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Transfer of Islamic Science to the West

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TRANSFER OF ISLAMIC SCIENCE TO THE WEST*

Prof. Dr. Ahmad Y. Al-Hassan**

From ancient history till the sixteenth century, the Near East was leading the world in technological innovation and advance. This is not to minimize the importance of Chinese civilization and its great contributions to the world, but what we want to point out is that the overall contribution of the Near East to human progress in general until the sixteenth century, surpasses anything that was achieved anywhere else in the world. This was true during the ancient civilizations of Egypt and Mesopotamia, as it was true during the Hellenistic and the Roman periods. What is called the Greco-Roman heritage was built on the great civilizations of the Near East. Furthermore, the major achievements in science and technology that are called Hellenistic and Roman were mainly Near Eastern achievements due to the scholars and artisans of Egypt, Syria, and Mesopotamia.

The pre-Islamic civilizations of the Near East and of all the lands extending from Central Asia and northern India to Spain were inherited by Islam; and under the influence of Islam and of the Arabic language, the science and technology of these regions were greatly developed and advanced.

During the rise of Islamic civilization, Europe was still at an early stage in its technological status. Charles Singer, in the second volume of *A History of Technology,* observes that "the Near East was superior to the West. For nearly all branches of technology, the best products available to the West were those of the Near East. Technologically, the West had little to bring to the East. The technological movement was in the other direction".[1]

Despite these facts, the influence of the medieval Arab-Islamic civilization in formulating the western tradition and in providing the foundation for its science and technology is hardly recognized in the mainstream of modern western literature, except for an occasional reference. There is a resistance by the mainstream of western historians in acknowledging this influence.

This paper summarizes the debt that the West owes to the Arabic-Islamic civilization in the field of technology. It comes as a response to the sudden interest in the West in the Arabic-Islamic achievements in science and technology; an interest that was awakened by the recent political and military events.

Avenues of Transfer

Transfer of Islamic science and technology to the West was affected through various avenues. We give below an outline of these.

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1 C. Singer, Epilogue, in C. Singer et al. (eds.), *A History of Technology,* Vol. II (Oxford: Oxford University Press, 1979), 756.

Al-Andalus

There was a remarkable flow of scientific and technological knowledge from the Muslim East to al-Andalus and that was central to its cultural and economic vitality. The most fruitful transfer to the West took place in the Iberian Peninsula, where over several centuries the generally tolerant rule of the Umayyad Caliphs and their successors permitted friendly relationships between Muslims and Christians.

The Spanish historian, Castro, argued that Christian Spain has always been an importer of technologies, and after the fall of Toledo in 1085 the exporters of technology were the Muslim Mudéjars[2] who formed enclaves of technological expertise that were geographically inside the country, but ethnically outside it. Ethnic boundaries are not hermetically sealed. Diffusion of techniques was continuous. The implantation of new techniques in Spanish Christian towns was effected through the migration of artisans, utilization of the skills of ethnic enclaves, or imitation of foreign wares. Castro is of the opinion that Christian economy was colonized by its own ethnic subordinates.

The Mozarabs[3] played also an important role in transferring Arabic culture and technology to Christian Spain. The Christian kingdoms could only continue to expand by successfully colonizing the territories that they had occupied. These territories were virtually depopulated because of the conquests and it was therefore necessary to repopulate them again. One method used was to attract Mozarab immigrants from al-Andalus. Such was the policy which enabled Alfonso III to colonize the conquered territories. The Mozarabs were to build important buildings, monasteries and fortresses that constituted typical examples of Mozarabic architecture. They brought with them their knowledge of the language that enabled them to compile Arabic glosses on Latin manuscripts, and to translate Arabic works. They provided the base of the intellectual movement of the 'School of Translators of Toledo'. They introduced Arabic-Islamic tastes, crafts and administrative skills. In this sense, it is undeniable that they contributed powerfully to the intellectual and cultural arabisation of the Christian kingdoms.

Muslim operations in agriculture, irrigation, hydraulic engineering, and manufacture were an integral part of everyday life in the southern half of the peninsula, and many Muslim skills in these fields and in others, passed from Christian Spain into Italy and northern Europe. These transmissions were not checked by the crusading wars which were going on against the Muslims in Spain. Indeed, they were probably accelerated, since the Christians took over the Muslim installations and maintained them in running order in the ensuing centuries.

Sicily

Sicily was part of the Muslim Empire and did not lag behind in the cultivation of a high standard of civilization including the founding of big institutions for teaching sciences and arts. Due to its proximity to mainland Italy it had played an important role in the transmission of Arabic science and technology to

[2] Spanish *'Mudéjar'* (from Arabic *mudajjar),* any of the Muslims who remained in Spain after the Christian conquest of the Iberian Peninsula (11th -15th century).
[3] From Arabic *"musta'rib",* "arabicized", any of the Spanish Christians living under Muslim rule, who, while unconverted to Islam, adopted Arabic language and culture.

Europe. During the Arab era (827-1091) and the Norman one (1091-1194) Sicily was, after Spain, a bridge between the Arabic-Islamic civilization and Europe.

In the Muslim period Palermo was a major city of trade, culture and learning. It became one of the greatest cities in the world. It was a period of prosperity and tolerance as Muslims, Christians and Jews lived together in harmony and peace.

The Arab tradition of tolerance toward other religions was perpetuated under the Norman kings. Under the rule of Roger II, Sicily became a clearing house where eastern and western scholars met and exchanged ideas that were to awaken Europe and herald the coming of the Renaissance. Arabic science was passed from Sicily to Italy and then to all of Europe.

The Arab presence in Sicily was the stimulus for artistic activity which characterized Norman Sicily. Virtually all monuments, cathedrals, palaces and castles built under the Normans were Arab in the sense that the craftsmen were Arab, as were the architects. As a result, Arabic influence on architecture can be seen in several Italian cities.

The Arabs introduced many new crops: including cotton, hemp, date palms, sugar cane, mulberries and citrus fruits. The cultivation of these crops was made possible by new irrigation techniques brought into Sicily.

The revolution in agriculture generated a number of related industries, such as textiles, sugar, rope-making, matting, silk, and paper. Other industries included glass, ceramics, mosaics, arms and engines of war, ship building, and the extraction of minerals such as sulphur, ammonia, lead and iron.

The proximity of Sicily to mainland Italy made it, together with Muslim Spain, a source for the transfer of several industrial technologies to Italian cities such as the manufacture of paper and silk.

By the late 11th or early 12th century sericulture had been established in Muslim Sicily; and by the 13th century silk textiles were being woven on the Italian mainland itself, principally at Lucca and Bologna. These two Italian cities were also the site of the first silk-throwing machine in Europe, a technology that was transferred from the Arabs of Sicily.

Byzantium

The proximity of Byzantium to the Islamic lands and the common borders between them resulted in active commercial and cultural contacts. Some Arabic scientific works were translated into Greek. The discovery of the Tusi Couple in a Greek manuscript that could have been accessible to Copernicus accounts fairly well for the possible transmission of that theorem through the Byzantine route. Technology was transferred from Islamic lands to Byzantium and from thence to Europe.

Wars

The Crusades in the Near East

In the high Middle Ages 'Orient' meant Arabic civilization for Europe, and although the influence of the Crusades on the transmission of science to Europe was small, yet the Crusaders, while in the Near East, experienced the attractive sides of Islamic life, and attempted to imitate these on their return home. These aspects of material civilization mean that the Crusaders transferred to Europe several technological ideas from the Near East[4]. The outcome was the adoption by the Christian West of some of the great achievements of Arabic civilization. This Arabic influence was to have an enormous impact on the further development of Europe.

Figure 1. *The Crusades in the Near East: Crac de Chevaliers on the Syrian coast is a symbol of the Crusading wars that lasted about 200 years, from the 11th to the 13th century. During this period the West became acquainted to the luxury products of Islamic civilization and this was instrumental in the rise of manufacturing centres in Europe to produce similar goods.*

The Crusades in Spain

The Crusades against the Muslims in Spain resulted in various kinds of technology transfer to the Christians of Spain. One of these technologies was the use of gunpowder and cannon. It is reported that this technology was transferred also to the English in 1340-42 at the siege of al-Jazira in al-Andalus. The English earls of Derby and Salisbury participated in the siege and it is reported that they carried back with them to England the knowledge of making gunpowder and cannon. After few years the English used cannon for the first time in Western Europe against the French in the battle of Crecy in 1346.

Commercial relations

Relations between Christian Europe and the Islamic World were not always hostile, and there were active commercial relations most of the time. This led to the establishment of communities of European merchants in Muslim cities, while groups of Muslim merchants settled in Byzantium, where they made contact with Swedish traders traveling down the Dnieper. There were particularly close commercial ties between Fatimid

[4] E. Barker, "The Crusades" in Thomas Arnold and Alfred Guillaume, eds., *The Legacy of Islam* (Oxford: Oxford University Press, 1931), 40-77; Singer et al., 764-5. Two sources are particularly useful: A.S. Atiya, *The Crusades, Commerce and Culture* (Mass.: Gloucester, 1969);

Egypt and the Italian town of Amalfi in the tenth and eleventh centuries. The ogival arch, an essential element of Gothic architecture, entered Europe through Amalfi - the first church to incorporate such arches being built at Monte Cassino in 1071.

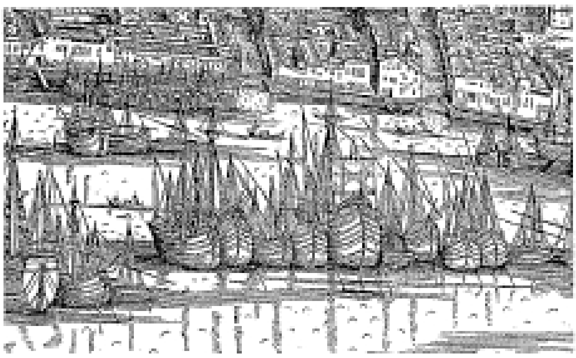

Figure 2. *Trade with the Muslim East: Venice was the most prominent among the Italian cities in its trade relations with the Near East. This is an illustration of a woodcut map of Venice (1500), Source: Deborah Howard,* Venice and the East *(New Haven: Yale University Press, 2000), 24.*

In the Middle Ages, oriental luxury goods were indispensable to the lifestyle of the European upper classes. Significant as these luxury goods were to European culture of the Middle Ages, they were no less important to the medieval economy. Foreign trade that provided these luxury items was an economic enterprise on a grand scale.

Islamic luxury goods and pepper were transported from Syria and Egypt. Venice became the chief transfer point in Europe. With the profits from this trade, the Venetian wholesale merchants built their marble palaces. The splendid architecture of Venice, lavishly displaying its oriental influence, became a sort of monument to its trade with Islamic lands.

The translation of Arabic works

The translation movement which started in the twelfth century had its impact on the transfer of technology. Alchemical treatises are full of industrial chemical technologies such as the distillation industries and the chemical industries in general. Arabic treatises on medicine and pharmacology are rich also in technological information on materials processing. Works on astronomy contain many technological ideas when they deal with instrument-making.

In the court of Alfonso X there was an active translation movement from Arabic where the work entitled *Libros del Saber de Astronomia* was compiled. It includes a section on timekeeping, which contains a weight-driven clock with a mercury escapement. We know that such clocks were constructed by Muslims in Spain in the eleventh century about 250 years before the weight-driven clock appeared in northern Europe. The West was acquainted with the Muslim science of surveying through the Latin translations of Arabic mathematical treatises.

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and P. Hitti, *Tarikh al-'Arab,* Vol. II (Beirut, 1965), 780-92, and his original English *History of the Arabs,* 10th ed. (Macmillan, 1970), 659-70.

Translations of technical materials from Arabic are evident in Adelard of Baths's new edition of Mappae Calvicula. Several recipes from Arabic were confirmed by historians of science. It is known that Adelard resided in Arabic lands and was a noted translator from Arabic. Another important text of Arabic origin is the *Liber Ignium* of Marcus Graecus. It is now acknowledged that gunpowder was first known to the West through this treatise.

Arabic Manuscripts in European Libraries

In his research into the avenues through which Copernicus became acquainted with the Arabic theorems on astronomy George Saliba[5] indicated that these theorems were circulating in Italy around the year 1500 and thus Copernicus could have learned about them from his contacts in Italy. Saliba demonstrated that the various collections of Arabic manuscripts preserved in European libraries contain enough evidence to cast doubt on the prevailing notions about the nature of Renaissance science, and to bring to light new evidence about the mobility of scientific ideas between the Islamic world and Renaissance Europe.

There was no need for Arabic texts to be fully translated into Latin in order for Copernicus and his contemporaries to make use of their contents. There were competent scientists in that period when Copernicus flourished who could read the original Arabic sources and make their contents known to their students and colleagues.

This information about the availability of Arabic manuscripts in European libraries and the familiarity of many Europeans with Arabic brings to light the possible transfer of Islamic technology into Europe in the sixteenth century through the possible understanding of un-translated Arabic works. We mentioned below that the Banu Musa, al-Jazari and Taqi al-Din described in their works innovations in mechanical technology much earlier than the appearance of similar devices in the West.

We may recollect in passing that Arabic was taught in academies and schools in Spain, Italy and France that were established mainly for missionary purposes, but they served other fields of knowledge as well. They were also taught in some universities.

Flow of Arabic recipes from Spain into Europe

Beside the known Arabic works that were translated into Latin, and the Arabic manuscripts in western libraries, there is ample evidence that there was an active traffic of recipes flowing from Spain into Western Europe.

Starting with Jabir ibn Hayyan in his book *Kitab al-Khawass al-Kabir* which contains a collection of curious operations some of which are based on scientific principles, physical and chemical, an Arabic literature on secrets arose. Some of these secrets are called *niranjat.* Military treatises also, such as al-Rammah's book, contain recipes of secrets in addition to the formulations of military fires and gun-powder.

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[5] Saliba, George, "Mediterranean Crossings: Islamic Science in Renaissance Europe", an article on the Internet: http://ccnmtl.columbia.edu/ services/ dropoff/ saliba/document/

The Arabic military and secrets recipes found their way into Latin literature. All recipes in the *Liber Ignium* had their corresponding ones in the known Arabic literature. Numerous other Latin works such as those of Albertus Magnus, Roger Bacon in the thirteenth century, and Kyeser and Leoardo da Vinci in the fifteenth, contain recipes of Arabic origin.

An explanation on how these Arabic recipes, military and secret, found their way into Latin literature has been suggested. There were in Spain persons with knowledge of Arabic science and technology, and of both Arabic and Latin, who embarked on compiling various collections of recipes from Arabic sources to meet the increasing demand in Europe. Jews were most active in this pursuit. These collections were purchased at high prices by European nobility, engineers and other interested parties. Some recipes were un-intelligible but they were purchased on the hope that they will be interpreted at some future time.

Migration of Artisans

An effective method of technology transfer was the migration of craftsmen and artisans. They migrated either through treaties and commercial relations, were driven westwards as a result of persecution and wars or to seek better opportunities.

As mentioned below, in the fifth/eleventh century, Egyptian craftsmen founded two glass factories at Corinth in Greece, then they emigrated westwards after the destruction of Corinth by the Normans. The Mongol conquest of the thirteenth century AD drove large numbers of Syrian glassworkers to glass-making centres in the West.

In 1277, Syrian craftsmen were sent from Syria to Venice as a result of a treaty between Antioch, and Venice, as we shall see below.

In Spain the migration of Muslim craftsmen to Christian Spain was taking place throughout the Crusade upon the fall of Muslim cities. Al-Andalus was an emporium from which Christians were importing those products which they did not produce themselves. The techniques, however, were transferred upon the conquest of Muslim towns. The technologies were practiced by resident Muslim craftsmen who, subsequent to the conquest, became very mobile and diffused manufacturing technologies throughout the Christian kingdoms.

As mentioned above, Mozarabs immigrated northwards to Christian territories either due to enticement or because of persecution and were influential in transferring Islamic technology.

In the thirteenth and fourteenth centuries the economy of Provence in the south of France was affected by contact with the Muslim West and the Muslim East. The imported crockery from al-Andalus became popular in Provence. Archaeology attests to the importation of techniques from the Muslim West for the manufacture of ceramics in imitation to the Muslim ones. In the thirteenth and fourteenth centuries a great proportion of artisans and workers in Marseilles and Provence were foreigners including moors and Jews from al-Andalus.

The fall of Muslim Sicily to the Normans resulted in the emigration of great numbers of Sicilian Muslims to North Africa but others remained. Around 1223 Frederick II deported the remaining Muslims to Lucera in

Apulia, Italy, and some had settled in other parts of southern Italy. The Muslims of Lucera practiced several occupations including the manufacture of arms, especially crossbows with which they supplied Christian armies. They produced also ceramics and other industrial products. When the colony was destroyed in 1230 and its inhabitants were sold into slavery, the manufacturers of arms were spared this fate and were allowed to stay in Naples to practice their craft.[6]

Livorno in Tuscany expanded and became a major port during the rule of the Medici family in the 16th century. Cosimo I (1537-1574) wanted to increase the importance of Livorno, so he invited foreigners to come to the new port.

Ferdinand I, grand duke of Tuscany from 1587 to 1609, gave asylum to many refugees - including Moors and Jews from Spain and Portugal. These immigrants were given many rights and privileges and they established in Livorno the soap, paper, sugar-refining and wine distillation industries.

Movement of Scholars, Converts, Diplomats, Commercial Agents, Clergy and Spies

In addition to the translators who flocked to Spain during the twelfth and thirteenth centuries there was a continuous movement of persons from the West to the Near East, and to al-Andalus and al-Maghrib countries, and a movement in the opposite direction also. This movement of persons contributed to the transmission of science and technology from Islamic lands to the West.

Gerbert who became Pope Sylvester II was a French educator and mathematician who spent three years (967-970) in the monastery of Ripolli in northern Spain during which he studied Arabic science. He is considered "the first ambassador who carried the new Arabic science across the Pyrenees".

Constantinus Africanus was the first to introduce Arabic medicine into Europe. He was born in Tunis (about 1010-1015 AD) and died at Monte Cassino in 1087. He traveled as a merchant to Italy and having noticed the poverty of medical literature there he decided to study medicine, so he spent three years doing this in Tunis. After collecting several Arabic medical works he departed to Italy when he was about 40 years old, and he settled first in Salerno and then in Monte Cassino where he became a Christian convert.

Constantinus translated into Latin the most important Arabic medical works that were known up to his time, and attributed then to him. But these works were later traced back to their real Arabic origin. Nevertheless he was responsible for introducing Arabic medicine into Europe and in heralding the start of proper medical education.

One of the earliest western scholars to travel to Arab lands was Adelard of Bath who was active between 1116 and 1142. He traveled to Sicily and Syria where he spent seven years during which he learnt Arabic and became acquainted with Arabic learning. Beside his important scientific translations Adelard was instrumental in the transfer of Islamic technology. He issued a revised edition of *Mappae Clavicula* which is a collection of recipes on the production of colours and other chemical products. This treatise is a very

[6] Julie Taylor, *Muslims in Medieval Italy, The Colony at Lucera* (Lexington Books, 2003), 114, 203,204.

important one in western medieval technology. Steinschneider listed it among works that are mostly of Arabic origin whose authors and translators are unknown.

Another important figure from the same era was Leonardo Fibonacci who was born around 1180. He was a great mathematician and at 12 was living with his family in Bougie in Algeria. He received his education in mathematics and Arabic under an Arab teacher. This was followed by an apprenticeship period in commercial travels to the ports of the Mediterranean during which he visited Syria and Egypt and was able to have access to Arabic manuscripts in mathematics and to gain experience in Arabic commercial mathematics. He compiled his important book *Liber abaci* in 1228. He wrote also other works of lesser importance, one of which was *Practica geometriae.* In this book he explained the utilization of geometry in surveying *('Ilm al misaha),* as it was practiced by Muslim engineers.

Another Arab convert to Christianity was Leo Africanus who was born in Granada between 1489 and 1495 and was raised in Fas (Morocco). His name is al-Hasan b. Muhammad al-Wazzan al-Zayyati (or al-Fasi). He was travelling in diplomatic missions, and while he was returning from Cairo by sea he was captured by Sicilian corsairs who presented him to Pope Leo X. The Pope was able to convert him to Christianity in 1520. During his stay of about thirty years in Italy, he learnt Italian, taught Arabic at Bologna, and wrote his famous book *Description of Africa* which was completed in 1526. He collaborated with Jacob ben Simon in compiling Arabic-Hebrew-Latin vocabulary. Before 1550, he returned to Tunis to spend his last years embracing back his ancestral faith.

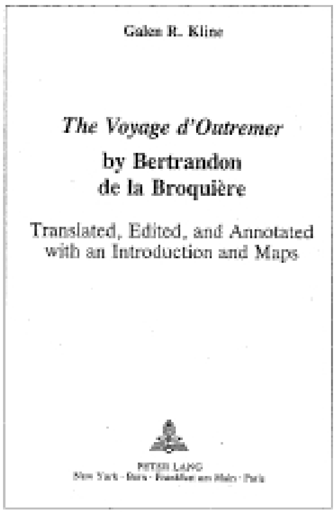
From the Renaissance period was Guillaume Postel, a French scholar who was born around 1510 and died 1581; he was well versed in Arabic and other languages, and had procured in two trips to Istanbul and the Near East a large number of Arabic manuscripts. The first trip which took place in 1536 was undertaken to collect manuscripts on behalf of the king of France. In the second trip Postel is believed to have spent the years 1548 to 1551 travelling to Palestine and Syria to collect manuscripts. After this trip, he earned the appointment as Professor of Mathematics and Oriental Languages at the College Royal. Two Arabic astronomical manuscripts from his collection are now in the Bibliothequc Nationale of Paris and in the Vatican, and they contain al-Tusi theorems and carry heavy annotations and notes by Postel himself. It is possible that among the manuscripts that he collected were some written by Taqi al-Din who was the foremost scientist in Istanbul at that time and who wrote treatises on astronomy, machines and mathematical subjects. Postel's precious collection of manuscripts went to the University of Heidelberg.

Another important scholar from this period is Jacob Golius (1590-1667), who was appointed Professor of Oriental Languages at the University of Leiden. Golius after his appointment spent the period 1625 until 1629 in the Near East, bringing back a harvest of 300 Arabic, Turkish and Persian manuscripts. He was an Arabist as well as a scientist, and it is reported that he translated some works of Jabir into Latin and had them published.

Some western diplomats played a role in the transfer of science and technology. Levinus Warner (1619-65) was a student of Golius in Leiden. In 1644 he settled in Istanbul. In 1655 he was appointed the Dutch representative at the Porte. During his stay he amassed a great library of manuscripts of about 1000 which he bequeathed to the University Library of Leiden.

Another important figure from the Renaissance period was Patriarch Ni'meh who immigrated from Diyarbakir in northern Mesopotamia to Italy in 1577 AD. He carried with him his own library of Arabic manuscripts. Ni'meh was well received by the Pope Gregory XIII and by the Medici Family in Florence and was appointed to the editorial board of the Medici Oriental Press. His own library is still preserved at the Laurenziana Library in Florence, and apparently formed the nucleus for the library of the Medici Oriental Press itself. During his service with the press several Arabic scientific works were published.

In addition to scholars and diplomats many travelers and pilgrims frequented Muslim lands throughout the centuries, and they contributed to the transfer of Islamic science and technology. We shall mention only one unique person who was a traveler as well as a spy. This was the French traveler Bertrandon de la Broquiere, who visited the Holy Land and the Muslim states of Anatolia in 1432 and wrote his book *Le Voyage d'Outremer.* His mission as a spy was to assess the possibilities of launching a new crusade to be led by the Duke of Burgundy.



Galen R. Kline

The Voyage d'Outremer

by Bertrandon de la Broquière

Translated, Edited, and Annotated with an Introduction and Maps

PETER LANG
New York · Bern · Frankfurt am Main · Paris

Figure 3. *The title page of the English translation of Le Voyage d'Outremer. Written by the French traveller Bertrandon de la Broquiere who was sent on a spying mission to Syria and the Anatolian Turkish states to evaluate the possibility of launching a new crusade. La Broquiere carried with him to France, among other things, the secret of fireworks. Source: The Voyage d'Outremer, by Bertrandon de la Broquiere, trans. Galen R, Kline (New York: Peter Lang, c. 1988).*

He was a highly competent spy and a very observant tourist and was keen to understand everything that came in his way. When he arrived in Beirut in 1432 the inhabitants were celebrating the *'Id.* He was surprised to see the fireworks for the first time. He realized fully their great potential in war and he was able, against a bribe, to learn their secret and he took the information with him back to France.

We can refer briefly to the role played by the commercial missions of Italian cities in Egypt, Syria and other Muslim cities. This influence has been the subject of recent research. One such study established the Muslim influence on the architecture of present day Venice due to its commercial missions in Muslim lands.
We may refer also to the importance of the Arab Maronites who resided in Rome and other cities in Europe during the Renaissance for educational purposes and for rendering services related to their knowledge of the Arabic language and Arabic culture. Among them were great scholars who became professors of Arabic in Rome and Paris.

Transmission of Islamic Engineering to the West

Medieval Islam was a prosperous and dynamic civilization, and much of its prosperity was due to an engineering technology that assisted in increasing the production of raw materials and finished products. In addition, the demand for scientific instruments, and the need to cater for the amusements and aesthetic pleasures of the leisured classes, was reflected in a tradition of fine technology based upon delicate and sensitive control mechanisms. This is a very wide subject indeed, and the Islamic contribution to the development of modern engineering will be indicated by means of citing individual cases of technology transfer.

Civil Engineering: Irrigation and Water Supply

With the spread of the Islamic Empire westward, agricultural and irrigation methods and techniques were introduced into the western regions of Islam. The rulers of al-Andalus and many of their followers were of Syrian origin, and the climate, terrain and hydraulic conditions in parts of southern Spain resemble those of Syria. It is hardly surprising, therefore, that the irrigation methods -technical and administrative - in Valencia closely resemble the methods applied in the Ghuta of Damascus.[7]

There is a unanimous opinion among historians that the present Spanish irrigation systems of Valencia and Andalusia are of Muslim origin. In 1960 a celebration commemorating the 'Millennium. Of the Waters' was held in Valencia, indicating public recognition of the establishment of the irrigation system and specifically of the Tribunal of Waters in the reign of 'Abd al-Rahman III.

The irrigation system that had been instituted in the days of the caliphs in Valencia was perpetuated and confirmed under the succeeding dynasties, until, when the Christian conquerors appeared in the thirteenth century, it recommended itself for adoption, backed by the experienced benefits of several centuries. The Arabic names used in the irrigation systems give distinct proofs of the Moorish origin of the irrigation systems in eastern Spain.

There is some difference between eastern Spain (Valencia and Murcia) and the kingdom of Granada. The chief object of the Granada water supply system was not the irrigation of crops only but the distribution of water to the fountains and baths of the capital. In Granada the system is still 'to an exceptional degree' the same as it was in the time of the Arabs, and we find undisturbed the institutions practiced by the Arabs themselves.

The Arabic systems in irrigations were diffused to Christian Spain. This accounts for the Aragonese traditions of irrigation.

These systems of irrigation had migrated from Spain to America where we find them still practiced in San Antonio in Texas. The story begins properly in the Canary Islands where in the late fifteenth century settlers from Spain introduced Islamic institutions of water distribution. They brought with them to the

[7] Thomas F. Glick, *Irrigation and Society in Medieval Valencia* (Cambridge, Mass. Harvard University Press, 1970), 169-170, 186, 214, 230, 264-265.

American southwest both the technology and the institutional framework for irrigation and the distribution of water.

The Qanat

The *qanat* system was an efficient method for irrigation and water supply. It originated in pre-Islamic Iran. The qanat technology spread westward to North Africa, Spain, and Sicily. The Andalusi agronomical writers provide practical advice on well-digging and qanat construction.

From Spain the qanat technology was transferred to the New World and qanats have been found in Mexico, Peru, and Chile. In the 1970s a qanat system 2.3 kilometres long was located in the La Venta area, just 10 km northwest of Guadalajara, Mexico.

In Palermo, Italy, a qanat system from the Arab days was used to bring fresh water to the city and to irrigate its beautiful gardens. There are current plans to revive and reconstruct the Arabic qanat and utilize it to solve the acute needs of the modern city of Palermo for potable water. The project in hand is of great historical, archaeological, geological and hydro-geological importance. It is already of great interest for tourists.

Dams

There are many Muslim dams in Spain, a large, number of which were built during the fourth/tenth century, the golden age of Umayyad power in the peninsula. In this period, for example, many small dams, or azuds, were built on the 150 mile-long River Turia, which flows into the Mediterranean at Valencia. (In passing it is important to note the Spanish word azud, from Arabic al-sadd, one of very many modern irrigation terms taken directly from Arabic and certain proof of Muslim influence on Spanish technology.) Eight of these dams are spread over six miles of river in Valencia, and serve the local irrigation system. Some of the canals carry water much further, particularly to the Valencian rice fields. These, of course, were established by the Muslims, and continue to be one of the most important rice-producing centres in Europe. Because of their safe design and method of construction, and because they were provided with deep and very firm foundations, the Turia dams have been able to survive the dangerous flood conditions for 1000 years.8

Mechanical Engineering: Water-raising Machines

The *saqiya* was widely used in the Muslim world from the earliest days onwards. It was introduced to the Iberian Peninsula by the Muslims, where it was massively exploited. Its maximum expansion in the Valencian country took place throughout the eighteenth century. In 1921 their number amounted to 6000 installed in the orchards of Valencia, which supplied water to 17866 hectares. Throughout the twentieth century they have been replaced by hydraulic pumps.

[8] N.A.F. Smith, *A History of Dams* (London: Peter Davies, 1971), 91.

The saqiya was introduced by the Spanish into Central America. Today, this ancient water raising machine is seen in a few farming areas in the northern Mexican states. It also survives in the Yucatan Peninsula. It is reported that one group of farmers in Veracruz, Mexico is reverting back to using the traditional technology of the saqiya.

The *na'ura* (noria) is also a very significant machine in the history of engineering. It consists of a large wheel made of timber and provided with paddles. The large-scale use of norias was introduced to Spain by Syrian engineers. An installation similar to that at Hama was in operation at Toledo in the sixth/twelfth century.

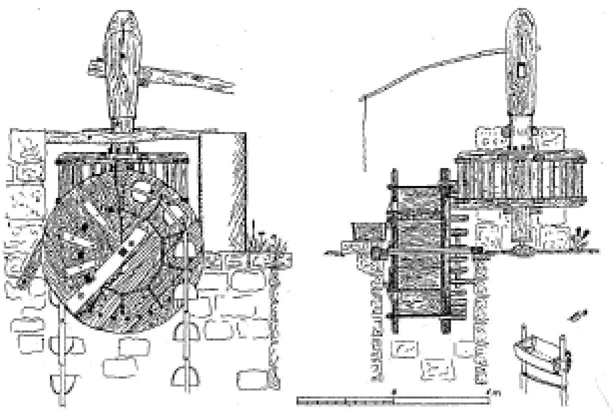


Figure 4. *A saqiya in Ma 'arrat an-Nu 'man near Aleppo. The saqiya travelled westward and was used by the thousands in Spain until recent centuries. It reached central and south America where it was used extensively, Source. Science and Technology in Islam (STI), (UNESCO, 2002), part II, 171.*

The noria of Albolafia in Cordoba also known as Kulaib, which stands until now, served to elevate the water of the river until the Palace of the Caliphs. Its construction was commissioned by 'Abd al-Rahman I, and has been reconstructed several times since then.

The noria was heavily exploited all over Muslim Spain. It was diffused to other parts of Europe, and like the saqiya has shown remarkable powers of survival into modern times.

Five water-raising machines are described in al-Jazari's great book on machines, composed in Diyar Bakr in 602/1206. One of these is a water-driven saqiya, three of the others are modifications to the *shaduf.* These are important for the ideas they embody, ideas which are of importance in the development of mechanical engineering as we shall mention below. The fifth machine is the most significant.

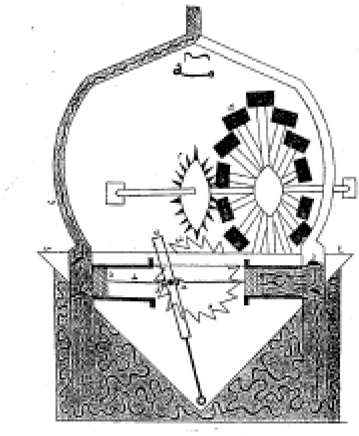


Figure 5. *Al-Jazarî's Suction Pump. Al-Jazari described in 1206 the first suction pump. The first description of such a pump in the West is attributed to Taccola (c. 1450). Source: STI, Part II 178, or Al-Jazari's Arabic text edited by Ahmad al-Hassan (Aleppo, 1979), 465.*

This is a water-driven twin-cylinder pump. The important features embodied in this pump are the double-acting principle, the conversion of rotary into reciprocating motion, and the use of true suction pipes. The hand-driven pumps of classical and Hellenistic times had vertical cylinders which stood directly in the water which entered them through plate-valves in the bottoms of the cylinders on the suction strokes. The pumps could not, therefore, be positioned above the water level. This pump of al-Jazari could be considered as the origin of the suction pump. The assumption that Taccola (c. 1450) was the first to describe a suction pump is not substantiated. The only explanation for the sudden appearance of the suction pump in the writings of the Renaissance engineers in Europe is that the idea was inherited from Islam whose engineers were familiar with piston pumps for a long time throughout the Middle Ages.

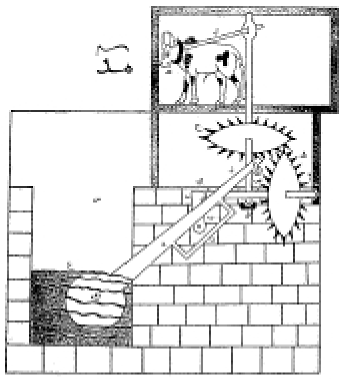


Figure 6. *The crank-connecting rod system. This important mechanism in mechanical engineering was first described by al-Jazari in 1206. The crank is the most important single mechanical device after the wheel. The invention of the crank-connecting rod system is considered by historians of technology to be the most important mechanical device of the early 15th century in Europe. But al-Jazari used this system in the pump illustrated here more than two centuries before its appearance in Europe. Source: Al-Jazarī's Arabic text edited by Ahmad Y. al-Hassan, 457.*

Evidence for the continuation of a tradition of mechanical engineering is provided by a book on machines written by Taqi al-Din about the year 959/1552. A number of machines are described, including a pump similar to al-Jazari's, but the most interesting device is a six-cylinder 'Monobloc' pump. The cylinders are bored in line in a block of wood which stands in the water - one-way valves admit water into each cylinder on the suction stroke. The delivery pipes, each of which is also provided with a one-way clack-valve, are led out from the side of each cylinder and brought together into a single delivery outlet. It is worthy of note that Taqi al-Din's book antedates the famous book on machines written by Agostino Ramelli in 1588. It is therefore quite possible that there was some Islamic influence on European machine technology even as late as the tenth/sixteenth century as we have alluded above.

Power from Water and Wind

The Muslim geographers and travellers leave us in no doubt as to the importance of corn-milling in the Muslim world. This importance is reflected by the widespread occurrence of mills from Iran to the Iberian Peninsula. Arab geographers were rating streams at so much 'mill-power'. Large urban communities were provided with flour by factory milling installations.

The ship-mill was one of the methods used to increase the output of mills, taking advantage of the faster current in midstream and avoiding the problems caused by the lowering of the water level in the dry season. Another method was to fix the water-wheels to the piers of bridges in order to utilize the increased flow caused by the partial damming of the river. Dams were also constructed to provide additional power for mills (and water-raising machines). In the sixth/twelfth century al-Idrisi described the dam at Cordoba in Spain, in which there were three mill houses each containing four mills. Until quite recently its three mill houses still functioned.

Evidence of the Muslims' eagerness to harness every available source of water power is provided by their use of tidal mills in the fourth/tenth century in the Basra area where there were mills that were operated by the ebb-tide. Tidal mills did not appear in Europe until about a century after this.

Figure 7. *The geared calendar of al Birunî. Geared calendars and various mechanisms of the water clock were the prelude to the appearance of the mechanical clock. Source: British Library, MS OR 5593. Reproduced in* Early Gearing, *Science Museum (London, 1985), 34, and in Donald Hill's* Studies in Medieval Islamic Technology *(Ashgate-Variorum, 1998), XIV, 150.*

Water power was also used in Islam for other industrial purposes. In the year 134/751 the industry of paper-making was established in the city of Samarqand. The paper was made from linen, flax or hemp rags. Soon afterwards paper mills on the pattern of those in Samarqand were erected in Baghdad and spread until they reached Muslim Spain. The raw materials in these mills were prepared by pounding them with water-powered trip-hammers. Writing about the year 435/1044, al-Biruni tells us that gold ores were pulverized by this method "as is the case in Samarqand with the pounding of flax for paper". Water power was also used in the Muslim world for fulling cloth, sawing timber and processing sugarcane. It is yet to be established to what extent industrial milling in Europe was influenced by Muslim practices. A likely area of transfer is the Iberian Peninsula, where the Christians took over, in working order, many Muslim installations, including the paper mills at Jativa.

Fine Technology

The expression 'fine technology', embraces a whole range of devices and machines, with a multiplicity of purposes: water clocks, fountains, toys and automata and astronomical instruments What they have in common is the considerable degree of engineering skill required for their manufacture, and the use of delicate mechanisms and sensitive control systems. Many of the ideas employed in the construction of ingenious devices were useful in the later development of mechanical technology.

The tradition of pre-Islamic fine technology continued uninterrupted under Islam and was developed to a higher degree of sophistication. Monumental water clocks in Syria and Mesopotamia continued to be installed in public places. The Abbasid Caliphs were interested in clocks and ingenious devices. The story of the clock that was presented by Harun al-Rashid (786-809), to Charlemagne in 807 AD is well known.[9]

The Evolution from Water to Mechanical Clocks

The technology of clock-making was transferred to Muslim Spain. About the year 1050 AD, al-Zarqali constructed a large water clock on the banks of the Tagus at Toledo in Spain. The clock was still in operation when the Christians occupied Toledo in 1085 AD.

A manuscript describing Andalusian monumental clocks was written in the eleventh century by Ibn Khalaf al-Muradi. Most of his devices were water clocks, but the first five were large automata machines that incorporated several significant features. Each of them, for example, was driven by a full-size water wheel, a method that was employed in China at the same period to drive a very large monumental water clock. The text mentions both segmental and epicyclical gears. (In segmental gears one of a pair of meshing gear-wheels has teeth on only part of its perimeter; the mechanism permits intermittent transmission of power). The illustrations clearly show gear-trains incorporating both these types of gearing. This is extremely important: we have met simple gears in mills and water-raising machines, but this is the first known case of complex gears used to transmit high torque. It is also the earliest record we have of segmental and epicyclical gears. In Europe, sophisticated gears for transmitting high torque first appeared in the astronomical clock completed by Giovanni de Dondi about AD 1365.

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[9] Einhard and Notker the Stammerer, *Two Lives of Charlemagne,* trans. Lewis Thorpe, (Hammondsworth, 1979), 50-51. See also D. Hill, *Studies in Medieval Islamic Technology* (Ashgate-Variorum, 1998), art. V, 179.

In a Spanish work compiled for Alfonso X in 1277 AD, in which all the chapters are translations or paraphrases of earlier Arabic works; we find a description of a clock. It consisted of a large drum made of wood tightly assembled and sealed. The interior of the drum was divided into twelve compartments, with small holes between the compartments through which mercury flowed. Enough mercury was enclosed to fill just half the compartments. The drum was mounted on the same axle as a large wheel powered by a weight-drive wound around the wheel. Also on the axle was a pinion with six teeth that meshed with thirty-six oaken teeth on the rim of an astrolabe dial. The mercury drum and the pinion made a complete revolution in 4 hours and the astrolabe dial made a complete revolution in 24 hours. Clocks incorporating this principle are known to work satisfactorily, since many of them were made in Europe in the seventeenth and eighteenth centuries. This type of timepiece, however, with its effective mercury escapement, had been known in Islam since the fifth/eleventh century, at least 200 years before the first appearance of weight-driven clocks in the West.

An important aspect of Islamic fine technology is the tradition of geared astronomical instruments which were described in Arabic literature. The most notable example is the astronomical geared mechanism that was described by al-Biruni and called by him *Huqq al-Qamar* (Box of the Moon). From al Biruni's text we understand that these mechanisms were known in Islamic astronomy. A surviving example is the geared calendar dated 1221/2 AD that is part of the collection of the Museum of the History of Science at Oxford. Derek J. de Solla Price[10] when describing the Antikythera mechanism (90 AD) remarked that "It seems likely that the Antikythera tradition was part of a corpus of knowledge that has since been lost but was known to the Arabs. It was developed and transmitted by them to medieval Europe, where it became the foundation for the whole range of subsequent invention in the field of clockwork."

Many of the ideas that were to be embodied in the mechanical clock had been introduced centuries before its invention: complex gear trains, segmental gears in al-Muradi and al-Jazari; epicycle gears in al-Muradi, celestial and biological simulations in the automata-machines and water clocks of Hellenistic and Islamic engineers; weight-drives in Islamic mercury clocks and pumps, escapements in mercury docks, and other methods of controlling the speeds of water wheels. The heavy floats in water clocks may also be regarded as weights, with the constant-head system as the escapement.

The knowledge that Christians in Spain learned about Muslim water clocks was transferred to Europe and there was a substantial advance in the fifth/eleventh century in the techniques of hydraulic time-keeping. Water clocks in Europe became very elaborate with complications that were often a source of fascination and amusement. There are records of an early medieval water clock where figures of angels would appear every hour, bells would ring, horsemen would appear and a little man, known as a jack, would strike the hour bell with a hammer. This is reminiscent of one of al-Jazari's water clocks.

In a treatise written by Robertas Anglicus in 1271, it is mentioned that the clockmakers - i.e. the makers of water clocks - were trying to solve the problem of the mechanical escapement and had almost reached their objective. The first effective escapement appeared a few years later. This evidence, circumstantial though it is, points strongly to an Islamic influence upon the invention of the mechanical clock.

Feedback Control and Automata

[10] Derek de Solla Price, in his paper on the "Antikythera Mechanism", *Scientific American,* June 1959, 60-67.

Feedback control is an engineering discipline. As such, its progress is closely tied to the practical problems that needed to be solved during any phase of human history.

The Book of Ingenious Devices *(Kitab al-Hiyal)* of Banu Musa was written in Baghdad about 235/850. It contains descriptions of a hundred devices, most of which are trick vessels which exhibit a bewildering variety of effects. For example, a single outlet pipe in a vessel might pour out first wine, then water and finally a mixture of the two. The means by which these effects were obtained are of great significance for the history of engineering.

By the end of the tenth century, the construction of automata was probably a well-established practice in the Arabic world. There is historical evidence that the skills of automata makers were enlisted to add distinctive features to royal palaces.[11]

The early history of automata in Europe goes back to Arabic automata in Muslim Spain. We have mentioned how the technology of water clocks had been transferred to Western Europe. The elaborate automata of Islamic water clocks became a feature of European water clocks also.

The Banu Musa used conical valves as 'in-line' components in flow systems, the first known use of conical valves as automatic controllers. An almost constant head was maintained in a float chamber by feedback control.

Other Muslim engineers used the float regulator and the important feedback principle of on/off control in their water clocks and automata.

As mentioned above, water clocks spread in Europe for some time before they were replaced by mechanical clocks, and it follows that European engineer and technicians were acquainted also to the float regulators and the automata that accompanied them.

In the late 1700's, regulation of the level of a liquid was needed in two main areas: in the boiler of a steam engine and in domestic water distribution systems. Therefore float regulator devices once again become popular during the Industrial Revolution.

The important feedback principle of on/off control that was used by Muslim engineers came up again also in connection with minimum-time problems in the 1950s.[12]

Astronomical instruments

The astrolabe was the astronomical instrument par excellence of the Middle Ages; from its Hellenistic origins it was brought to perfection by Muslim scientists and craftsmen. A number of astronomical problems, which otherwise have to be solved by tedious computation, can be solved very quickly by using

[11] Some ingenious devices of the Banu Musa type could be seen until now in the Near East. They are exhibited by street magicians in Egypt, Palestine and Syria. The writer remembers that he witnessed several of these street magicians' shows in Palestine.
[12] F. L. Lewis, *Applied Optimal Control and Estimation* (Englewood Cliffs, N.J.: Prentice-Hall, 1992). Re-printed at the web site

the astrolabe. It has been established that the first European treatises on the astrolabe were of Arabic inspiration and were written in Latin at the beginning of the fifth/eleventh century in the abbey of Ripoll in Catalonia. From this centre the knowledge of the instrument was diffused to the rest of Europe.

Other computing instruments were devised in the Muslim world in the later Middle Ages, perhaps the most important of these being equatoria, which were invented in Muslim Spain early in the fifth/eleventh century. The objective of the equatorium was the determination of the longitude of any one of the planets at a given time. As with the astrolabe, knowledge of equatoria was diffused into Europe from the Muslim world.

Technology Transfer in the Chemical Industries Transmission of Practical Chemistry

Arabic works on alchemy and chemistry were translated into Latin in the twelfth, thirteenth and fourteenth centuries. The first treatise on alchemy was translated by Robert of Chester in 1144. It was the dialogue between Khalid ibn Yazid and Maryanus the Hermit. Since then several alchemical works for Jabir ibn Hayyan (Geber), al-Razi (Rhazes), Khalid ibn Yazid (Calid), Ibn Umail (Senior Zadith) and others were translated also. Thus the Latin West became acquainted with Arabic alchemy. This included the transmutation theories as well as the practical chemistry which involved the various chemical processes such as distillation, calcinations, assation, and a multitude of others. It involved also the laboratory equipment that was used to carry out the chemical processes such as the cucurbit, the alembic, the aludel, and the equipment needed for melting metals such as furnaces and crucibles. Knowledge of the various materials was included also such as the seven metals; the spirits of mercury, Sal ammoniac, and sulphur; the stones; the vitriols; the boraxes and the salts. Potassium nitrate was among the boraxes.

Nitric and Mineral Acids

During their extensive experimentation Islamic alchemists prepared mineral acids which they called sharp waters, among other names. They distilled the materials that produced nitric, sulphuric and hydrochloric acids.

It was established that the Arabic natrun and the Latin nitram denoted frequently potassium nitrate in Arabic and Latin alchemy and that there are Arabic texts using natrun in the preparation of nitric acid and aqua regia which date from before the thirteenth century.

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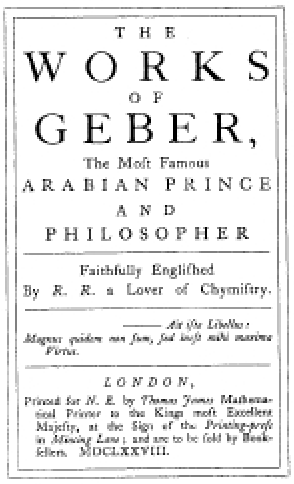

THE
WORKS
OF
GEBER,
The Most Famous
ARABIAN PRINCE
AND
PHILOSOPHER

Faithfully Englished
By R. R. a Lover of Chymistry.

——— *Ait ipse Libellus:*
Magnus quidem non sum, sed inest mihi maxima Virtus.

LONDON,
Printed for N. E. by *Thomas James* Mathematical Printer to the Kings most Excellent Majesty, at the Sign of the *Printing-press* in *Mincing Lane*; and are to be sold by Booksellers. MDCLXXVIII.

Figure 8. *Title page of the English translation of Jabir's (Geber) works in Latin. These works represent Arabic chemistry that was transferred to Europe from the 12th century. They appeared at the end of the 13th century. It was thought until recently that nitric acid was first described in one of these works. But recent research had revealed several other recipes for nitric acid in the Arabic works of Jabir, al-Razî, and others which preceded the 13th century. Source:* The Alchemical Works of Geber, *trans. Richard Russell (Maine: Samuel Weiser, 1994), xxv.*

One of these recipes describes the solution of sulphur with acids, and is given in *kitab al-mumarasa* (the book of practice) that forms book sixty-five of the *Book of Seventy* by Jabir ibn Hayyan (d. about 815). The ingredients in the recipe are: rice vinegar, yellow arsenic *(zarnikh asfar),* natrun, alkali salt, live *nura* (unslaked lime), eggshells, and purified Sal ammoniac. Distillation produces aqua regia that is strong enough to put the sulphur into solution. There is, in the *Sunduq al-Hikma* manuscript, a recipe attributed to al-Razi which reads as follows: "Take the water of eggs, [of] one hundred eggs, and one quarter of one *rail* from Sal ammoniac *(nushadir),* and two natrun, and Yamani alum *(shabb)* two *qaflas.* Bury this [mixture] in dung for seven days then take it out and distil it twice using the *qar'* (cucurbit) and ambiq. This distilled water is suitable for *zarnikh,* sulphur and mercury".

In an Arabic treatise, *Ta 'widh al-Hakim* we read a description of the preparation of aqua regia which is called *al-ma' al-ilahi* (the divine water) or *ma' al-hayat* (the water of life). The ingredients are natrun, alum, the viriol of Cyprus, and Sal ammoniac.

In the *Liber Luminis luminum,* that is attributed to al-Razi, and sometimes to Michael Scot we find a recipe for the preparation of nitric acid or aqua regia, that involves distilling a mixture of sal nitrum, Sal ammoniac and vitriol.

We find a recipe for nitric acid also in *De inventione Veritatis* which is a work in Latin ascribed to Jabir (Geber) that appeared at the end of the thirteenth century. Berthelot (end of nineteenth century) thought that this recipe for the preparation of nitric acid was the first of its kind. He went further to assume that Geber was not Jabir. This hypothesis of Berthelot is now baseless since there are in fact several Arabic recipes for nitric acid proceeding the thirteenth century as we have just mentioned.

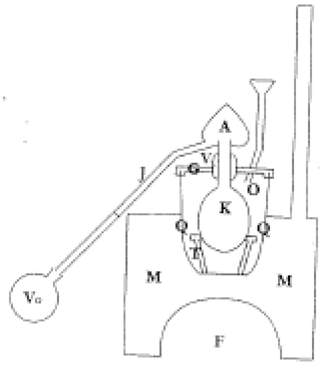

Figure 9. *Distillation in a water bath according to al-Kindî. Al-Kindî's book on the* Chemistry of Perfume and Distillations *describes, in the 9th century, a great number of methods to obtain perfumes and other distillates. It mentions the distillation of wine to produce an alcohol Distilled alcoholic drinks were known since the early centuries of Islam. Source:* STI, *Part II, 66, Fig. 4.6.*

Explosive Gunpowder and the First Cannon

The first use of explosive gunpowder and cannon is another critical issue in the history of civilization. Gunpowder was first known in China but the mixture used was weak and not explosive. The proportions of the ingredients were not the right ones for cannon and the purity of the nitrate was not adequate because of the lack of a purification process.

In the thirteenth century the military engineer Hasan al-Rammah (d. 695 AH/1295 AD) described in his book *al-furusiyya wa al-manasib al-harbiyya* (The Book of Military Horsemanship and Ingenious War Devices) the first process for the purification of potassium nitrate.

The process involves the lixiviation of the earths containing the nitrate in water, adding wood ashes and crystallization. Wood ashes are potassium carbonates which act on calcium nitrate which usually accompany potassium nitrate to produce potassium nitrate and calcium carbonate. The carbonates are not soluble and are precipitated.

Al-Rammah deals extensively in his book with explosive gunpowder and its uses. The estimated date of writing this book is between 1270 and 1280. The front page states that the book was written as "instructions by the eminent master Najm al-Din Hasan Al-Rammah, as handed down to him by his father and his forefathers, the masters in this art and by those contemporary elders and masters who befriended them, may God be pleased with them all". It is unmistakable from this statement that Al-Rammah compiled inherited knowledge. The large number of gunpowder recipes and the extensive types of weaponry using gunpowder indicate that this information cannot be the invention of a single person, and this supports the statement of the front piece in his book. If we go back only to his grandfather's generation, as the first of his forefathers, then we end up at the end of the twelfth century or the beginning of the thirteenth as the date when gunpowder became prevalent in Syria and Egypt.

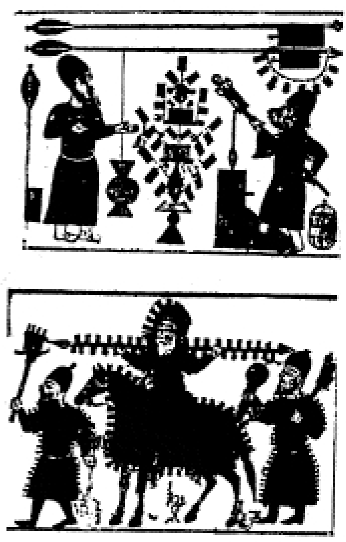

Figure 10. *Two illustrations from an Arabic military treatise (known as the Petersburg manuscript) showing the first use of explosive gunpowder and cannon. This early cannon was used to frighten the horses of the Mongols army during the Battle of 'Ayn Jalut in Palestine in 1260. The composition of gunpowder for the illustrated cannon was 74.1 % nitrate, 11.1 sulphur and 14.8 charcoal This is an explosive gunpowder which is very close to the best established composition. Al-Rammah's average composition for rockets in the 13th century gave 75% potassium nitrate which is identical with the best modern value for explosive gunpowder. Source;* STI, *Part II, 128, Fig. 422.*

The book contains 107 recipes for gunpowder. There are 22 recipes for rockets *(tayyarat,* sing, *tayyar).* Among the remaining compositions some are for military uses and some are for fireworks. The gunpowder composition of seventeen rockets was analyzed, and it was found that the median value for potassium nitrates is 75 percent.

The ideal composition for explosive gunpowder as reported by modern historians of gunpowder is 75 percent potassium nitrate, 10 percent sulphur, and 15 percent carbon. Al-Rammah's median composition is 75 nitrates, 9.06 sulphur and 15.94 carbon which is almost identical with the reported ideal recipe.

Analysis of the composition of explosive gunpowder in several other Arabic military treatises of the thirteenth and fourteenth centuries gave results similar to those of al-Rammah. These included the composition of gunpowder in the first cannon in history that was used, according to the military treatises, to frighten the Tatar armies in the battle of 'Ayn Jalut in 1260.

The correct formula for the explosive mixture was not known in China or Europe until much later. The Arabs in al-Andalus used cannon in their conflicts with the crusading armies in Spain and their first knowledge of the art was effective in their encounters. But ultimately the Muslim technology of gunpowder and cannon was transferred to Christian Spain and was used by them in the last encounters with the Muslims. From Christian Spain this technology reached Western Europe. We have mentioned above that the Earls of Derby and Salisbury who participated in the siege of al-Jazira (1240) took back with them the secrets of gunpowder and cannon to England.

Alcohol

The date of the first appearance of alcohol is another critical issue in the history of science. The distillation of wine and the properties of alcohol were known to Islamic chemists from the eighth century. The prohibition of wine in Islam did not mean that wine was not produced or consumed or that Arab alchemists did not subject it to their distillation processes. Some historians of chemistry and technology assumed that Arab chemists did not know the distillation of wine because these historians were not aware of the existence of Arabic texts to this effect.

The first reference to the flammable vapours at the mouths of bottles containing boiling wine and salt occurred in *Kitab ikhraj mafi al-quwwa ila al-fi'l* of Jabir ibn Hayyan (d. 200/815).

This flammable property of alcohol was utilized extensively after Jabir and we find various descriptions of the alcohol-wine bottles in Arabic books of secrets and military treatises.

Literary evidence from Arabic poetry and prose indicate that distilled wine was consumed in the Abbasid period in the second/eighth century.

Among the early chemists who mentioned the distillation of wine is al-Kindî (d. 260/873) in *Kitab al-Taraffuqfi al-'itr* (also known as *The Book of the Chemistry of Perfume and Distillations).* Al-Farabi (d c. 339/950) mentioned the addition of sulphur in the distillation of wine. Similarly Abu al-Qasim al-Zahrawi (d. 404/1013) mentioned the distillation of wine when he was describing the distillation of vinegar from white grapes. Ibn Badis (d. 453/1061) described how silver filings were pulverized in the presence of distilled wine to provide a means of writing with silver.

We find in the military treatises of the thirteenth and fourteenth century that alcohol from the distillation of old grape-wine became an ingredient in military fires.

In the fourteenth century alcohols were exported from the Arab lands of the Mediterranean to Europe. Pegolotti mentions alcohol and rosewater among the list of exported commodities (1310-1340).

By the fourteenth century knowledge of the distillation of wine was transferred to the East and West and the word *'araq* in its various forms became widely used outside the Islamic lands of the Near East. The word *arak* was used for example by the Mongols in the fourteenth century. Mongol *araki* is first mentioned in a Chinese text in 1330. The word spread to most lands of Asia and the eastern Mediterranean.

It is assumed in western literature that the earliest references in a Latin treatise to the distillation' of wine occurred in either in a text from Salerno around 1100 AD or in a cryptogram which was added by Adelard of Bath to the *Mappae Clavicula* (c. 1130). But the information given above indicates that knowledge about the distillation of wine preceded these dates and that both the recipe of Salerno and of Adelard of Bath were based on Arabic sources.

Most histories of distilled spirits inform us that the art of distillation of spirits is credited to the Arabs, especially the Arabs of al-Andalus. Wine was distilled in al-Andalus as we have seen above (see al-Zahrawi), and sherry[13] was produced in Jerez. The word sherry comes from Sharish, the Arabic name for Jerez.[14] The first to produce this were the Moors during their rule in southern Spain. We learn also from these histories that Armagnac was produced in the south of France some time before Cognac, and that it was probably produced by the Moors in the 12th century.

Perfumes and Rosewater

According to some historians of perfumes, the Arabs became for several centuries the perfumers of the world.[15] It is reported that among the many presents of Harun al-Rashid to Charlemagne were several types of perfumes. Forbes says that only with the coming of the golden age of Arab culture was a technique developed for the distillation of essential oils. By distilling their favourite flower, the rose, the Arabs succeeded in extracting from it a perfume that is still a favourite all over the world: rosewater. Rosewater came to Europe at the time of the Crusades.
Damascus was famous for its rosewater. We have detailed descriptions in the literature of rosewater distillation installations in Damascus. It was exported to several countries including Europe.

According to Arab geographers, rosewater was distilled also in Jur, and in other towns in Fars. The rosewater of Jur was the best quality and it was exported to all countries of the world including: the Rum (Byzantium), Rumia (Rome) and the lands of franja (France and Western Europe), India and China.

Soap

In Mesopotamia several detergents were known and used but soap as such was unknown. The classical world did not have better detergents, and bran, pumice-stone, natron, vegetable alkali and the like were used. Later on, Pliny described a soft kind of soap made by the Gauls but historians think that this was pomade made from un-saponified fat and alkali.

In medieval times the soaps that were made in northern Europe by the action of wood-ash lyes on animal fats and fish-oils were soft soaps of unpleasant odour. Personal cleansing by using hard soap was not a common practice in Europe.

Syria was renowned for its hard soap, which was pleasant to use for toilet purposes. Geographers of the tenth century reported that Nabulus in Palestine was prominent in its soap exports. Soap was manufactured in the other Mediterranean Arab-Islamic lands including Muslim Spain where olive oil was abundant. In 1200 AD Fez alone had in it 27 soap manufacturers. In the thirteenth century, varieties of hard soap were imported by Europe from the Arab lands of the Mediterranean and were shipped across the Alps to northern Europe via Italy. The technology of soap-making was transferred to Italy and south France during the Renaissance.

Paper

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[13] Sherry is a fortified wine. All sherry is fortified after fermentation with high-proof brandy, to about 16-18 percent alcohol, depending upon type, brandy used to fortify sherry contains about 80-95 percent alcohol by volume.
[14] Cesar Saldana, General Manager of the Regulatory Council for Sherry, November 2002, http://www.crushmarketing.ca/Images%20Sherry/Sherry%20Seminar%20book%2072dpi pdf

The introduction and spread of the paper-making industry in the Near East and western Muslim Mediterranean, and then Europe was one of the main technological achievements of Islamic civilization. It was a milestone in the history of mankind. The manufacture of paper facilitated the production of books on an unprecedented scale. Its diffusion and its replacement of parchment led to the evolution and success of printing, and with these two important achievements a true cultural revolution took place in human civilization.

Figure 11. *A woodcut of early paper-making in Europe. The technology of paper-making was transferred from Jativa in Muslim Spain to Fabriano in Italy in the 13th century and then to the rest of Europe. It took five centuries for paper-making to reach Europe after its first establishment in Samarqand and Baghdad. Source: Dard Hunter, Paper-making Through Eighteen Centuries (New York: William Edwin Rudge, 1930), 124, illustration no. 77.*

Paper-making from mulberry bark started in China and it is claimed that it was a state monopoly. Chinese prisoners of war at the battle of Talas River in 133/751 started this industry in Samarqand. Before the end of the century there were floating paper mills on the Tigris River, in Baghdad. Paper mills then spread to Syria, to Egypt, and then to North Africa. Finally the manufacture of paper reached Muslim Sicily and Spain. Jativa became famous for its paper mills. Paper-making technology was then transferred to Italy and then the rest of Europe. The first paper mill in Europe was established in Fabriano in Italy in 1276, more than five centuries after the start of this industry in Samarqand and Baghdad. It took more than a century later before the first German mill was established in Nuremberg in 1390.

The Muslims revolutionized the industry of paper-making. They introduced several important innovations and the basic steps of Islamic paper-making technology remained virtually the same until modem times, the main later change being the conversion of the very small scale industry into a mammoth one by using huge modern machinery and modern methods of production.

Sugar

[15] John Trueman, *The Romantic Story of Scent* (N.Y.: Doubleday, 1975), 83-84.

Sugar is a basic commodity that owes most of its development and spread to the Islamic civilization. It is thought that sugar-cane originated in eastern Asia from where it spread to India and then to Persia before Islam.

When Islam came to Persia in 642 AD sugar-cane was being grown and unrefined sugar was known. With the rise of the Arab-Muslim Empire sugar-cane spread into all the Islamic Mediterranean lands including Sicily and Spain and sugar production became a large scale industry.

Figure 12. *Sugar cane cultivation and sugar manufaring spread westward during the early centuries of Islam. It reached Muslim Spain and Sicily and was transferred afterwards to the New World. This illustration of sugar cane is from an Arabic manuscript on natural history. Source: STI, part II, 34, Figu. 4.2.*

Sugar refining was developed greatly and several qualities of sugar were produced* and exported. Sugar became a foodstuff as well as a medicinal material in all Muslim countries and then Europe.

Sugar was first known to western Europeans as a result of the Crusades in the 11^{th} century AD. Crusaders returning home talked of this 'new spice' and how pleasant it was. The first sugar was recorded in England in 1099. It became a luxury commodity in high demand. It is recorded, for instance, that sugar was available in London at 'two shillings a pound' in 1319 AD. This equates to about US $100 per kilogram at today's prices.

Pegolotti in his lists of goods imported into Italy between 1310 and 1340 wrote that these included powdered sugar of Alexandria, Cairo, Kerak, Syria and Cyprus. Also lump sugar, basket sugar, rock candy, rose sugar, and violet sugar from Cairo and Damascus. England was importing its sugar from Morocco as well. We may remember that the words sugar and candy are both of Arabic origin.

From Spain sugar-cane plantations were established in the 1400's in Madeira, the Canary Islands, and St. Thomas. The Islamic technology of sugar-cane processing and sugar refining were established there.

In 1493 Columbus carried sugar cane cuts from the Canaries to Santa Domingo, and by the mid-1500's its manufacture had spread over the greater part of tropical America.

Glass

As was the case with the transfer of science to the West, the art and techniques of glass-working were transferred also. As mentioned above the first phase of technology transfer took place in the fifth/eleventh century when Egyptian craftsmen founded two glass factories at Corinth in Greece. Here they introduced contemporary techniques of glass manufacture, but the factories were destroyed during the Norman conquest of Corinth in AD 1147 and the workers emigrated westwards to contribute to the revival of western glass-making.[16]

Technology transfer took place again after the Mongol conquest of the thirteenth century AD, which drove large numbers of Syrian glass-workers from Damascus and Aleppo to glass-making centres in the West.[17]
A third and a unique method of technology transfer, which reminds us of modern technology transfer, is a treaty which was drawn up in June 1277 AD between Bohemond VII, the titular prince of Antioch, and the Dodge of Venice. It was through this treaty that the secrets of Syrian glass-making were brought to Venice. Raw materials as well as Syrian Arab craftsmen were sent from Syria. The techniques of Islamic glass-making formed the foundations upon which Venice established its famous glass industry.[18]

Ceramics

The glazed and painted ceramics which are exhibited in world museums reveal the splendours of the glorious Islamic art of pottery. Egypt, Syria, Mesopotamia and Persia had a continuous history in this art before Islam, but under Islam a revival took place, and the art spread throughout the Islamic World reaching Muslim Spain and then the West.

As early as the twelfth century the superior artistic pottery of Islamic countries had already attracted the notice of Europeans as an article of luxury for the wealthy. It is reported that Arab potters were brought into Italy, France and Burgundy to introduce the practice of their art, while Italian potters certainly penetrated into the workshops of Muslim Spain and elsewhere and gathered new ideas.[19]

Valencian tin-glazed wares, a legacy of the Andalusian wares, were exported to Italy, with Majorcan trading ships and were called maiolica (majolica). The Italian potters extended the name to the tin-glazed pottery which they made in imitation to the Valencian and the Andalusian wares. Another example is the Sgraffito ware. This technique was derived from the Islamic East through the Byzantine medium. It attained artistic importance in Italy towards the end of the fifteenth century and was made in Bologna until the seventeenth.

[16] Singer et al., 328.
[17] R. W. Douglas and S. Frank, *A History of Glass-making* (Oxfordshire: G. T. Foulis & Co., Henley-on-Thames, 1972), 6.
[18] G. Sarton, *Introduction to the History of Science* (Baltimore, Williams & Wilkins), Vol. II, pt. II, 1040; see also Atiya, A. S., *Crusade Commerce & Culture* (Indiana University Press, 1962), 238-239.
[19] See T. Glick, *Islamic and Christian Spain in the Early Middle Ages* (New Jersey: Princeton University Press, 1979), especially 238-241.

Tin glazing was an important development. Tin oxide was added to lead to render the glaze opaque. This tin glaze was decorated in cobalt blue, green and sometimes also manganese brown or yellow. This type was found in Samarra, was produced also in Persia and it reached Spain and then Italy. The golden pottery of Granada was tin-enamelled earthenware painted in metallic colours derived from silver and copper.

Tanning

The major tanning operations have come down from the earliest times as a slow empirical development. The Islamic civilization inherited the skills of the Near East and during several centuries tanning technology flourished and Muslim craftsmen contributed in developing this art. From Islamic craftsmen the know-how of leather-making began to reach Europe. A great variety of leathers were first introduced to the West by the Arabs in Spain. Morocco and Cordova leathers became widely known throughout Europe for their fine quality and pleasing colours. Through this technology transfer the tanning industry was already established in Europe in the fifteenth century. However the basic tanning technology remained unchanged, and until the end of the nineteenth century the only notable change in leather production was the introduction of power-driven machinery. The first change in 2000 years in tanning technology was the use of chrome salt at the end of the nineteenth century.

Other Transferred Technologies

The author of this article hoped to be able to include the transfer of other important technologies, but there is an inevitable length limit to any paper. We did not discuss for example the textiles industries, nor did we have space to speak about dyes and inks. We did not include the metallurgy of metals, especially that of iron and steel. There is, as well, much information to include about building methods and the influence of Islamic architecture including the Mudejar one. Military technology, navigation, and artisan crafts did not have space for them also. It is hoped however that this paper will be considered as a starting point for more exhaustive and detailed surveys in future.

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