JOHN FREELY

LIGHT FROM THE EAST

How the Science of Medieval Islam Helped to Shape the Western World

I.B.TAURIS

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To Emin Saatçi, Memo and Anne Marie Sağıroğlu

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I.B. TAURIS
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PROLOGUE

The Scriptorium at the Süleymaniye

The Süleymaniye mosque in Istanbul, built by the architect Sinan for Sultan Süleyman the Magnificent in the years 1550–56, is the most splendid of the Islamic monuments that adorn the former capital of the Ottoman Empire. The mosque is the centre of a vast complex of pious foundation that also includes half-a-dozen madrasas (Arabic), a hospital, an insane asylum, a refectory, a caravansarai, a primary school, a public bath, a market, and the tombs of Süleyman and his wife Roxelana. The Ottoman Turks reached their peak under Süleyman, who ruled from 1520 until 1566, his realm extending from the Danube to the Nile and from the western Mediterranean through the Middle East. Their sultanate endured until 1923, the last of the great Muslim empires that emerged with the rise of Islam in the seventh century.

Many of the institutions of the Süleymaniye complex have been restored, though only the public bath still serves its original function. The hospital is now a maternity clinic, the primary school houses a children's library, the refectory has been converted into a restaurant specialising in Ottoman cuisine, and one of the madrasas is a library, whose scriptorium contains several thousand manuscripts, many of them works of medieval Islamic science.

Some years ago I spent a day at the scriptorium of the Süleymaniye examining medieval manuscripts of Islamic science with the curator, Muammer Bey. I looked at Arabic translations of ancient Greek classics in science and philosophy, including works of Aristotle, Archimedes, Euclid, Galen and Ptolemy, along with Islamic treatises in philosophy, physics, mathematics, astronomy, medicine, geography, astrology and alchemy, many of them illustrated with beautiful miniatures. Most of the texts dated from the ninth century to the twelfth, the golden age of Islamic science.

When Europe was shrouded in the relative darkness of the Middle Ages following the end of Graeco-Roman civilisation, Arabic astronomers were observing the heavens from observatories in Samarkand, Baghdad, Damascus, Cairo, Marrakech and Cordoba, where Islamic physicians, philosophers, physicists, mathematicians, geographers and alchemists were pursuing their researches, preserving and extending the knowledge that they had obtained principally from the ancient Greeks, with some contributions from ancient Mesopotamia, Sasanian Persia, India and China. It was through these men of science and learning that knowledge gained in the Islamic world passed to Europe, beginning as far back as the ninth and tenth centuries. Translations from Arabic to Latin inspired the developments that led to the scientific revolution of the sixteenth and seventeenth centuries, with the theories and discoveries of Copernicus, Kepler, Galileo and Newton. Islamic scholars continued to do original work up to the middle of the sixteenth century, particularly in astronomy, creating geometric models that fit the observed phenomena of planetary behaviour better than those designed by Ptolemy and which in turn influenced Copernicus. They continued to debate the great question of whether the earth moved, propose new and revolutionary ideas, create new calculations and design groundbreaking mathematical and astrological models well into the sixteenth century and perhaps even into the seventeenth century in some places. From the fifteenth century, migrants, diplomats, scholars, merchants, missionaries and adventurers from eastern, southern and western Europe flocked to the Ottoman Empire. Some of them brought with them knowledge of Galileo, Descartes and Newton and in turn absorbed Islamic knowledge of mathematics and astrology.

But by the seventeenth century Europe had forgotten its debt to Islam, for although Newton, in saying that he had seen farther than his predecessors 'by standing on the shoulders of Giants', gives credit to earlier European and ancient Greek thinkers, he makes no mention of the medieval Arabic scholars from whom Europe had first learned about science.

Many modern historians of science are beginning to establish the important role that Arabic scientists and philosophers played in the European renaissance and the subsequent scientific revolution. But most of their writings are scholarly works that cover only certain areas of the subject, particularly mathematical astronomy, and none of them has written a comprehensive history of Islamic science for the general reader. This was what prompted me to write *Light from the East*.

The book focuses in turn on several questions. First, what were the factors that led the people of the Islamic world to absorb science and philosophy from the Greeks and other earlier civilisations, including Mesopotamia, Persia, India and China? Aside from preserving the science that they acquired, did the scientists and scholars of the Islamic world make any original contributions? What were the factors in these Islamic societies that led to the eventual decline in Arabic science in most areas and why did certain disciplines such as philosophy, arithmetic and astrology continue to flourish long after the others had become moribund?

The book is also a cultural travelogue that takes the reader in turn from ancient Mesopotamia and Egypt to classical Athens and Hellenistic Alexandria, 'Abbasid Baghdad, Ayyubid Cairo and Damascus, Almoravid Marrakech and Cordoba, Ilkhanid Persia, Timurid Samarkand.

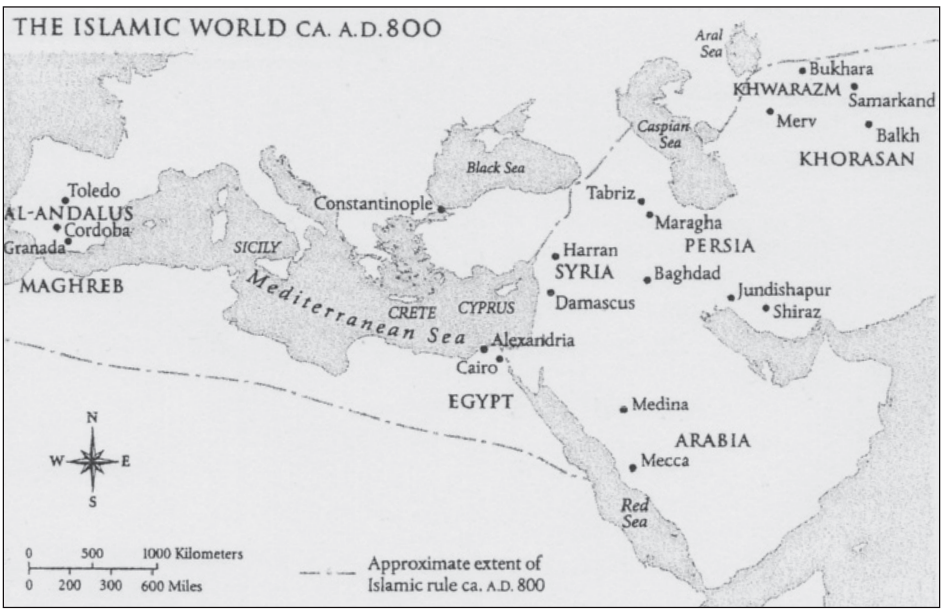
The scope of Islamic science was immense, as one can see from a genre of Arabic works in popular science dealing with the infinite marvels of divine creation. This immensely broad definition of scientific knowledge is evident in the works of the most renowned Islamic scholars, polymaths who wrote on many different areas within and beyond the traditional bounds of science, including the occult pseudo-sciences of alchemy, astrology, number mysticism and magic.

The very names Islamic and Arabic as associated with the word 'science' require some discussion. The science that emerged and flourished in the medieval Islamic world was looked upon as 'foreign' by Muslim scholars, since it had largely been imported from the Greeks, in contrast to branches of learning such as the study of the Qu'ran, the traditions of the Prophet, Sharia law, orthodox theology, Persian poetry and the Arabic language. Most of the scientists in the Islamic world were Muslims, but there were a number of Christians and Jews and even a few who adhered to a form of an ancient Mesopotamian astral religion. Most of them wrote in Arabic, but a survey of extant Islamic scientific manuscripts by Boris A. Rozenfeld and Ekmeleddin Ihsanoğlu records works in Persian, Syriac, Sanskrit translated into Persian, Tajik, Turkik Urdu, Tatar, Uzbek and other Asiatic languages. But whatever their religion, ethnic origin or language, they were part of the Islamic world, just as western scholars of the late medieval era belonged to the Latin Christian world, while those of the Byzantine Empire, with its capital in Constantinople, were largely Greek-speaking Orthodox Christians who still retained a link with ancient Graeco-Roman culture.

The survey by Rozenfeld and Ihsanoğlu records the extant manuscripts of 1,711 works of scientists from the Islamic world, along with 1,376 works whose authors are unknown. The subject headings under which the works are classified include mathematics, astronomy, mechanics, physics, music, mathematical geography, descriptive geography, chemistry and alchemy, mineralogy, meteorology, zoology, botany and philosophy, not to mention astrology, magic and the many forms of divination. Only a very small number of these works have been studied and published in modern translations, but the survey by Rozenfeld and Ihsanoğlu gives a brief summary in English of the contents of each one of the manuscripts.

These works are preserved in the libraries of cities in fifty countries, including sixteen in Istanbul alone, the most important collection being that of the scriptorium of the Süleymaniye, where I first became aware of the rich heritage of Islamic science.

This, then, is a story of how science emerged and developed in the Islamic world, and of how elements of this knowledge were transmitted to Europe at the dawn of the Renaissance, changing the world forever.


THE ISLAMIC WORLD CA. A.D.800
Aral Sea
Bukhara
KHWARAZM
Samarkand
Merv
Caspian Sea
Balkh
KHORASAN
Black Sea
Toledo
AL-ANDALUS
Cordoba
Granada
Constantinople
Tabriz
Maragha
PERSIA
SICILY
Harran
SYRIA
Baghdad
MAGHREB
Mediterranean Sea
Jundishapur
Shiraz
CRETE
CYPRUS
Damascus
Alexandria
Cairo
EGYPT
Medina
ARABIA
Mecca
N
W
E
S
Red Sea
0 500 1000 Kilometers
0 200 300 600 Miles
Approximate extent of Islamic rule ca. A.D. 800

CHAPTER 1

Science Before Science: Mesopotamia and Egypt

The Greeks of the classical era believed that they had acquired their knowledge of astronomy from Mesopotamia and Egypt. Herodotus credits the Babylonians with inventing the gnomon, the shadow-marker of the sundial, which the Greeks used in determining the hours of the day and the seasons of the year. He writes that ‘knowledge of the sundial and the gnomon and the twelve divisions of the day came into Greece from Babylon.’ According to Herodotus, ‘The Egyptians by their study of astronomy discovered the solar year and were the first to divide it into twelve parts – and in my opinion their method of calculation is better than the Greek.’

Herodotus also attributed to the Egyptians ‘The invention of geometry, which the Greeks brought back to their own country.’ The idea was that the Egyptians first developed geometry so that they could redivide their land after the Nile valley was inundated by the annual flood. They also would have needed an advanced knowledge of geometry in the design of huge monuments like the pyramids, which so impressed the Greeks when they first saw them after establishing their trading colonies on the Nile delta.

Although Herodotus credits the Egyptians with the invention of geometry, their geometrical knowledge was for the most part restricted to computing the areas of triangles, rectangles, trapezoids, and circles, for which they used the relatively accurate value of 3.16 for π, and for finding elementary volumes, such as that of a truncated pyramid. But, as Otto Neugebauer remarks in his discussion of Egyptian mathematics, abstract geometry, ‘in the modern sense of this word, owes very little to the modest amount of basic geometrical knowledge which was needed to satisfy practical ends'. Neugebauer also remarks that: 'Egyptian astronomy had much less influence on the outside world for the very simple reason that it remained throughout its history on an extremely crude level which had practically no relations to the rapidly growing mathematical astronomy of the Hellenistic age.'

The one area in which the Egyptians influenced Greek astronomy was in the use of their calendar, as Herodotus pointed out. The Egyptian civil calendar was a completely practical one, consisting of 12 months of 30 days each, unrelated to the phases of the moon, with five additional days at the end of each year. Neugebauer remarks that 'the Egyptian calendar became the standard astronomical system of reference which was kept alive through the Middle Ages and was still used by Copernicus in his lunar and planetary tables.' He goes on to say that the Egyptian calendar was revived in Persia by King Yazdigerd, just before the Sasanian dynasty fell to the forces of Islam; nevertheless the so-called 'Persian' years of the Yazdigerd era, beginning 632 AD, 'survived and are often referred to in Islamic and Byzantine astronomical treatises'.

The Egyptians originally began their year with the so-called heliacal rising of the star Sothis (Sirius), that is when it rose shortly before the sun, after an interval of about seventy days when it was invisible because of its closeness to the sun when observed from the earth. This had special significance because the heliacal rising of Sothis occurred around the time of the annual flood that inundated the Nile valley. The Egyptian calendar year of 365 days had a systematic error since the time between summer solstices, as measured by the Babylonians, is about 365.25 days. This error amounted to about a day in four years, a month in approximately 120 years, and a whole year in 1,456 years, a period called the Sothic cycle. It was noted in 139 AD that the beginning of the civil year coincided with the heliacal rising of Sothis. And so similar coincidences of the civil and astronomical calendars must have taken place in the past at intervals of 1,456 years; that is, in 1317 BC, 2773 BC, and 4,229 BC Some Egyptologists take 2773 BC as the date when the Egyptian civil calendar was created, while others hold that it was 4229 BC, although some say that the problem of establishing such a reference point is more complex.

The Egyptians divided the region of the celestial sphere along the ecliptic into 36 zones called decans, a Greek word stemming from the fact that each decan spanned ten degrees, one-third of a zodiacal sign. The Egyptians created a star clock in which the heliacal rising of certain bright stars, one in each of the decans, mark the passing of the hours. Since there were 36 decans this would have led to a division of the complete cycle of day and night into 36 hours. But since the reference point for the astronomical year was the heliacal rising of Sirius, which is in summer, when the nights are shortest, only 12 decans can be seen rising during the hours of darkness. Thus the night was divided into 12 hours and likewise the day. Originally the hours were not of equal length and changed with the seasons, but in the Hellenistic period, when Greek culture dominated Egypt, the day was divided into 24 hours of equal length. At the same time the adoption of the sexagesimal system in Greek astronomy led to the division of the hour into 60 minutes and ultimately the further division of the minute into 60 seconds.

One branch of science in which Egypt excelled was medicine. Egyptian medicine is distinguished by the fact that its practitioners recognised physical symptoms as the first signs of disease, whose treatment was based on their experience of previous cases that they had treated and recorded, although magic and religious rites still played a large part in their practice.

The Greeks almost certainly did acquire some geometry from the Egyptians, but they probably learned far more mathematics from the Babylonians, whose widespread commercial activities brought them in contact with the Greek colonies that had been established at the beginning of the first millennium BC along the Aegean coast of Anatolia, and its offshore islands.

The Mesopotamian and Egyptian interest in astronomy stemmed from their astral religions, in which the celestial bodies, the sun, moon, planets and stars, were worshipped as divine. Their mathematical astronomy was developed through the need to coordinate their observations of the heavenly bodies and to create a calendar.

These celestial deities appear in the Babylonian creation epic, the *Enamu Elish*, whose earliest known version dates to about 1800 BC The *Enamu Elish* describes the mythical events that led up to the creation of the world and the birth of mankind, telling of how Anu, god of the upper heavens, aided by his son Marduk, defeated the forces of chaos and created order in forming the universe, which was a flat disc of earth floating in a vast ocean, roofed over with the celestial sphere.

After their victory Marduk was given charge of the world, built the city of Babylon at its centre, and created mankind to populate the earth and serve the gods. Marduk then set in motion the sun, moon and stars, so that by their eternally recurring motions mankind could tell the time of day and night and determine the passing seasons of the year, creating a celestial clock and calendar. Observation of the celestial bodies and the study of their motions became tasks of the Babylonian priest-astronomers, working in the great towers known as ziggurats, which were both temples and astronomical observatories, one of them appearing in the Bible as the Tower of Babel.

Babylonian astronomy was also motivated by the belief that there is an intimate connection between the celestial and terrestrial regions. Because of this events in the celestial sphere, such as eclipses of the sun and moon, were interpreted as signs of things to come on earth. Thus a close study of celestial motions can be a guide to predicting future events on earth, the belief that underlies the pseudo-science of astrology, one of the principal motivations for observing the heavens from antiquity up until the beginning of modern times.

The earliest examples of writing in Mesopotamia, as well as in Egypt, date to about 3300 BC Mesopotamian writing was in cuneiform, or wedge-shaped, script on clay tablets, which hardened quickly and left a permanent record. Most of the known cuneiform tablets with mathematical contents are from the Old Babylonian period, ca. 1800 BC According to Neugebauer, one of those who first studied these tablets, 'No astronomical texts of any scientific significance exist from this period, while the mathematical texts show the highest levels ever attained in Babylonia.'

There are also a few mathematical texts from the Seleucid period, from around 300 BC to the beginning of the Christian era, when Mesopotamia was ruled by a dynasty founded by one of the successors of Alexander the Great. The level of these texts is comparable to those of the Old Babylonian period, though, as Neugebauer remarks, 'The only essential progress that was made consists of the "zero" sign in the Seleucid texts.' Neugebauer notes that the Seleucid period 'has furnished us with a great number of astronomical texts of a most remarkable character, fully comparable to the astronomy of the *Almagest*', referring to the famous work written by the Greek scientist Claudius Ptolemaios (Ptolemy) of Alexandria in the mid-second century AD.

The Babylonian mathematical texts are of two types: 'table texts' and 'problem texts'. The most common of the first type are multiplication and division tables, which were evidently used in the education of scribes. According to Neugebauer, there are also 'tables of square and square roots, of cubes and cube roots, of sums of squares and cubes needed for the numerical solution of certain types of cubic equations, of exponential functions, which were used for the computation of compound interest, etc.' The latter tables in particular would indicate that the principal motivation in the development of Babylonian mathematics was its application in economics, and this can be seen in some of the problem texts, one of which represents 'the calculation of the harvest yield of the province of Lagash for the third year recorded in the text'.

The sexagesimal system first came into use in the Old Babylonian era; it was still in use during the Seleucid period, when, according to Neugebauer, 'this method became the essential tool in the development of a mathematical astronomy, whence it spread to the Greeks and then to the Hindus.' This system survives in the modern world in the division of the circle into 360 degrees, where each degree equals 60 minutes of arc measure, and each minute is 60 seconds of arc, as well as in the division of the hour into 60 minutes of time measure, where each minute equals 60 seconds.

The Babylonians were the first to develop place-value notation in mathematics, where the value of a symbol depends on its place in the number. As an example, writing 111 in the decimal system, the same symbol has the value 1 (10 to the power zero), 10 (10 to the power one) or 100 (10 to the power two), depending on where it is placed in the number. In the sexagesimal system the same symbol would be expressed as 60 to the successive powers zero, one, two, etc.

The Babylonians were familiar with the Pythagorean theorem, but as a relationship between numbers rather than one in geometry. Some of the texts deal with problems in geometry, such as finding the radius of a circle that circumscribes an isosceles triangle, or determining the areas of regular polygons. These and other texts led Neugebauer to remark that Babylonian mathematics at its highest level 'can in many respects be compared with the mathematics, say, of the early Renaissance'.

Many of the Babylonian cuneiform tables for multiplication and division are combined with tables of weights and measures needed in everyday commercial life. This was the beginning of metrology, the creation of uniform measures and physical standards of length and weight. Examples of these Mesopotamian measures and their physical standards have survived, notably those in the Museum of the Ancient Orient in Istanbul but also in collections in Chicago, London and Berlin, including bronze bars marked with the different units of length and bronze masses corresponding to weights of various amounts.

The earliest cuneiform astronomical tablets date from the middle of the second millennium BC, when for several years during the reign of Ammisaduqa records were noted of the appearances and disappearances of Venus, the Babylonian Ishtar, who was worshipped as a fertility goddess. The dates are given in the contemporary lunar calendar, an important factor in determining the chronology of the Old Babylonian period. These observations seem to have provided data for omens of things to come, which Neugebauer remarks are 'the first signs of a development which would lead centuries later to judicial astrology and, finally, to the personal or horoscopic astrology of the Hellenistic age'. He notes that there were at least seventy tablets of this sort with a total of some 7,000 omens, extending over several centuries and reaching its final form ca. 1000 BC One tablet records a prediction based on a disappearance and reappearance of Venus in the seventh year of the reign of Ammisaduqa: 'If on the 21st of Ab Venus disappeared in the east, remaining absent in the sky for two months and 11 days, and in the month Arakhsamma on the 2nd day Venus was seen in the west, there will be rains in the land; desolation will be wrought.'

Two texts from ca. 700 BC, though undoubtedly based on older material, contain a summary of the astronomical knowledge of their time. The first deals mostly with the fixed stars, which are arrayed in three zones spanning the celestial equator, with the central one some thirty degrees wide, an early attempt at mapping the heavens. The second tablet concerns the moon and the planets as well as the seasons, the latter determined by observation of shadows cast by a gnomon, the winter and summer solstices occurring when the noon shadow is longest and shortest, respectively, the spring and autumn equinoxes when the sunrise and sunset shadows are due east and west. Neugebauer remarks that 'The data on risings and setting [of the stars], though still in a rather schematic form, are our main basis for the identification of the Babylonian constellations.'

Tablets from ca. 700 BC contain systematic observations of court astronomers who served the Assyrian emperors. The observations recorded in these tablets include eclipses of the sun and moon, where it was noted that solar eclipses only occurred at the time of new moon, the end of a lunar month, while lunar eclipses took place when the moon was full, in the middle of the month. The Greek astronomer Ptolemy would seem to have had access to this data, for he notes that he had records of eclipses dating back to the time of Nabonassar (747 BC).

Twelve constellations, known to the Greeks as the signs of the zodiac, each of them about thirty degrees wide, were chosen to chart the progress of the sun in its yearly motion through the stars. Greek astronomers of the Hellenistic era defined the sidereal year, the time taken by the sun to make one complete circuit of the zodiac. The month was measured by observing the lunar cycle from new moon to full moon and back to new moon again. New moon is when the moon is between the earth and sun so that it is showing its dark side; full moon is when it is on the far side of the earth from the moon and its full disc is visible. The point of this cycle that is easiest to observe is the first crescent, which appears a day or two after new moon above the western horizon after sunset. One lunation, a lunar month, is the time between two successive appearances of the first crescent, which can be either 29 or 30 days, averaging about 29.5 days over the course of 12 months. Twelve lunar months is equal to approximately 354 days. Thus a purely lunar calendar, such as the one generally used in the Islamic world, will fall out of phase with the year of the seasons by close to 11.25 days each year. At first the Babylonians adjusted for this by adding a thirteenth month every three years or so. Then, early in the Seleucid period they devised a scheme that the Greeks called the Metonic cycle, in which there were 12 ordinary years of 12 months each interspersed with 7 intercalary lunar years of 13 months each. This cycle produced the calendar of Seleucid Mesopotamia, which had an error of only one day in 350 years, as measured by the predicted appearance of a new moon. The Metonic cycle also formed the basis for the Jewish and Christian calendars as well as two of the earliest astronomical calendars of India.

An advance in mathematical astronomy made during the Seleucid period was the introduction of the great circle in the celestial sphere known as the ecliptic, which traces the path of the sun among the fixed stars. This was the first step in mapping the heavenly bodies on the celestial sphere, a procedure that was fully developed by Greek astronomers of the Hellenistic period.

Another advance made during the Seleucid period was the ability to predict whether a given month would have 29 or 30 days. The Babylonian scribes solved this problem by recording the lengths of the passing months over a very long period of time and identifying the factors, such as the angle of the ecliptic with the horizon, that determined whether a lunation would be 29 days or 30. They did this by a study of the various cycles involved, the earliest example of a scientific theory, the collection of observational data that was subjected to mathematical analysis to predict a measurable result. A similar analysis was made of the synodic periods of planetary motions, that is the time of recurrence of their cyclical motions as seen from the earth. The tables of observations that provided the dates for these studies were almanacs which the Greeks called ephemerides. These are represented by somewhat less than 250 cuneiform tablets, more than half of which are lunar and the rest planetary, according to Neugebauer, who notes that there are also about seventy tablets describing the mathematical procedures for analysing this data.

Neugebauer, in summarising his discussion of Babylonian mathematics and its influence on Greek mathematicians and those of later civilisations, concludes that 'All that we can safely say is that a continuous tradition must have existed, connecting Mesopotamian mathematics of the Hellenistic period with contemporary Semitic (Aramaic) and Greek writers and finally with the Hindu and Islamic mathematicians.'

The spread of astrological belief was the principal reason for the transmission of astronomical knowledge from one culture to another, such as from Mesopotamia to the Greek world and then to India. Neugebauer also noted that 'the terminology as well as the method of Hindu astrology are clearly of Greek origin; for example the names of the zodiacal signs are Greek loan words.' He also remarked that 'it seems reasonable to assume that Babylonian methods, parameters and concepts reached India in two ways, either via Persia or the Roman sea routes, but only through the medium of Hellenistic astronomy and astrology.'

The system used in Babylonian astrology had each day 'ruled' by one of the seven moving celestial bodies, i.e., the sun, moon and five planets. The order in which these bodies appear in Babylonian horoscopes is Sun – Moon – Jupiter – Venus – Mercury – Saturn – Mars. Greek horoscopes had them in the order Sun – Moon – Saturn – Jupiter – Mars – Venus – Mercury. Eventually this changed to the order that is used in modern horoscopes: Sun – Moon – Mars – Mercury – Jupiter – Venus – Saturn, an arrangement that gave the days of the week their names in the European languages.

The Babylonian astronomer Berossos, who moved to the Greek island of Cos ca. 270 BC, may be a direct link in the transmission of Mesopotamian knowledge to the Greeks, but his fragmentary extant works contain no writings on mathematical astronomy. Nevertheless, as Neugebauer remarks, 'Babylonian influence is visible in two different ways in Greek astronomy; first, in contributing basic empirical material for the geometrical theories we have outlined…; second, in a direct continuation of arithmetical methods which were used simultaneously with and independently of the geometrical methods.'

The Babylonian mathematics and astronomy that was absorbed by the Greeks was passed on in turn to the Arabs, some of it, as we will see, through the Hellenised people of south-eastern Anatolia and Mesopotamia, and some through the Hindus after they acquired it from the Greeks, such was the ebb and flow of knowledge through the interconnected cultures of East and West.

CHAPTER 2

The Land of the Greeks

One of the early Islamic scientists, Hunayn ibn Ishaq, writes of going off to *bilad-al-Rum*, 'the land of the Greeks', where he improved his Greek in order to read scientific manuscripts that he eventually translated into Syriac and then into Arabic. The land of *Rum* was for him Greek-speaking Asia Minor and Constantinople, capital of the Byzantine Empire.

Around the beginning of the first millennium BC there was a great migration that took the Greeks from their homeland in south-eastern Europe across the Aegean to the western coast of Asia Minor and its offshore islands. Three Greek tribes were involved in this migration: the Aeolians to the north, as far as the Hellespont, south of them the Ionians, and farther to the south the Dorians. Together they produced the first flowering of Hellenic culture, the Aeolians giving birth to the lyric poets Sappho and Alcaeus, the Ionians to the natural philosophers Thales, Anaximander and Anaximenes, and the Dorians to Herodotus, the Father of History.

Herodotus tells us that the Ionian cities organised themselves into a confederation called the Panionic League, which comprised the islands of Samos and Chios and ten cities on the mainland of Asia Minor opposite them: Phocaea, Clazomenae, Erythrae, Teos, Lebedus, Colophon, Ephesus, Priene, Myus and Miletus. Miletus surpassed all of the other Greek cities of Asia Minor in its maritime ventures, founding colonies around the shores of the Black Sea as well as along the Hellespont and on the Nile delta. Other cities, most notably Phocaea, established colonies along the western shores of the Mediterranean, particularly in southern Italy and Sicily, which became known as Magna Graecia, or Great Greece, because of the number of Hellenic settlements there.

Miletus was the birthplace of Thales, Anaximander and Anaximenes, who flourished in turn during the first half of the sixth century BC Aristotle refers to them as *physikoi*, from the Greek *physis*, meaning 'nature' in its widest sense, contrasting them with the earlier *theologoi*, or theologians, for they were the first who tried to explain phenomena on natural rather than supernatural grounds.

The most enduring idea of the Milesian philosophers proved to be their belief that there was an *arche*, or fundamental substance, which was at the basis of all matter, enduring through all apparent change. Thales believed that the *arche* was water, which is normally liquid but when heated appears in the gaseous state as steam and when frozen is solid ice. Anaximander called the fundamental substance *apeiron*, or the 'boundless', meaning that it was not defined by having specific qualities. Anaximenes held that the *arche* was *pneuma*, meaning 'air' or 'spirit', which assumes various forms through its eternal motion.

Ionia was also the birthplace of Pythagoras, who was born on Samos in the mid-sixth century BC and moved to the Greek colony of Croton in southern Italy.

There, it is believed – though we cannot be certain – that he founded a philosophical school and mystical sect, whose beliefs included that of *metempsychosis*, or the transmigration of souls. Pythagoras and his followers are credited with laying the foundations of Greek mathematics, particularly geometry and the theory of numbers. The most famous of their supposed discoveries is the Pythagorean theorem, which states that in a right triangle the square on the hypotenuse equals the sum of the squares on the other two sides. As we have noted, the Babylonians were aware of this a thousand years earlier, but as a relationship between numbers rather than a geometrical theorem.

According to tradition, their experiments with stringed instruments led the Pythagoreans to understand the numerical relations involved in musical harmony. This made them believe that the cosmos was divinely designed according to harmonious principles that could be expressed in terms of numbers. According to Aristotle, the Pythagoreans 'supposed the elements of numbers to be the elements of all things, and the whole heavens to be a musical scale and a number'.

The Greek colonies in Magna Graecia rivalled Ionia as a centre of natural philosophy, beginning with the Pythagoreans and continuing with Parmenides and Zeno of Elea in southern Italy, as well as Empedocles of Acragas in Sicily, who flourished around the same time as the Milesian physicists.

Parmenides denied the possibility of motion and any other kind of change, which he said were mere illusions of the senses. The philosophy of Parmenides was defended by his follower Zeno, who proposed several paradoxes designed to show that examples of apparent motion are illusory. Empedocles agreed with Parmenides that there was a serious problem regarding the reliability of our sense impressions, but he said that we are utterly dependent on our senses for they are our only direct contact with nature. Thus we must carefully evaluate the evidence of our senses to gain true knowledge.

Empedocles proposed that everything in nature is composed of four fundamental substances, earth, water, air and fire. The first three of these correspond, albeit superficially, to the modern classification of matter into three states of matter, earth representing solids, water liquids, and air gases, while fire for Empedocles represented not only flames but phenomena such as lightning and comets. According to Empedocles the four substances alternately intermingled and separated under the influence of what he called Love and Strife, corresponding to the modern concept of attractive and repulsive forces.

A radically different theory of matter was proposed in the mid-fifth century BC by Democritus of Abdera, a Thracian city founded by Ionians from Teos. Democritus thought that the *arche* exists in the form of atoms, the irreducible minima of all physical substances, which through their endless motion and mutual collisions take on all of the many forms of matter observed in nature. Democritus seems to have learned the theory from his teacher Leucippus, whose only extant fragment states that 'Nothing occurs at random but everything for a reason and by necessity', by which he meant that the motion of the atoms is not chaotic but obeys the immutable laws of nature.

The history of Greek medicine begins with Hippocrates, who was born on the island of Kos ca. 460 BC The writings of Hippocrates and his followers, the so-called Hippocratic Corpus, comprises some seventy works dating from his time to ca. 300 BC. They include treatises on all branches of medicine as well as clinical records and notes of public lectures on medical topics. A treatise on Deontology, or Medical Ethics, contains the famous Hippocratic Oath, which is still taken by physicians today.

Athens became the cultural centre of the Greek world during the classical period, 479–323 BC, which began with the end of the Persian Wars and ended with the death of Alexander. The first philosopher to reside in the city was Anaxagoras (ca. 520–ca. 428 BC) of Clazomenae, who left Ionia at the age of twenty and moved to Athens, where he resided for thirty years, becoming the teacher and close friend of Pericles.

Anaxagoras believed that the cosmos had a directing intelligence that he called *Nous*, or Mind, as Plutarch writes of him in his *Life of Pericles*: 'he was the first to enthrone in the universe not Chance, nor yet Necessity, but Mind (*Nous*) pure and simple, which distinguishes and sets apart, in the midst of an otherwise chaotic mass, the substances which have like elements.'

Anaxagoras believed that the cosmos was filled with an invisible element called the aether, which is in constant rotation and carries with it the celestial bodies. He says in one of his surviving fragments that 'The sun, the moon and all the stars are red-hot stones which the rotation of the aether carries round with it.' The nebulous concept of the aether proved to be very enduring, and it keeps reappearing in cosmological theories, as in the nineteenth century when it was thought to be the medium that transmits the electromagnetic force.

The intellectual life of classical Athens was dominated by its two famous schools, the Academy of Plato and the Lyceum of Aristotle. The Academy was founded by Plato ca. 380 BC and functioned more or less continuously until 529 AD, when it was closed by the emperor Justinian. Aristotle was a student at the Academy during the last twenty years of Plato's life, and then in 335 BC he founded the Lyceum, which he directed until 324 BC, when he returned to his native Macedonia, a year before he died.

Plato's attitude toward the study of nature is evident from what he has Socrates say in his dialogues. In the *Phaedo*, Socrates tells of how he had been attracted to the ideas of Anaxagoras because of his concept of *Nous*. But he was ultimately disappointed, he says, when he 'saw that the man made no use of Mind, nor gave it responsibility for the management of things, but mentioned as causes air and aether and water and many other strange things'.

Socrates was dissatisfied with Anaxagoras and the other early natural philosophers, because they only told him *how* things happened rather than *why*. What he was searching for was a teleological explanation, for he believed that everything in the cosmos was directed toward attaining the best possible end. Plato's most enduring influence on science was his advice to approach the study of nature as an exercise in geometry, particularly in astronomy. Through this geometrisation of nature, applicable in disciplines such as astronomy that can be suitably idealised, one can arrive at laws that are as 'certain' as those in geometry. As Socrates says in the *Republic*, 'Let's study astronomy by means of problems as we do in geometry, and leave the things in the sky alone.'

The problem for Greek astronomers was to explain the motion of the celestial bodies – the stars, sun, moon and the five visible planets – as