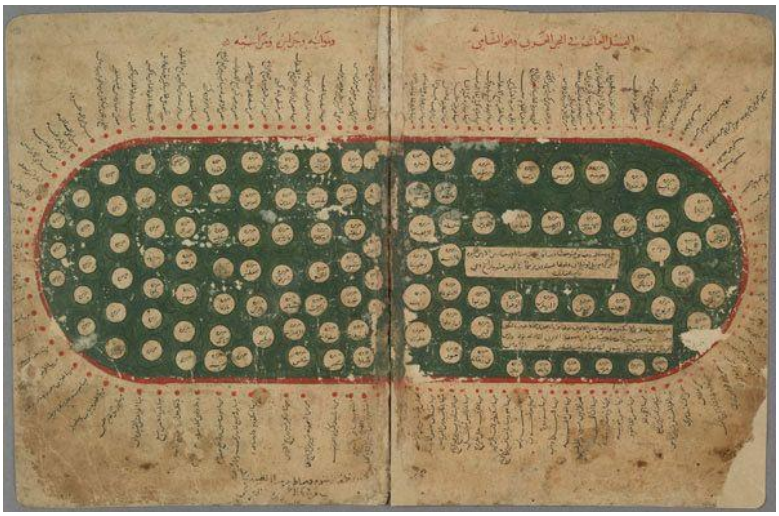
Andalusian geographers studied the works brought to Córdoba and other Andalusian libraries from Baghdad. Working in the same tradition close to home, Ahmad ibn Muhammad al-Razi (d. 955 CE) produced a geography and history of Al-Andalus, and Muhammad ibn Yusuf al-Warraq (904-973 CE) wrote a description of the topography of North Africa.

Another notable Andalusian geographer was Abu 'Ubayd al-Bakri (1014-1094 CE) of Seville, who wrote the Book of Highways and of Kingdoms, and is well known for his early descriptions of West Africa. He wrote a geography of the Arabian Peninsula, listing villages, towns and places of interest to Muslim travelers. He created an encyclopedia of the world, including its known countries, their people, customs, history, and climate and

listing their cities and landmarks, and relied on several earlier sources, including al-Tariqi (d. 973 CE) and al-Warraq.

The Andalusi Jewish merchant Ibrahim bin Ya'qub traveled to Germany and the Slavic countries during the time of Otto the Great and wrote about those places. The Granadan Abu Bakr al-Zuhri wrote the Book of Geography (jughrafiyah in Arabic) in which he relied on work done earlier at Baghdad. Another Granadan, al-Mazini (1080-1169 CE), traveled extensively in the eastern Muslim lands and wrote several important works, one of which is in the library at Madrid's Historical Academy.

Travelers making the Hajj pilgrimage wrote some famous geographic works, including Ibn Jubayr (1145-1217 CE), who visited the Holy Land during the Crusades, and also wrote about Sicily after the Norman invasions, and visited Damascus, Cairo, and Baghdad. His work was used by many other Muslim writers, and exists in English today. Ibn Battuta (born 1304 CE) was a Moroccan, but he dictated the story of his decades-long, world-spanning travels to a writer while staying at the court of Granada. Ibn Battuta traveled for 28 years and related information about people, places, sea and caravan routes, cities, roads, and caravanserais. Ibn Sa'id al-Maghribi wrote a geographic work whose information ranged from West Africa to Mongolia, and included latitude and longitude coordinates that allow scholars to create maps from his work.



9An Arabic map of the Mediterranean from 1065 CE (The Oxford Map Companion: One Hundred Sources in World History by Professor Patricia Seed).

A very simple map of the known world according to Arabs, created by Muhammad al-Idrisi around 1154 CE. Note that the South is at the top of the map (Oxford's Bodleian Library on Wikimedia).

The most famous geographer of Al-Andalus was al-Idrisi, who studied at Córdoba. He traveled far and wide, and collected information for Roger II, Norman king of Sicily, who supported publication of a set of maps and information called the Book of Roger. The information contained in the Book of Roger was also engraved on a silver planisphere, a disc-shaped map that was one of the wonders of the age. Although al-Idrisi is famous for the round map of the world shown at right, he made over 70 maps that charted territories never before put onto a map. The lands around the Mediterranean are so accurately shaped that parts of them can be compared with satellite images. The al-Idrisi rectangular map at the beginning of this article is an example.

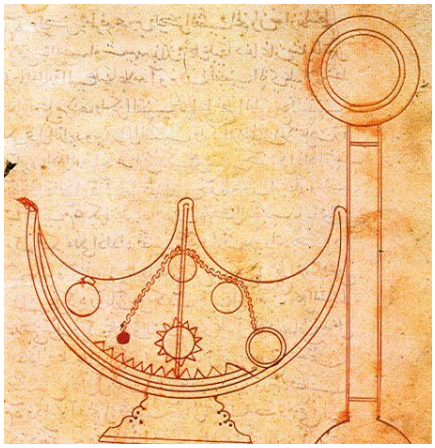
19. Engineering

Muslim civilization developed at a time in human history when numerous large territorial empires had been established in various parts of Afroeurasia. Long-distance trade, the spread of religions, and extensive recording of knowledge in writing had preserved a legacy of human ideas.

Major civilizations had advanced disciplines such as astronomy and mathematics, and philosophical as well as ethical systems of thought had begun to explore theories of knowledge. Human inventiveness had solved many challenges such as how to irrigate dry land and store water, work with metals, work with fibers and other natural fabrics, and to preserve food. The expansion of territory under Muslim rule, and the expansion of trade and economic growth in general, brought many peoples and places into contact. Historians say that from the 8th to the 15th centuries, human networks of exchange expanded and intensified.

La Albolafia Mill on the Rio Guadalquivir, which raised water to the caliph's palace (Elliot Brown on Flickr).

In order to increase trade and expand the economy, production of many goods and natural resources had to be increased. Construction of cities, roads, ports, dams, and bridges required planning and engineering. Muslim engineers were able to draw on the ideas already built up by earlier societies' efforts. They combined these ideas with new mathematical knowledge and tools to create machines, instruments and construction techniques that advanced human skill and knowledge. From China, Central Asia and India in the east, to Al-Andalus and North Africa in the far west, the ideas and knowledge of technology was able to circulate. Libraries were built to house books on these subjects, artisans were commissioned to travel where their skills were needed, and news of the latest ideas spread.



10Illustration of a self trimming lamp (The Granger Collection).

The brothers Banu Musa bin Shakir (ca. 850 CE) were inventors and engineers from the eastern Muslim lands. They translated and wrote over 20 books on engineering. They described about a hundred useful mechanical devices in Kitab al-Hiyal (The Book of Ingenious Devices). Their work seems to reflect knowledge of the Alexandrian Hellenistic tradition of mechanics, since they translated important works of Hero, and Philo of the 3rd century, into Arabic. Some of the Banu Musa bin Shakir's devices are similar to those earlier technologies, but others go far beyond them.

In engineering, there are certain mechanical components, or parts of machines, that have many uses. Examples of these components are: a device that controls the flow of liquids by opening and closing in a cycle, crankshafts and gears that

transfer energy or regulate the speed and movement of the machine, a ratchet that stops the movement of gears in a certain direction, and parts that multiply the force of the machine. Some of these important milestones in engineering that are found in Kitab al-Hiyal are shown for the first time in the history of technology. Some of them would not be seen in engineering works until 500-1000 years later in modern industry.

Al-Muradi of Andalusia was an 11th century CE scientist who wrote The Book of Secrets about the Result of Thoughts, which contains the earliest description in Arabic of water clocks and other mechanical devices called automata. The book contains 31 models run by water wheels that regulate the intensity of flowing water. Nineteen of the devices are clocks. They use a component called a clepsydras, and the figures (often human or animal) ran by means of elaborate gear systems, lubricated by mercury. These innovations were not seen again in any society until the 13th century CE, when they were used in European clocks. At the court of Alfonso of Castile in about 1277 CE, a Spanish book, Libros del Saber, contained translations and summaries from Arabic sources. Al-Zarqali must have had access to this knowledge when he built two large water clocks in Toledo in the 11th century CE. Other components used in water clocks were siphons (small tubes that flow by gravity), and float valve devices, similar to the valve in household toilets and sump pumps that turn the device off or on with the water level.

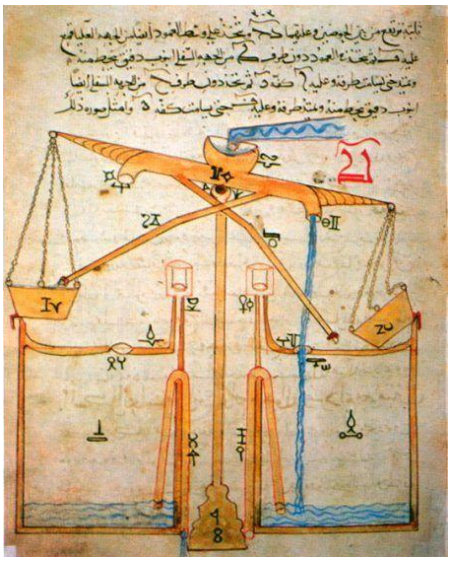
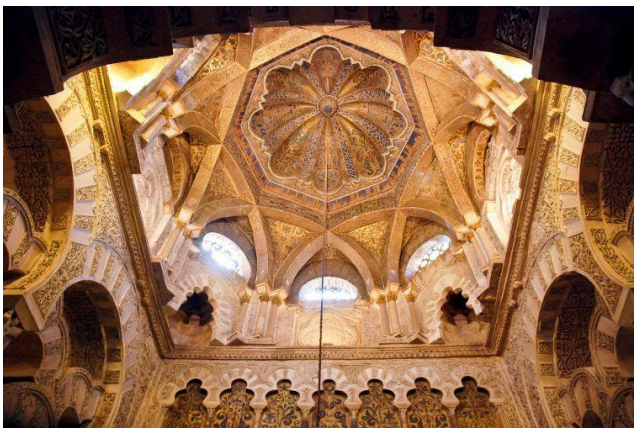


Diagram from a book by Al-Jazari, an Islamic inventor from the 13th century CE (Mladifilozof on Wikimedia).

The 13th century work of al-Jazari, which was published with drawings that engineers can use today to re-create these machines, helped solve mechanical problems by creating components that were later used in steam and gasoline engines. Escapements, another important mechanism developed by al-Jazari and used in Spain, are important for timing the movements of machines. They were used in automata (self-moving machines) that featured as curiosities in the palaces of Medieval Muslim rulers, but which were important for the development of serious mechanical devices; they showed off the society's technical abilities.



11The dome of the Great Mosque of Cordoba, showing how arches were used for both stability and grandeur (Ruggero Poggianella on Wikimedia).

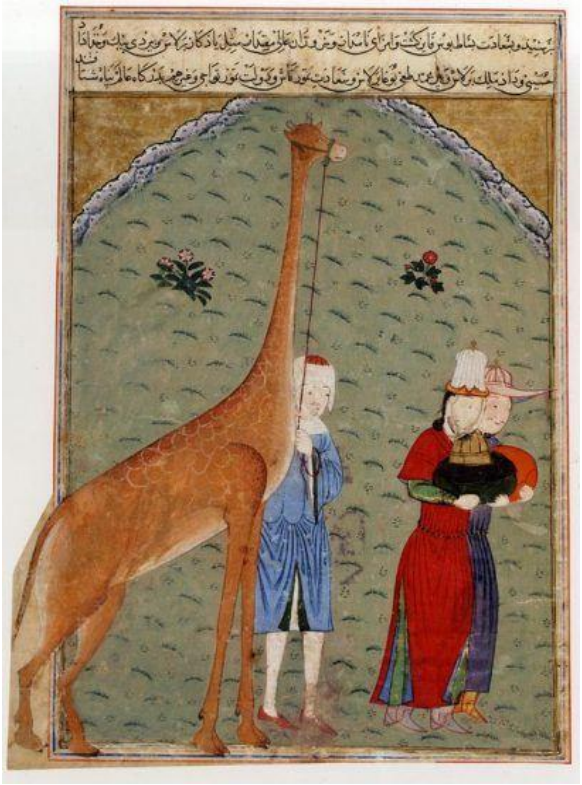
Another form of engineering is seen in public works and buildings. Constructing a heavy stone or wooden structure that does work and lasts a long time requires engineering knowledge of the first order. The accumulated knowledge of architecture involves knowing how to distribute the weight of building parts like roofs, walls, and towers so that they do not collapse. Arches that open a building must carry its weight downward, and towers must have carefully calculated foundations and wind resistance to keep them from sinking into the earth, leaning, or falling over. Dams that hold back rivers'

floodwaters are built straight or curved according to exact mathematical proportions, and they need gates that control the flow of water.

In Spain, Roman construction of aqueducts was maintained under Muslim rule, and complex irrigation, drinking water, and flood control systems were built on Spain's many rivers. The oldest dam constructed by Muslims is at Córdoba, a long, zig-zag shaped wall about 8 feet above the high-water mark and eight feet thick. To figure out where to place the dams, surveying with instruments like astrolabes and calculations using advanced mathematics like geometry and trigonometry were necessary.

The dams were engineered from stone and cement by mixing sand and water with ashes and baked lime to make it harder than stone against cracking. One writer states that "these dams needed hardly any repair in a thousand years." The design had to be suited both to the vertical drop of the river, the energy of its flow, and the softness or hardness of the riverbed. Each was differently engineered. In addition, the dams were placed so that water power could be used to run waterwheels linked to machines for grinding grain, pounding pulp and paper, raising water, and other heavy labor.

20. Zoology



Drawing of a giraffe from an unknown manuscript (courtesy of Chugtai Museum).

Zoology is the study of animals. Among Muslim and specifically Andalusian writers and practitioners on zoology, there were two types of zoological studies: literary and practical, (related either to agriculture or veterinary medicine). These eventually merged in some ways, with both contributing to the scientific study of animals. Islamic learning inherited three traditions that fused into what we call zoology today. One was the pre-Islamic Arab tradition of nomadism and breeding of horses, camels, sheep and goats, which with the spread of Islam, came in contact with the Indian-Persian and Greek traditions of animal study.

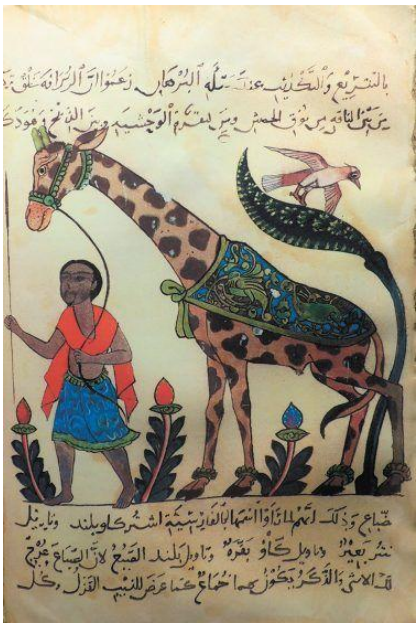
In classical and Medieval times, writers and artists produced bestiaries — a bestiary is a zoo in a book — in which exotic animals were described. Many rulers kept gardens in which exotic animals were raised, such as nightingales and peacocks, and rare animals might feature as royal gifts. Falcons and other animals used for hunting were especially popular, and there were many guides on the art of falconing. Other fields related to zoology were the study of domesticated animals and their care, breeding (reproduction) and veterinary medicine. Sheep, cattle, and especially horses were important, but so were fowl, such as chickens, ducks, geese, and doves.

The most famous Muslim writer on animals is al-Jahiz (776-868 CE), a literary figure in Abbasid Baghdad. He was able to draw on the works being translated in the House of Wisdom, and was known to rent bookshops in order to read what they contained. His most famous work is Kitab al-Hayawan, or Book of the Animals, which built upon the work of Aristotle's Generation of Animals, as well as including stories about animals, verses from the Qur'an and Hadith concerning animals, poetry and proverbs.

The book is not purely zoology, nor is it just a bestiary, because al-Jahiz was an essayist and man of literature who valued entertainment for his audience. He did, however, succeed in inserting many scientific observations into the work. For example, he discusses mimicry and camouflage, sensitivity to light, and the impact of climate and geography on the fauna of a region, and investigates animal behavior, communication and organization into communities, particularly among insects.

Some critics find ideas related to the evolution of creatures and their similarities and adaptations to the environment. Kitab al-Hayawan was produced in many illustrated editions that found their way into libraries across the Muslim lands, including Al-Andalus. In this way, he may be said to have succeeded in his mission of entertaining and informing.

Other writers, such as the Christian Ibn Bakhtishu, wrote in this field. He worked in the House of Wisdom and gained access to Greek works for translation into Arabic there. He wrote The Uses of Animals in a practical vein in the 8th century. Al-Asmai (740-828 CE) contributed to the fields of zoology and animal husbandry (care and breeding of animals). His important work on breeding horses and camels was highly valued and pioneered as a systematic study of scientific breeding, an area in which Arab contributions are still important today. Kamal al-Din al-Damiri wrote a popular Muslim book, The Great Book on the Life of Animals, and Abu Yahya Zakariyya al-Qazwini wrote an encyclopedia, The Wonders of Creation, both in the 14th century CE.



A giraffe from Kitab al-hayawan, or "Book of the Animals", by the 9th century CE naturalist Al-Jahiz (courtesy of Chugtai Museum).

In Al-Andalus, Abu Ubaidah (728–825 CE) wrote more than fifty books on the study of the horse. The Calendar of Córdoba, which was translated and given to the German Emperor Otto during the 10th century, also included information about animal care and breeding, and the use of manure for fertilizer. Al-Ishbili, who wrote in Seville during the 12th century, included livestock rearing and veterinary medicine in his book on agriculture. Ibn al-Awwam's 12th century Kitab al-Filaha (Book of Agriculture) included both animal husbandry and bee keeping. Ibn al-Baytar's book on pharmacology included useful medicines for veterinary uses.

Lasting Influences: The Andalusian horse is one of three breeds from which modern horses descended, and most modern breeds have Andalusian blood. The Andalusian breed was perfected during Muslim rule in Spain, and spread to the New World with the Spanish conquistadors. One of the Arabs' innovations was the pedigree, or tracing the ancestry of a horse. The Spanish continued this tradition, which has lasted to the present day.

12A page from Kitab Na't al-Hayawan wa-Manafi'ihi, or "Animals and their Uses" from the 13th century CE (courtesy The British Library).

Arab knowledge of horses is still an important contribution today, and so are Arabian horses as a prominent breed. Fine Merino wool, which probably originated in Morocco, was the result of careful sheep breeding. The broad sweep of the Muslim lands meant that different animals could be cross-bred from many regions. Selective breeding of animals from different parts of the world improved these breeds and introduced new qualities and adaptability to various environments. Economically, knowledge of animals was important in better nutrition, better wool and leather, and improved transport animals.

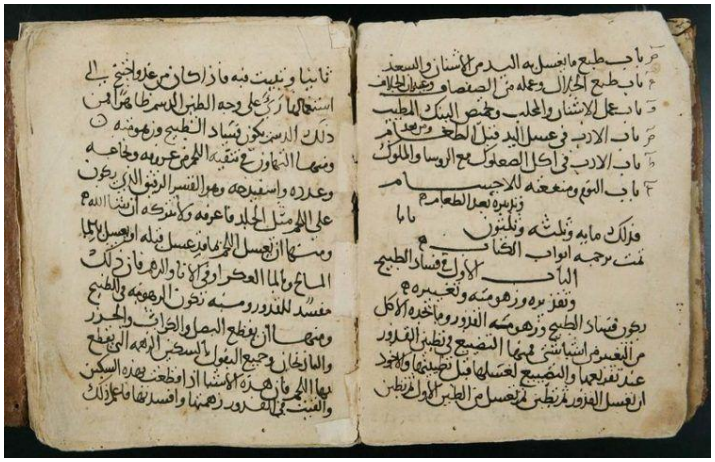
21. Cuisine

Cooking in Al-Andalus was an international affair, flavored by the tastes of India, the Spice Islands, Persia, Africa, and places in between from which cultural elements were gathered and brought to the Iberian Peninsula with the Muslims. Herbs and spices like basil, saffron, coriander, jasmine, and mint and spices such as ginger, aniseed, tamarind, cloves, and cinnamon combined exotic imported plants with those that were native to the Mediterranean climate of Spain.

A spice market in Syria (James Gordon on Wikimedia).

The transfer of new crops, from sugar cane to grains, fruits, and vegetables, was aided by irrigation systems and trade connections in the Muslim lands. Eggplants, artichokes, melons, bananas, spinach, figs, dates, citrus fruits, and a wide variety of nuts and seed crops for oil were added to the native plants known in Roman times.

Syrian, Persian, and Central Asian cooking combined with foods from India that had reached Iran in pre-Islamic times, and then spread rapidly westward along the Mediterranean. Abbasid Baghdad was a meeting place for cuisines collected by the empires that had flourished there in previous centuries. A 10th century literary dictionary of Baghdad listed a dozen cookbooks. Food fashions spread among the newly wealthy families of elite Abbasid era society.



A folio of a 10th century CE cookbook from Baghdad (Nawal Nasrallah on Atlas Obscura).

In the urban and urbane societies of Córdoba, Seville, Valencia and Granada, and in the lesser cities and countryside, farming and cooking arts flourished and combined in new ways. Ziryab, the musician who brought fashionable ideas from the east, also brought the idea of different courses for a meal and table manners. Some cookbooks from the time survived, but even more, ways of preparing food and combining ingredients passed from cook to cook, despite the turmoil of exile, conquest, conversion, and migration that happened to the Muslims and Jews of Al-Andalus.

Among the ways of cooking and eating habits that can still be recognized in Spain and Portugal today are:

- Sharing food from a communal dish, such as paella (the rice, saffron and seafood dish), and prepared grains like semolina and shredded bread

- Flavors of coriander, cumin, and saffron for savory and sweet dishes; meats, rice, fish, and beans
- Spicy stews using chickpeas, lentils and other beans, and cracked wheat; these were brought from North Africa and the eastern Mediterranean, and as far away as India (Mexican mole sauce dishes are believed to have come from this tradition)
- Fritters like doughnuts, and desserts with almonds, cinnamon, and other ingredients
- Flatbreads, thin pasta, grilled meats and shish kebabs
- Exotic vegetables and fruits like eggplant, artichoke, quinces, and apricots, among many other foods that made their way westward from Asia.

The invention of pasta or macaroni is claimed by many cultures, and multiple claims may be true. One sure way to trace the invention of pasta is the parallel spread of hard, or durum wheat. Durum wheat, unlike soft bread wheat, contains less moisture and more gluten (protein), which makes the stretchy dough that can be rolled and shaped. Durum wheat can also be stored for a long time. Where only soft wheat was grown, pasta wasn't possible.

Scholars trace the movement of durum wheat from Central Asia across the Muslim lands through literary sources. Spain and Sicily under Muslim rule were both places where pasta was mentioned and durum wheat or semolina was grown. Andalusian geographer Ahmad al-Razi described hard wheat in Toledo in the 9th century CE, saying, "The air [of Toledo] is excellent and grain stays a long time without changing."

Watermelon sharbat (Miansari66 on Wikimedia).

It is repeated by other writers, and a 13th century Andalusian cookbook contains early references to macaroni — round balls, thin sheets, and long noodles like vermicelli. The Arabic name for pasta is *itriya*, a word that spread with variations into other languages, including Spanish alatria and familiar word tria or trij in Italian.

The introduction of sugar cane and its refining process was also crucial to certain foods. Sweetened, spiced or herbed fruit drinks known in Arabic as sharbat (pronounced shar-BAAT) were made into the pinnacle of luxury at the Andalusian courts by adding to them ice carried from the mountain snows. Many a traveler would never forget them. Some sweet drinks had medicinal qualities and were used in concentrated form as the sweetened syrups that made bitter medicine go down, such as cough syrups.

A candied pumpkin dessert (Scott Dexter on Flickr).

Sugar is also a preservative, and summer fruits could be kept in an even more delicious form when dried, like figs or dates, or candied like oranges, cherries, or ginger slices. Boiling in sugar syrup made fruit preserves such as jams and jellies which could be kept for months. Candied pumpkin turned ordinary squash into

an Andalusian treat, for example, or quince jam made an inedible but healthful fruit delicious.

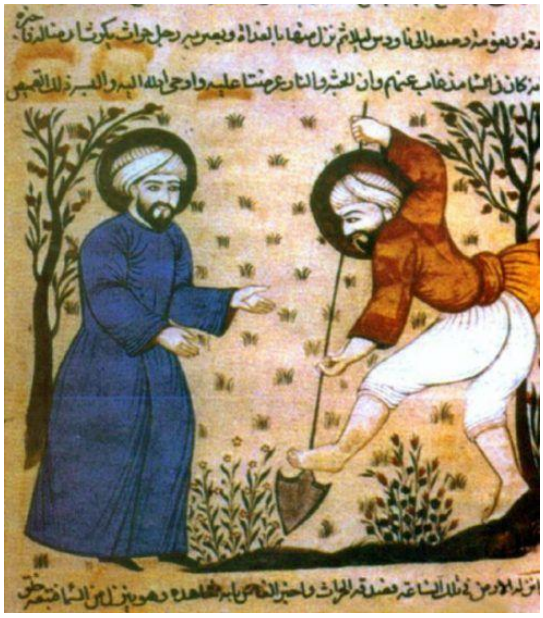
It is very likely that scholars who came to Toledo to feast on the libraries of scientific works in the 11th century also feasted their sweet-tooth on the famous confection of that city: marzipan. Just as the scientific literature crossed the Pyrenees, so did that candy (Arabic= qandi) made of almonds and sugar. Something like it may have originated in Central Asia, but marzipan became an art form in Al-Andalus.

It was made possible by the Arab introduction of sugar to the Iberian Peninsula, combined with almond trees so plentiful that the Andalusian hills looked as if they were covered in snow when they bloomed. As early as 700 CE, Arab writers mention marzipan, and by the 11th century in Toledo, it had become a Christmas custom among the Spanish Christians. It then spread into northern Europe, where it is still a traditional holiday treat.

13A freshly molded marzipan cake (James Petts on Flickr).

Many more dishes and types of food might be mentioned, and with the flow of people today between North Africa and Europe, the earlier conquest by cookstove is being repeated in the 21st century, restoring some of the cuisine of Al-Andalus to Spain.

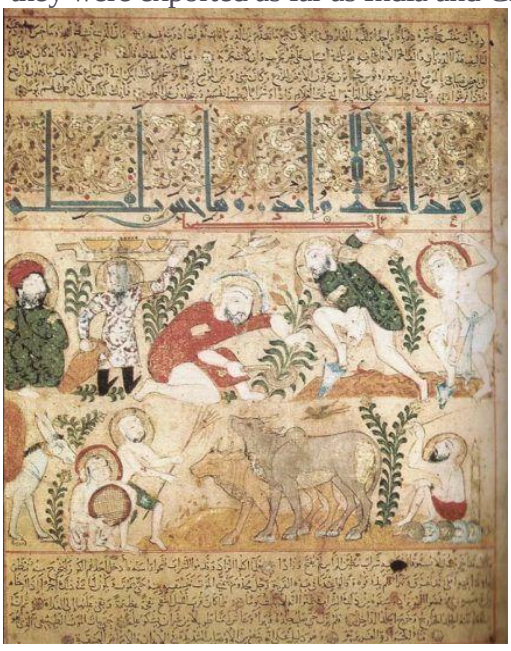
22. Agriculture



14A scene of agricultural work with a man digging herbaceous plants with a spade, among cultivated trees, from a mediaeval Arabic manuscript from Al-Andalus (courtesy of muslimheritage.com).

The Medieval Iberian Peninsula enjoyed a Mediterranean climate, like many of the coastal lands such as Morocco, Algeria, Palestine, Syria, and Lebanon. It was in many ways similar to the irrigated lands farther east, in Iraq and Persia, on the same latitudes. Because of this, Spain too shared in the agricultural revolution of the Medieval period, which brought many new crops under intense cultivation. In fact, Al-Andalus was one of the centers of that agricultural revolution. Food and fiber crops such as rice, sugar cane, sweet oranges and hard wheat for bread and pasta were introduced into Spain from farther east, along with the migration of farmers and transfer of irrigation technologies.

Agriculture and gardening flourished in Muslim Al-Andalus, and its crops of oranges, almonds, and other fine foods enriched the tables and poetry of Europe. Oranges, lemons, and limes would not have become such a popular fruit in the west without the gardens of Spain. Figs were another important fruit brought to Spain by Muslims. The best ones were grown in Malaga, where they were exported as far as India and China. This was possible because figs, with their high sugar content, could be preserved by sun-drying and transported over a year's journey. Sugar was produced and refined on a large scale, and played a part in the development of fine cuisine and fancy desserts, but also in the preservation of fruits before refrigeration. The taste for sugar entered Europe from Spain and from European contact during the Crusades.



15A page from the Kitab al-Diryaq, or Book of Antidotes, from the late 12th century AD (Selciukide from Seljuq Art).

Cotton was an essential non-food crop that made the textile industry possible, and its cultivation in Spain was also responsible for cotton's spread to the New World. It would have been unthinkable to introduce these new crops without the intensive system of irrigation, water management, and agricultural technologies such as crop rotation, management of pests, and fertilizing crops by natural means. Spanish agricultural books describe these technologies and comprehensive knowledge about cultivation.

Ibn Bassal (fl. 1038-1075 CE) was an original scientist and engineer who lived in Toledo and wrote about agriculture. He described different types of soil and stated how often each should be plowed and irrigated to get the best yields. He described how to best engineer hydraulic systems made up of wells,

ditches, and pumps. Other agricultural writers like ibn al-Awwam, and Abul Khair (early 1100s CE), al-Ishbili (late 1100s CE), and al-Tignari of Granada described sophisticated techniques such as grafting fruit trees, sugar-making, and preservation of fruits and vegetables. As a result, much new land was brought into cultivation under Muslim rule.

Irrigation systems were studied and policies were set down, determining exactly when each crop was irrigated, how stored reservoir and rainwater was used, and how water use by farmers and city dwellers was managed. As an example of how effective these systems were, the "Tribunal of the Waters" in Valencia is a group of officials that is still functioning from the time of Muslim rule until the present day, despite the fact that many other Islamic institutions were erased after the Reconquista and the expulsion of Muslims. This, however, was too vital a system to lose.

16Muslims developing irrigation systems (Eduardo J. Padial on webislam.com).

Lasting influences: Sugar cane, cotton and rice were key crops that the Spanish and Portuguese carried to the New World after the end of Muslim rule. In the New World, these crops were grown on a large scale in plantations using African slave labor. French, British and Dutch colonists gained great wealth from their possessions in the Caribbean. Without these cash crops, colonization of the New World by Europeans would not have been such an economic success. These global cash crops and several others that came to the attention of Europeans through trade and migration from Muslim lands were coffee, tea, bananas, and vegetables such as spinach and asparagus.

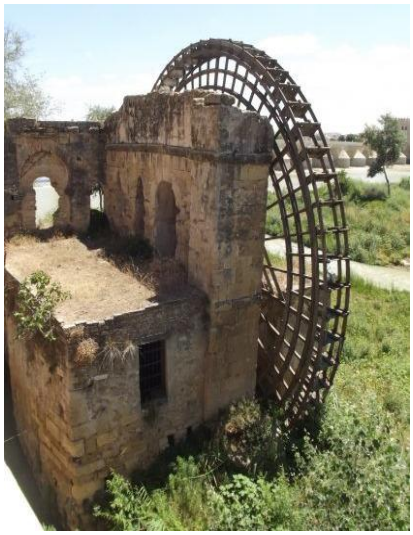
Flowers of many kinds that are common in gardens today also reached Spain during the heyday of Muslim rule, and their cultivation spread into Christian Spain and into other parts of Europe. The agricultural advances of the Scientific Revolution also owe much to the writings and practices in agriculture that passed into Europe through Islamic Spain and through their spread to the New World.

23. Hydraulic Technology

The Mediterranean region is one where water conservation is vital in summer. Rainfall is limited mainly to the winter, and summer crops need irrigation, while people and animals need water for drinking and bathing. Deserts meet the southern and eastern borders of the Mediterranean region, and because of this, water management technologies have spread to the better-watered areas of the Mediterranean from arid lands.

17The gardens of al-Hambra, an Islamic fortress located in Granada, Spain, which later became the residence of Ferdinand and Isabella (Eva L on Wikimedia).

Hydraulic technologies in the region have reaped wonderful rewards: productive fields, beautiful gardens, sparkling fountains and populous cities. Many important food, fiber, and flower crops were introduced to the region because of careful water management. A few examples are rice, sugar, cotton, citrus, almond, peach, apricot, and fig, but also roses and other beautiful and fragrant flowers, medicinal herbs and spices. They all became part of Mediterranean and Medieval Andalusian life.



18La Albolafia Mill on the Rio Guadalquivir, which would've raised water to the caliph's palace (Elliot Brown

What technologies were used to collect, channel, redirect and conserve water in Medieval Andalus? Rainwater was collected from ceramic-tiled roofs through a system of gutters and pipes that moved the water to underground cisterns for storage. Water from the winter rains thus became available for summer gardens. Spain's rivers, such as the Guadalquivir (Arabic: Wadi al-Kabir, or Great Valley), had a system of dams and flood control walls built by its Muslim rulers.

Aqueducts that had been built by the Romans were maintained and improved under Muslim rule to carry water from mountain streams to the cities and fields where it was needed. Some aqueducts let out into dancing fountains that worked without electric pumps (of course), by carefully harnessing the powers of gravity and water pressure using narrow pipes. Norias, or huge wooden waterwheels, were also carried over from Roman times and improved upon. Some norias are still functioning today. Their purpose was to raise the level of water from the source into the canal system, and maintain this level. Irrigation of farmland was carried out through a system of ditches and gates

called in Spanish acequia (Arabic al-saqiyyah, “to quench”), which spread to the New World with the Spanish, and is still used in the American southwest.

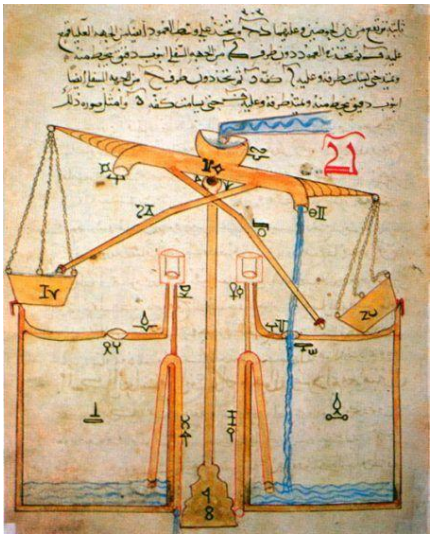


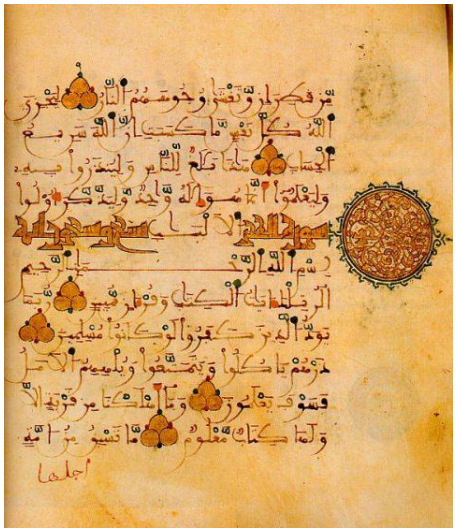
Diagram from a book by Al-Jazari, an Islamic inventor from the 13th century CE (Mladifilozof on Wikimedia).

Another important use of hydraulic technologies went far beyond farming or gardening, and beyond the beauty of sparkling fountains. Hydraulic technologies can be used to generate power — to harness the motion of water to do work. Today of course, hydroelectric power is generated as electricity. That innovation did not come until about a century ago. In Medieval times, water power was harnessed — literally like an animal — to push, pump, grind, pound, drill, and spin. The motion of water falling on a wheel fitted with paddles, or a river’s current pushing the paddles of the wheel, could provide a steady source of circular motion that could be transferred through a series of gears to turn a grinding wheel or a potter’s wheel. It could be changed into up-and-down motion with trip-hammers to pound wood pulp for paper, sugar cane stalks to extract the juice, or rice to break the hulls. This innovative use of the waterwheel in al-Andalus was transferred from eastern Muslim lands, from Persia, and even as far away as China. From Spain it spread to other parts of Europe. Another technology similar to hydraulic power is the windmill. This technology is believed to have come from Persia, and the windmill became a prominent symbol of life in Spain, and then in Holland.

Windmills were also used to pump water out of wells, or out of mines, to keep miners safe. Windmills could grind grain much as a waterwheel could, but a windmill did not require a river, making it especially suited to arid, windswept lands. Windmills and waterwheels were among the important technologies that spread from Andalus to other parts of Europe during the time of the translation efforts of the 11th century. One way to trace the origin of something is to find evidence in the culture of the country. Don Quixote’s famous attack on the imaginary giants, which were actually windmills, is one such piece of evidence. Another is poetry, as in this poem about a waterwheel originally written in Arabic:

How wonderful is the waterwheel! It spins around like a celestial sphere, yet there are no stars on it.
It was placed over the river by hands that decreed that it refresh others’ spirits as it, itself, grows tired.
It is like a free man, in chains, or like a prisoner marching freely.
Water rises and falls from the wheel as if it were a cloud that draws water from the sea and later pours it out.
The eyes fell in love with it, for it is a boon companion to the garden, a cupbearer who doesn’t drink.
~ Ibn al-Abbar (Valencia, d. 1260 CE)

24. Calligraphy



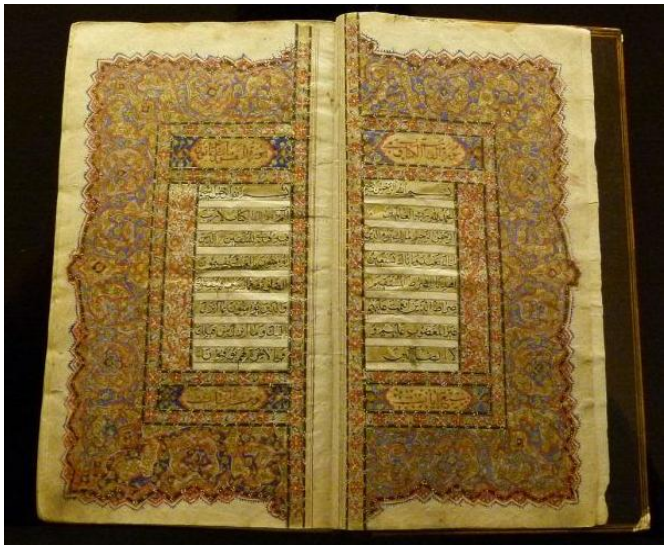
19Page from a manuscript from Al-Andalus, 12 century CE. The thicker strokes in the center of the page are in the Kufic style of calligraphy (Rythin on Wikimedia).

Calligraphy, from the Greek, means the art of beautiful writing. Before printing, writing was done by pressing lines into clay, carving a hard surface like stone, or tracing lines with ink on surfaces such as papyrus, leather, parchment (beaten, stretched sheepskin), or paper. Paper — a Chinese invention made from wood or plant pulp, cotton fiber or recycled rags entered Muslim culture with the spread of Islam into Central Asia during the seventh and eighth centuries.

Paper played a major role in the spread of literacy and the culture of the book, and in the expansion of the Arabic language as the medium of Islamic culture and learning. Paper is lighter and much less expensive than parchment, lasts much longer than papyrus, and accepts all kinds of ink, colored pigments and finishes to make it smooth or rough. As a result of these qualities, literacy and libraries expanded very quickly in Muslim lands.

The art of beautiful writing in Arabic — first used to honor the words of Islam's holy book, the Qur'an became the highest art form. Figurative art, in contrast, which involved drawing people and animals, was never associated with religious literature and arts. It was limited to secular, or worldly, works of art and literature. For example, medical books were illustrated with human figures for a purpose. Stories were illustrated, but until later centuries, stories from the Qur'an and the prophets were not. In the decoration of houses of Islamic worship the masjid, or mosque figurative drawing was very rare. Images of flowers and plants, geometric designs and mathematical patterns were interwoven with the words of the Qur'an.

Over time, various styles of Arabic calligraphy developed. Square, angular Kufic script was one of the early forms. Other forms, more flowing and rounded developed over time. One major change from the earliest Arabic scripts was the effort to make it easy for non-Arabs to read accurately. That was an important factor in preserving the Qur'an. A system of dots or points was added to the letter shapes to distinguish them clearly from one another, and a set of vowel marks and other symbols was added to signify how the word should be pronounced. Both of these added features were incorporated into the forms of calligraphy in harmonious and well proportioned ways.



A Quran depicting the use of geometric designs in the margins of each page (Lanke Llion on Wikimedia).

Calligraphers working in Al-Andalus and parts of North Africa and later West Africa developed a distinctive style of Arabic calligraphy. An example of the round, flowing Andalusi script is shown at left, with a

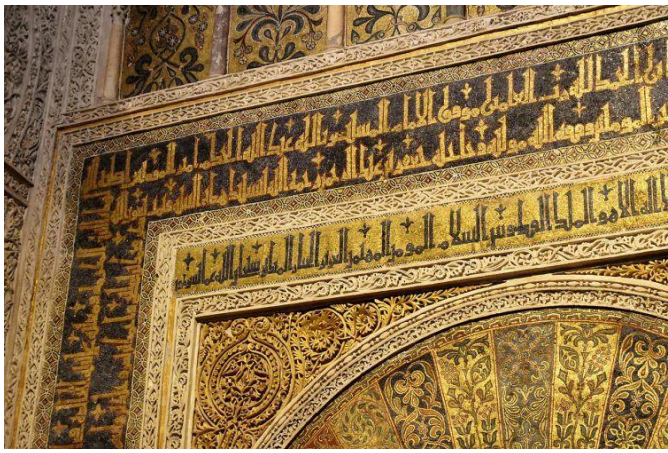
heading in the angular Kufic script in gold, at the top of the page. This style is also found in many libraries of West Africa such as Timbuktu, where efforts are being made to preserve thousands of beautiful examples of this script.

20A page of a Quran dating from the late 13th–early 14th century CE (Rogers Fund on Wikimedia).

Arabic calligraphy also served the interest of building libraries in Al-Andalus, to hold collections that reproduced the knowledge gathered in Muslim lands over the centuries. Rulers of cities like Córdoba, Seville, and Toledo sponsored libraries of thousands of books, all hand written, and employed staffs of calligraphers to make copies and embellish works in Arabic. It is known that there were women in Al-Andalus working both in decorative calligraphy and as copyists of books, and that wealthy patrons of libraries and private collections included educated women in cities such as Córdoba, Seville, and Granada.

Among the known women scholars of Spain recorded during the 11th century CE were names such as Ayisha bint Ahmad, Radiyah, Khadijah bint Ja'far, Labna and Fatimah. Radiyah (died 1032 CE) was the wife of Labib, a noble at the Córdoban court. Women of less wealthy families were employed as copyists, and historian Ibn al-Fayyad reported that 170 women were engaged as copyists in only one section of Córdoba. Books of poetry, astronomy, philosophy, mathematics, agriculture, and medicine were decorated with illustrations and written out in an efficient, well defined script.

PartCalligraphy was also a major decorative feature in other art forms. It appeared on ceramic vessels, carved wooden and ivory boxes, and leather-covered objects with gold stamping. It was woven into tiraz borders on textiles, inlaid or engraved on metalwork and scientific instruments, and stamped onto coins.

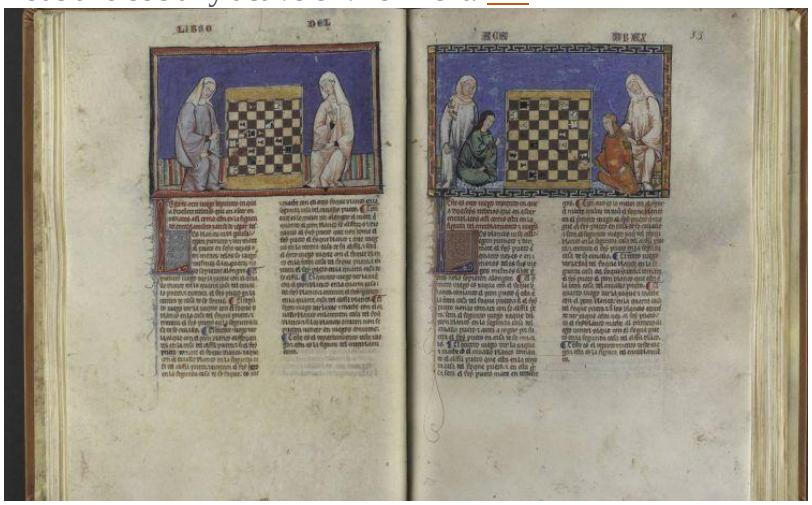


Part of the mihrab area of the Great Mosque of Cordoba, towards which Muslims pray (Richard Mortel on Wikimedia).

Architecture in Al-Andalus was richly decorated with calligraphy. Not only the interior of mosques, but also the walls and niches of palaces, were embellished with calligraphy. In the mosque (or masjid), walls, domes, doorways and arches, as well as bands around the perimeter, or on a minaret (tower for the call to prayer) were architectural elements that displayed elegant designs of Qur'anic verses. Repetition of a name of God might be incorporated into brickwork, or combined with curving arabesques or plant forms. Geometric designs were usually alternated with bands of calligraphy. The forms of Arabic lettering in Al-Andalus were distinctive for their use of simple, angular Kufic such as the mosaic lettering done in golden glass tesserae in the Mosque of Córdoba, shown below, and a flowing Andalusi style with dramatic curves, shown in the plasterwork of the Nasrid period, at left.

25. Games

Much like video games today, Medieval board games were exercises of the mind that served not only as pastimes but as social occasions and serious mental training. Games require leisure time and reflect a luxurious and socially active environment. Al-Andalus was just such a place. In the courts and gardens of rulers and wealthy elites, and in the cities and marketplaces, people took time to play games. Rulers considered games of strategy like chess to be worthy activities for themselves, their courtiers, and their children's training as thinkers. Many literary sources such as poetry, biographies, and even scientific works prove that chess was played in Al-Andalus along with other games brought there from eastern Muslim lands.



The "Book of Games" contains the earliest known depiction of a chessboard.

An important source of knowledge about games played in Al-Andalus is a 100-page illustrated book in Castilian called the Book of Games, or Libro de los Juegos, commissioned between 1251 and 1282 CE by the Christian ruler of Toledo after the conquest of the city from Muslims. Alfonso X, King of Leon and Castile, "Alfonso the Wise," commissioned many translations of Arabic works into Latin, and his work documents the transfer of knowledge and culture from Al-Andalus to European or Western civilization. As he dictated the book to a scribe, he noted that God permits pastimes, and said:

...those who like to enjoy themselves ... or those who have fallen into another's power, either in prison, or slavery, or as seafarers, and in general all those who are looking for a pleasant pastime which will bring them comfort and dispel their boredom. For that reason, I, Don Alphonso ... have commanded this book to be written."

21A Jew and a Muslim playing chess in 13th century al-Andalus (courtesy of Escurial Library).

The book describes chess, the game that originated in India or even China, and became known in Persia as shatranj. Originally, the game was played with animal pieces — an elephant, a crocodile, a mythical bird (see left). Later the pieces came to represent the shah, or king, his minister (wazir), knights, and soldiers. In Europe, the game pieces came to reflect the feudal system. As the battle game moved westward, the wazir seems to have changed into a queen, and became a more important piece in the game. Scholars are not certain, but this change may have come about in Al-Andalus. The object of the game, which requires great

patience, skill, and analytical effort, is to kill the king — *al-shaykh maat* in Arabic, or "checkmate."

Chess entered Europe on more than one pathway. Harun al-Rashid (d. 809 CE) is said to have sent a diplomatic gift of a chess board and pieces to Charlemagne (d. 814 CE) — an ivory set that still exists — but some scholars think chess came to Europe around 1000 CE through Al-Andalus, and the set belongs to a later time.

Another game depicted in Alfonso's book is backgammon, still played widely today in many countries. Al-Masudi (d. 956 CE) wrote about backgammon in his collection of anecdotes Meadows of Gold. It is a game of skill, but depends on luck as well. People enjoy the combination of luck and skill as a reflection of the tension between human fate and individual free will. Backgammon came to Al-Andalus with the transmission of other fashions and lifestyles.

The game shown below is called Morris — the mill game — in Spanish alquerque. Its board has lines that intersect, onto which players move pieces with a roll of dice. By strategy, the pieces move to form a line of three pieces on intersections or other variation, and eliminate the opponent's pieces from the board. The origins of this game is said to be the Roman Empire, but there is evidence that it arrived from Asia, and was played in Al-Andalus.

Alfonso's book contains many other games whose origins are not always certain, but surely reflect the mingling of many cultural groups from Africa, Asia and the Mediterranean region, and are unified by the enjoyment and togetherness that games bring to families, friends, and associates. They have been enjoyed in social circles among rich and poor, men, women, and children, like the early version of 3-in-a-row or tic-tac-toe from the Book of Games at right.