

Science made great, even revolutionary, strides in medieval Islam and Muslims and Arabic-writing non-Muslims (largely Christians, Jews, and Syriac-speaking Harranian star-worshippers who were thoroughly Hellenized by the time Islam emerged in history) share credit for the remarkable achievements in this field.

#### **A. Characteristic Features: An Analytical Survey**

One characteristic feature of Islam's scientific achievements is what may be called its double dialectic: on the one hand, the interplay, dialogue, and substantive exchange among different scientific streams that flowed into Islam from other cultures; and, on the other, cross-currents and cross-fertilizations between science and other Arabic disciplines, or between different scientific disciplines themselves, or within various ramifications and aspects of a single scientific field internally. So we see, for example, a problem arising in Greek astronomy being resolved by Indian astronomical methods; or, again, breaking open of a moribund mathematical legacy of the Greeks such as the study of triangles and giving it an independent and free existence by the application of aspects of Hindu mathematics after developing the latter in highly original ways. Indeed, Islam took over not only both the Alexandrian and Athenian Greek scientific legacies, which loom very large in complex ways in Arabic, dominant especially after the ninth-century, but it directly naturalized into its own cultural matrix a host of other scientific traditions too, in particular Persian, Harranian, Byzantine, and of course Indian traditions, cultivating at the same time Near Eastern Hellenism and Hermeticism, and espousing also some other attitudes and products of the Old World.

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Medicine constitutes one clear case here. Thus one notes that the dominant, court-sponsored, elite-patronized, mainstream Aristotelian-Galenic system of the Islamic world was itself a synthesis of many different elements. In general physiology and pathology, Galen had espoused the famous Hippocratic doctrine of the four humors, but his anatomy had come from the Alexandrian medical tradition; then, he had taken over the pharmacology of Dioscorides; and, finally, his physiology drew heavily upon Platonic, Stoic, and Aristotelian conceptions—all of this, along with other Greek ideas, was picked up by the Islamic world. But, then, this package was further mixed in Islam with Syrian, Persian, and Indian ideas, bringing with them some Hermetic tendencies and additional pharmacological data. The story is in fact even more complicated by the historical situation that in parallel with the Aristotelian-Galenic medicine other medical traditions also existed in Islamic society—particularly the one called Prophetic Medicine, based on naturalistic Qur'anic declarations and Prophetic Traditions (*Hadith*) concerning healing of the sick and reversing magical spells. A time comes in the Islamic Middle Ages when these two currents begin to ride on each other, replacing the Hellenized philosopher-physician by the Islamic legist-physician, with non-trivial consequences for both the theory and practice of scientific medicine.

But the other horn of the double dialectic shows us more: so in the case of mathematics, for example, one finds for the first time in history vigorous applications of one mathematical discipline to another. But more generally, there is to be seen an unprecedented, complex *pattern* of substantive movements not only between science and other indigenous or naturalized fields of rational inquiry, but also between science and material culture. What has been called a 'double movement' between metaphysics and mathematics constitutes an instructive example here. Thus we find the famous Muslim theologian-astronomer Naṣīr al-Dīn al-Ṭūsī (d. 1274)—whose momentous mathematical device, the 'Tusi Couple', made an appearance as an integral element in none other than the system of Copernicus—borrowing combinatorial rules from algebraists for the articulation of an ontological doctrine of the emanation of multiplicity from the One that he found in the Aristotelian-Neoplatonic speculations of the 'Grand Master' (*al-Shaykh al-Ra'īs*) Ibn Sīnā (Latin Avicenna, d. 1037). What is fascinating, by a process of 'back-formation', this borrowing turned out to be of major benefit to the benefactor since it gave birth to the mathematical discipline called combinatorial analysis, a discipline fully exploited by Ṭūsī's mathematical successors who soon developed it into an autonomous discipline.

There exist many other examples in the same vein—the application of mathematics to physics, an operation never conceived heretofore, is one; the invention of a discipline able to express its results by positional geometry, a

discipline we call topology, is another; and the discovery of what is now referred to as retro-azimuthal map projections, many centuries before it is found in the West, a discovery resulting from the Muslim enterprise to find the direction of Makka from all locations of the world, is yet another. And then, manipulation of geometry, including the exploitation of complex geometric transformations, to generate intricate design patterns in architectural decoration constitutes both an eminent and unique example of interdisciplinary movements in Islamic culture involving the visual arts.

Another defining feature of Islam's scientific achievements is their sheer range, scope, scale, and endurance—none of this had acquired such massive magnitude in world history before. Continuing with the example of the field mathematics, one would observe some 700 years of uninterrupted flourishing of a whole multiplicity of disciplines: algebra, algebraic geometry, theory of parallels, Diophantine analysis, numerology, computational techniques, methods of projection, geometric transformations, cartography, mathematical geography, and so on. It is in this environment of a mathematical *tradition* and *thrust*, rather than isolated pursuits of certain talented individuals, that al-Khayyāmī ('Umar Khayyām, d. 1122), employed by the Seljuks for a solar-calendar reform, managed to discover the binomial expansion, discovering also the modern generalized solution of cubic equations by applying higher geometry to algebra—'algebra', the term deriving from the Arabic *al-jabr*, having been conceptually differentiated already in the ninth century by al-Khwārizmī (the name enduring as our common noun 'algorism'/'algorithm') as an independent, self-sustaining new discipline of mathematical operations. It is this very tradition and thrust that provides the historical context for the work of the redoubtable Ibn al-Haytham (Latin Alhacen, d. ca. 1040) on the foundations of Euclidean geometry, leading him in the process to prove theorems in non-Euclidean geometry, including a formulation of what is today called the Strong Hilbert Axiom of Parallels. And it is this very environment of large-scale feverish mathematical research that explains the appearance of decimal fractions in Arabic writings some six centuries before one finds them in the Latin West.

In terms of range, whether it is alchemy or proto-chemistry; anatomy, clinical medicine, pharmacology, or surgery; mathematics, astronomy, cosmology, or cartography; mechanics, impetus theory or optics—there is an impressive record of Islam throughout the entire domain of scientific activity known in the Middle Ages. And as for endurance, it was in the early ninth century that a massive translation movement began, integrating practically the entire Greek scientific legacy into the Arabo-Islamic milieu, lasting for over 150 years, and following a phase of Arabic translations of Pahlavi and Sanskrit texts that were made in the very early days of the emergence of Islamic civilization; Ibn Sīnā

writes his celebrated medical work, the *Canon (al-Qānūn)*, and the grand philosophical treatise, the *Healing (al-Shifāʾ)*, in the tenth to eleventh centuries; in the same period Ibn al-Haytham produces his monumental work on optics, *De Aspectibus (Kitāb al-Manāẓir)*, creatively integrating the disparate metaphysical, mathematical, and physical approaches found in the classical theory of vision, and thereby marking a major scientific event that forever changes the nature of this entire classical field with ramifications even beyond science.

Then, it was in the thirteenth century after sacking the Abbasid capital Baghdad that the Mongols found the historic Maragha observatory where al-Ṭūsī works in an already centuries-old Islamic tradition intensely critical of Greek astronomy and discovers the ‘Couple’ named after him, proving his theorem that circular motion can generate linear motion and vice-versa. The astronomer al-ʿUrḍī, whose Lemma forms another element of the mathematical foundations of Copernicus’ astronomy, was part of al-Ṭūsī’s team at this time; it is in the same century that the legist-physician Ibn Nafīs discovers the pulmonary circulation of blood; and then, it is as late as the fourteenth century that in an uninterrupted scientific drift critical of Greek astronomy, a Damascene mosque employee Ibn Shāṭir, responsible for the determination of prayer times, develops his models of the motion of the moon and mercury that are also incorporated verbatim by Copernicus in his own planetary scheme. The fifteenth century is not scientifically hollow either: for example, one finds a host of intricate design patterns in Islamic architecture of the period that exhibit surprisingly advanced decagonal quasicrystal geometry—a concept discovered by Western mathematicians and physicists only in the 1970s and 1980s. This endurance is no minor historical fact, as these highlights show.

It seems quite legitimate to say that it was medieval Islam that ushered in the modern phase of this rational enterprise we call science. It is here that it took on truly international humanistic character to become a defining cultural impulse of the Islamic milieu—an impulse sustained and nourished by numerous religious, ethnic, sectarian, linguistic, and doctrinal communities, with Arabic fully developed as their common scientific language. In the narrative of world culture, one important episode is the rise of scientific institutions, and this too came to the modern world as part of the legacy of Islam. What the Latin West took from the Islamic civilization was not just scientific texts, but also institutional structures, administrative know-how, and instruments and equipment of the hospital and the observatory. The former is known for its comprehensive range of services, containing within its premises surgical theaters, lecture halls, libraries, and rehabilitation centers; the latter for its advanced instruments and international scientific collaboration. This humanistic institutional dimension of science in Islam deserves to be held in our historical consciousness as one of its fundamental characteristics which is a defin-

ing attribute of modernity.

## B. Local Specificities

What are the local specificities of science in Islam? To answer this question, three historical contingencies need to be kept in view. One is the fact that, as against the case with the Latin West, there existed a continuity here with the classical tradition: there were Hellenized academies and monastic schools in the Islamic territories that survived well into the early Caliphate period; then, at the same time, many communities steeped in the Greek intellectual tradition lived in these territories—the Harranians, Near Eastern Nestorian Christians, and Persians trained at the famous Sassanid academy of Jundishapur were particularly prominent among them. This continuity explains the characteristic maturity, sophistication, and confidence that are found in the Arabic scientific works from the earliest times, works that overlap, or even precede, the grand Graeco-Arabic translation movement. Second, this translation movement seems to have been initiated by another historical accident—namely, the imperial ambitions of the Abbasid Caliphs who had a political stake in the promotion of science to emulate the Sassanid glory. Even though Islam’s colossal Greek into Arabic translation enterprise—unprecedented in world history in terms of magnitude, durability, social support, and concern—came to pass in a specific milieu, historians have claimed its consequences to be equal in significance to the Scientific Revolution of the sixteenth and seventeenth centuries.

The third contingency that explains local specificities of science is the peculiar intersection of six different institutions that served as cradles of intellectual activity in the Islamic Middle Ages: 1) Royal bureaus and 2) libraries such as the well-known House of Wisdom (*Bayt al-Hikma*) of the early Abbasids, and the House of Knowledge (*Dār al-‘Ilm*) of the Fatimids, as well as the numerous private libraries which grew rapidly from the ninth century onward partly due to the proliferation of manuscripts now copied on locally-manufactured paper; 3) hospitals, which also performed teaching, training, and clinical research functions; 4) mosques, particularly in the later medieval period when fully institutionalized in them was the office of the “time-keeper” (*muwāqqit*), a mathematician-astronomer-jurist responsible for the determination of the ritual prayer times; 5) observatories, especially the post-Mongolian ones; and, finally, 6) the madrasas—autonomous endowed colleges that were established by the Seljuk vizier Nizām al-Mulk in the eleventh century, ostensibly for teaching religious law. The intersection of these six institutions has also been identified in terms of three attitudes—Arabism, Hellenism, and Islamism. Science in Islam arose from the bosom of this intersection.

### C. Some Outstanding Historical Questions

For a long time it has been said that science was a marginal activity in Islamic culture. But the picture that emerges out of serious historical research is otherwise; this should be evident already. Just the recognition of the Graeco-Arabic translation movement's huge social and temporal proportions alone would serve as a corrective. Calling it an astounding achievement, a historian pointed out not so long ago that the entire Abbasid elite—soldiers and rulers, merchants and scholars, civil servants and scientists, caliphs and princes—had actively supported it with funds and blessings, with patronage cutting across all lines of religious, sectarian, ethnic, tribal and linguistic demarcation, and including Arabs and non-Arabs, Muslims and non-Muslims, Sunnis and Shiites. Resulting from a deliberate and conscious choice of the milieu, this event cannot possibly be called marginal. The body of evidence to the contrary is simply overwhelming.

Genuine historical research should correct another falsehood that is still prevalent in many educated circles—that the scientific culture of Islam was more or less a passive imitation of the Greek legacy, that science began in Islam only after Greek texts were faithfully translated into Arabic and subsequently assimilated. Then, promoted by some broad-minded Muslim rulers, a number of gifted individuals—really Arabic-writing Hellenes—made some good scientific advances. And, finally, this somewhat enlarged Greek legacy was transmitted to the Latin West. Though ideologically satisfying, this narrative is historically false. To begin with, the translation activity was itself a highly creative act: to take just one example, when Qusta ibn Lūqa (d. 912) translated Diophantus' *Arithmetica* as the *Art of Algebra*, he recast the Greek text's mathematical operations in terms of al-Khwārizmī's new discipline; this was a major *conceptual* shift that would not have been recognized by the Greeks, nor do we have any *lexical* justification for the translation the Greek word in that way. The point is that the Graeco-Arabic transmission process was a highly complex one, involving re-conceptualizations, re-mappings, and integration with concepts and materials drawn from non-Greek sources, and therefore one cannot in general recover a Greek text by means of a reverse translation. To reconstruct a Greek source from an Arabic text, one must move beyond the text and enter into the specific cultural and intellectual setting in which it was created.

The neat chronological and logical order—Graeco-Arabic translation, then assimilation, then scientific activity—also breaks down upon historical investigation. There is much evidence to show that the translation activity was in its inception a result, not a cause, of the intellectual ferment that had gripped the early Abbasid society. Despite their own imperial agendas, royal patrons were only able to promote this activity because there was a pre-exist-

ing intellectual and social need for it; here one must not overlook the fact that concurrent or prior work in the Islamic religious sciences had played a crucial role in creating this need. But already exposed, too, is the untenability of crediting Islam's scientific achievements atomistically to a handful of Hellenized (and marginalized) individuals. No doubt, the theoretical content of Islamic science was largely a Greek import; however, this import was not a finished product, but a work-in-progress, inevitably interacting with indigenous Islamic traditions and achievements, to produce mature Islamic science.

One hardened myth still circulating is that science in Islam was brought to a halt in the early twelfth century by the famous Muslim thinker al-Ghazālī, the supreme spokesman of 'Islamic orthodoxy', the 'theologian' who dismissed the principle of natural causation and bitterly censured the philosophers for being incoherent. Despite flying in the face of massive contrary evidence, this ready-made myth has stuck since it fits nicely into certain ideological moulds. A quick historical response is that science made some of its highest achievements in the Islamic world in the post-Ghazali period. That there is no orthodoxy in Islam in the sense of orthodoxy in the Christian tradition has been pointed out over and over again: here one finds no centralized institutional authority analogous to, say, the Catholic Church; no ordained clergy; no institutionalized religious orders; no synods; no 'official' pontifical truth a deviation from which would be a theological transgression called heresy. That what is called 'Islamic theology' is a rather misleading translation of *'ilm al-Kalām* (literally, 'Science of Discourse/Speech'), and that it is a rational and not an anti-rational discipline, providing a viable alternative to Greek philosophy, must be understood. That many madrasa-trained 'theologians' made outstanding contributions to science is a historical truth which ought to be recognized. And that madrasas did include rational sciences in their curricula should now be admitted as an established fact.

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