Science and Math from the Islamic Golden Age

The material in this package was developed by an interdisciplinary team of math, science and social studies teachers to support *1001 Inventions* (http://www.1001inventions.com/), a traveling exhibit on Islamic science, math, culture, and history at the New York Museum of Science in Queens, New York (http://www.nysci.org/). An excellent resource is Salim Al-Hassani, Elizabeth Woodcock, and Rabah Saoud, eds (2007). *1001 Inventions: Muslim Heritage in Our World, 2nd edition* (UK: FSTC). Contributors include Carmen Bernier-Rodriguez (medicine), Lauren Buchbauer (optics), Justine Dziura (water), Renée Lewis (mathematics), and Ashley Petraglia (circulatory system).

Michael Cook, in *A Brief History of the Human Race* (2003), tells much of the story of humanity from the perspective of the Islamic world and the regions it dominated. He even uses the Islamic scholar, Tabari (circa 900), to discuss the nature of history itself. Tabari argued, "no knowledge of the history of men of the past … is attainable … except through information and transmission provided by informants and transmitters . . . this knowledge cannot be elicited by reason or inferred by internal thought processes." The National Standards for World History argue that one of the most dramatic developments of the 700-year period (300 AD to 1000 AD) was the rise of Islam as both a new world religion and a civilized tradition encompassing an immense part of the Eastern Hemisphere. Commanding the central region of Afro-Eurasia, the Islamic empire of the Abbasid dynasty became, in the 8th through the 10th century period the principal intermediary for the exchange of goods, ideas, literacy, and technologies across the hemisphere. This enabled Islamic scholars to integrate the knowledge of Arab, Persian, Egyptian, and European traditions and produced major scientific accomplishments

Between approximately 700 AD and 1800 AD the Islamic religion was the unifying force that held together a vast empire that stretched from the Atlantic coast of Spain to the Philippines and Indonesia and into sub-Sahara Africa. Islamic religious belief spurred Islamic scientific study. In the Qur'an (88: 17-21), Muslims are instructed to look at the camel and asked, "how it was created? "; to look at the sky and ask, "how it was raised up?"; to look at the mountains and ask, "how they were embedded?"; and to look at the Earth and ask, "how it is spread out? " As a result, taking an interest in science was seen as an important part of religious worship.

Focusing on scientific and mathematical developments during the Islamic "golden age" introduces global history students to achievements made by non-western cultures, many of which later influenced events associated with Western societies. For example, pioneering work on gears, cranks, pistons, and pumps was incorporated hundreds of years later into machinery developed during the European-based industrial revolution including steam pumps, steam engines for boats and trains, and internal combustion engines used in automobiles. It also highlights the importance of basic research in fields that might not yield direct results of the scientific method and experimentation, public support of institutions for higher learning, and of a critical mass of scholars and researchers who can communicate and build off of the efforts of each other. One of the strengths of both Islamic science and Islamic civilization during then "golden age" was tolerance towards and respect for the contributions of ethnic and religious minorities. Some of the notable scientists of the Islamic "golden age" were Christians and Jews and many were Persians rather than Arabs. – Alan Singer

Moving Water

By Justine Dziura

Water is a vital resource needed by every civilization around the world to sustain life and irrigate crops. Rice must be kept submerged. In hot dry climates sugar cane must be watered every four to eight hours. The importance of handling water carefully was underscored in a passage from the Qur'an, "We made from water every living thing." Because the climate of North Africa and Southwest Asia is hot and dry, it is extremely hard to transport water without losing at least some of it through evaporation. As a result, Islamic societies during the golden age became expert's in raising and transporting water-using devices such as underground canals and waterwheels to supply a continuous flow of water to farms or towns.

The Islamic world inherited the idea of the underground canal (*qanat*) from Persia. However, the canals were dependent on gravity for power and could only flow from higher to lower elevations. Engineers such as Al Jazari (1136–1206) from southwestern Turkey and Taqi Al-Din (1525-1585) from Damascus developed more efficient ways to transport water in larger quantities.

Although credit is usually given to Leonardo da Vinci of Italy, Al Jazari was actually the first inventor to use hydraulics, gears and to study of the flow of fluids. He developed a suction pump that could draw water through a closed system, however the gear was probably Al Jazari's most important invention. Constructed out of mulberry wood, the gears made it possible to alter the direction of motion and to attach other machinery to waterwheels. Al Jazari also created the first crank, a device that eventually evolved into a crank-connecting-rod system. Since the industrial era, gears and cranks can be seen in engines, trains, cars and other mechanical devices.

Alhambra, a mountaintop Arab fortress in southern Spain has an elaborate water delivery system.

Using his different inventions, Al Jazari was able to design a series of intricate water raising machines. The water-driven *saqiya* was animal powered and used cranks and gears to raise water. The most significant of Al Jazari's water raising machines is the double-action suction pump. It was powered by a flowing river and worked automatically. Water was able to move in and out of pipes through specially designed valves.

Taqi Al-Din's six-cylinder water pump

Taqi Al-Din wrote a book on mechanical engineering called *The Sublime Methods of Spiritual Machines* with "How To" guides for constructing various water pumps including Al Jazari's six-cylinder water pump. In the six-cylinder water pump a waterwheel was connected to a long horizontal axle (also known as a camshaft). The camshaft was connected to six rods with lobes or cams that rotated at specific times and had the ability to lift connecting rods. These rods were each connected to a lead weight that pulled a piston upwards creating a vacuum effect that sucked water through a valve. Each cam had to rotate at a specific time so the pistons could open forming the vacuum effect. Without this synchronization, the device would not function. The principles behind the pumps and their designs contributed to the development on internal combustion engines.

The House of Wisdom by Jim Al-Khalili (NY: Penguin, 2011) is an excellent survey of Islamic, or what the author calls, Arabic scientific achievement during the "golden age." Al-Khalili is a nuclear physicist based in England. He focuses on the Abbasid Caliphate centered in Baghdad. Al-Khalili was instrumental in creating the BBC series *Science and Islam* (http://www.bbc.co.uk/programmes/b00gksx4).

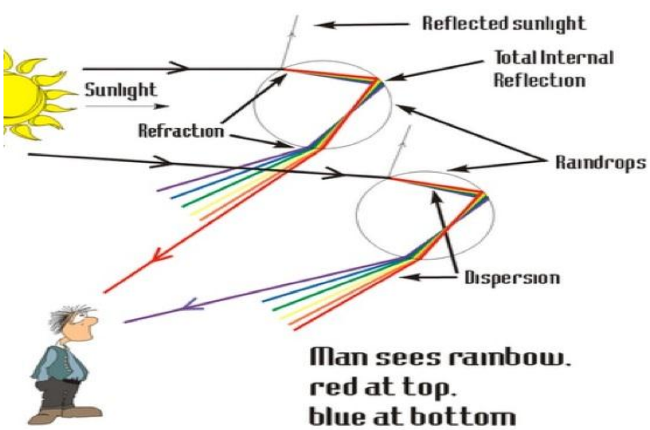
Exploring Optics

by Lauren Buchbauer

What are known as the Middle Ages in Western Europe were a golden age for scientific and mathematical discovery in the Islamic world. Giant leaps were made in the study of physics, particularly in its sub-field of optics. In Greco-Roman civilization, philosophers and scientists such as Aristotle and Galen thought vision was the result of particles entering our eyes. Gradually, however, educated people in Europe and the Mediterranean world adopted a Euclidian view that sight resulted from the movement of light rays from an observer's eyes to an object. These rays can be compared to laser beams shooting out of your eye and falling on an object, but not penetrating or damaging it. Both concepts were challenged by Islamic scientists during the Islamic "golden age."

In the 9th century, Ya qub ibn Ishaq al-Kindi from the Tigris-Euphrates region of southwest Asia became the first Islamic scientist to systematically challenge these two views. al-Kindi, a scholar in the service of the Abbasid Caliphs in Baghdad, translated ancient Greek texts into Arabic and began to reconsider their explanations for natural phenomenon. He believed vision is the result of radiation in the environment rather than particles entering the eye or rays emanating out of them. al-Kindi wrote two treatises on physiological and geometric optics that were widely used for centuries.

During the next century, al-Kindi's discoveries were elaborated on by Abu Saʿd al-Ala Ibn Sahl, a Persian scientist who published *On Burning Mirrors and Lenses*, a work that explained how mirrors and lenses can bend and focus light, and al-Hasan Ibn al-Haytham, who was the Islamic world's most noted physicist. Al-Haytham was the first person to *both* observe *and* scientifically prove that vision was made possible when light reflects off objects (refraction) and enters the eye. Al-Haytham carried out extensive experiments and is the earliest known physicist to check theories through experimentation.



Al-Haytham, who was originally from Basra in current day Iraq, later migrated to Egypt where he attempted to create a device to stop the Nile from flooding. While in Egypt, he studied lenses, experimented with mirrors, applied theories of refraction and reflection to the eye, and calculated the height of the Earth's atmosphere using atmospheric refraction of sunlight. Al-Haytham's most praised work, *Book of Optics*, discusses light, sight, eye structure, reflection and refraction of rays, and images in mirrors (Catoptrics). In this book, Al-Haytham lays the foundation for what later becomes known as Snell's Law or the law of refraction, which is a formula for describing the bending of light as it passes through a medium such as water or glass. Al-Haytham was also the first to discover and record both that white light consists of rays of every other color and that people actually "see" objects upside-down and that images are then transposed by the brain.

Al-Haytham came to this last conclusion while studying the Camera Obscura, or "dark chamber," with his student Kamal ad-Din. The Camera Obscura led to the development of the modern day camera. It consisted of a dark room with a small hole in the wall. There is a screen opposite the hole. When light was shone into the chamber and reflected off of objects, the rays projected an inverted image on the screen. Al-Haytham also refined the development of curved glass to correct vision, a process which was first invented by another Islamic physicist, Abbas Ibn Firnas from Cordoba, Spain.

Other Islamic physicists also contributed to the field of optics during the golden age. In the 11th century, Avicenna, a Persian, and Abu Rayhan al-Biruni, from Central Asia, deduced that light had a definite speed and that light is a collection of particles that are emitted by a source, discoveries that would not be proven for centuries. Their observations and studies also led them to the conclusion that the speed of light was much greater than the speed of sound. Another great Islamic physicist from the 11th century was Abu 'Abd Allah Muhammad Ibn Ma'udh who calculated the Sun's angle to the Earth during morning and evening twilights using the refraction of the Sun's rays. In the late 13th and early 14th centuries, physicists Qutb al-Din al-Shirazi and Kamal al-Din al-Farisi explained (both mathematically and conceptually) the phenomenon of the rainbow, Al-Farisi also made a complete revision of al-Hatham's *Book of Optics*, elaborating on his findings.

When optics is taught in a conventional western classroom, credit is rarely given to these pioneering Islamic scientists. However, these Islamic physicists laid a firm foundation of knowledge and experimental proof for further studies, which greatly contributed to the successes of scientists who were later to come.

Discovering Medicine

by Carmen Bernier-Rodriguez and Ashley Petraglia

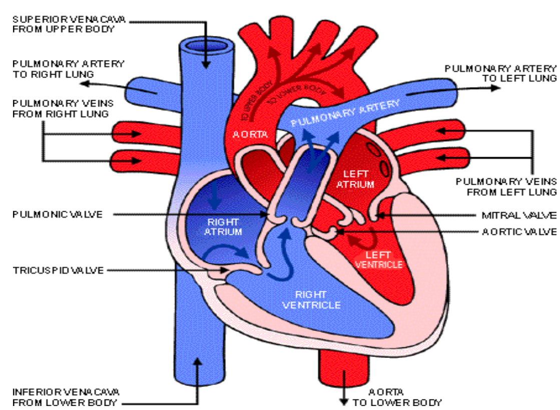
A number of scholars made contributions to medical understanding during the Islamic "Golden Age" (http://www.uab.edu/ reynolds/histfigs). Rhazes (860-930) of Persia, also known by his Arabic name Al-Razi, studied in Baghdad, Palestine, Egypt, and Spain. He also taught and directed hospitals in Persia, and Baghdad where he became court physician. His special area of study was pharmaceuticals or medicines. Among his achievements was a book, *Man la Yahduruhu*, on home medical remedies, a translation into Arabic of studies done by the Greco-Roman scientist Galen, *Al-Hawi*, an encyclopedia, later translated into Latin, where he compiled Islamic civilizations knowledge of medicine; and the first known treatise to describe small pox and chicken pox.

Another contributor to the medical field during the Islamic Golden Age was Avicenna (980-1037), also known by his Arabic name Ibn Sina. He was born in a region that is located in the far south of Russia, was court physician, vizier or advisor to several caliphs, and was the chief physician to the Baghdad hospital. Avicenna wrote over one hundred books. His best-known work is *The Canon of Medicine*, in which he collected knowledge gathered from many civilizations. The *Canon* consisted of five books: *General Medicine*, *Materia Medica*, *Diseases in particular part of the body*, d*iseases not specific to particular parts of the body*, and *Compound Remedies*. Avicenna's own area of specialization was the study of bone fractures.

Abu al-Qasim Khalaf ibn al-Abbas Al-Zahrawi (936–1013), also known as Albucassi, was born in Andalusia or Islamic Spain where he developed surgical procedures, including the use of catgut for internal stitching, and invented surgical instruments. His best-known work was *At- Tasrif*, a thirty-chapter treatise completed in year 1000. It was translated into Latin and was used as a medical reference work in Europe into the 16th century. *At-Tarif* included descriptions of procedures to use in dentistry and during childbirth and discussed the importance of the relationship between physician and patient. Abu Muhammad Abdallah Ibn Ahmad Ibn al-Baitar Dhiya al-Din al-Malaqi (1188-1248), also known as Ibn al-Baytar, was another Andalusian scientist. He specialized in botany wrote extensively about plants and their medical properties in his *Dictionary of Simple Remedies and Food*.

Islamic advances in medicine had an impact on the broader Mediterranean and European world because of the influence of translators and travels. In the 11th century, Constantine the African, a Tunisian scholar translated many Islamic studies from Arabic into Latin. Gerard of Cremona (1114–1187) was an Italian scholar who lived in Toledo, Spain where he translated Al-Zahrawi's *al- Tasrif*, from Arabic to Latin. Much later, Lady Mary Wortley Montagu (1689-1762), an English aristocrat and wife of the British ambassador to the Ottoman Turkish Empire introduced smallpox variolation, an early form of inoculation, from Turkey into England.

A major Islamic contribution to medical knowledge was early study of the human circulatory system by Ala-al-din abu Al-Hassan Ali ibn Abi-Hazm al-Qarshi al-Dimashqi (1213-1288), who was also known as Ibn al-Nafis. Ibn al-Nafis was born in Damascus, Syria, and educated there the Medical College Hospital, founded by Nur al-Din Zinki. In 1236 he relocated to Egypt and became both the chief of physicians at a hospital and the Sultan's personal physician. He is best known for his careful observation and description of the functioning of the various parts of the circulatory system especially the chambers of the heart.



For example, Ibn al-Nafis wrote: "The blood at the right chamber of the heart must arrive at the left chamber but there is no direct pathway between them. The thick septum of the heart is not perforated and does not have visible pores as some people thought or invisible pores as Galen [a Greco-Roman scientist] thought. The blood from the right chamber must flow through the vena arteriosa [pulmonary artery] to the lungs, spread through its substances, be mingled there with air, pass through the arteria venosa [pulmonary vein] to reach the left chamber of the heart and there form the vital spirit." One of his discoveries was that blood that reached the left ventricle had to pass through the lung where it was oxygenated.

Inventing Math

by Renée Lewis

Islamic mathematicians made major strides in algebra, geometry, and trigonometry as they used math to solve practical and religious problems and to describe the world around them. Mathematics was essential for astronomical calculations in navigation and cartography (map-making). It was also used in religious practice to predict the proper time for fasting and prayer. It also played a role in design, decorative art, measurement, trade, financial transactions, land division, and taxation. Mathematical exploration developed a logic of its own and contributed to philosophical speculation, such as why we cannot divide a number by zero and how knowledge can be deduced from an existing set of principles. In addition to their own discoveries, Islamic mathematicians played an important role as conduits for connecting discoveries made in different places. They adapted the Indian version of numerals into the modern numbers 1 to 9 that we use today.

Islamic contributions to mathematics probably began in the 9th century when Muhammad ibn Musa al-Khwarizmi (780-850), a Persian living in Baghdad, introduced the beginnings of what would become algebra. Al-Khwarizmi translated, used, and expanded on the work of Euclid, Archimedes, Apollonius of Perga, Ptolemy and Diophantus. In his algebraic system there was room for rational numbers (any number that can be written as a simple fraction), irrational numbers (numbers that cannot be written as simple fractions such as π which can only be rounded off to 3.14 or 22/7), and geometric magnitudes (e.g., length, area, or volume). Al-Khwarizmi also worked extensively with quadratic equations. He came up with a method now called "completing the square" that is still used today. The application of "zero" was the work of al-Khwarizmi and his contemporary al-Kindi (801–873) or Alkindus. Islamic mathematicians expanded on both the definition and application of zero, making it a mathematical property similar to other numbers. This made it possible for zero, which had previously been regarded as just a lack of something, to be a property that could be multiplied and used in decimalization. Al-Khwarizmi's successor, al-Karaji (953-1029), continued his work and was the first to separate algebra from geometry, define monomials, derive rules for multiplying them, and use the arithmetical operations we are familiar with today. He also discovered the binomial theorem, a key component in numerical analysis based on the decimal system.

Islamic mathematicians vigorously studied astronomy to determine the exact times for ritual prayers. They used circles and chords to measure angles and developed spherical trigonometry. Through the study of astronomy and the use of spherical trigonometry, Islamic scientists and scholars such as al-Battani, al-Biruni, Abu al-wafa, Ibn Yunus, and al-Kashi laid the foundation for the development of the primary trigonometric functions sine, cosine, and tangent.

Mosaic designs at the Alhambra in Grenada, Spain

Islamic mathematicians used geometry to solve practical problems such as designing lens and mirrors for focusing light and constructing sundials. A pioneering Islamic geometrician was Abu Sahl al-Kuhi (940-1000) who focused his attentions on Archimedes' work and found that it was possible to construct spheres using conic sections and create heptagons (shapes with seven sides and seven angles). Ibrahim ibn Sinan (908-946) is well known for continuing work on Archimedes' investigations of areas and volumes, as well as on tangents of a circle. However, he is probably most recognized for his work on conic sections and parabolas. Geometry also inspired Muslim artists, architects and calligraphers who used the patterns in nature and mathematics, such as tessellations (a pattern with no overlaps and no gaps), in their work. Tessellations in nature include patterns in snakeskin, armadillo armor, and beehives.