How Classical Knowledge Reached Baghdad

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The Classical Achievement in Mathematics and Science

With Ptolemy's *Almagest* giving detailed accounts and predictions of the movement of the planets, we reach the end of the great classical period in science. Let's review what was achieved.

First, the Babylonians developed a very efficient system of numbers and measures of all kind, primarily for business purposes. Unfortunately, it did not pass through to the Greeks and Romans, except for measures of time and angle, presumably those are the units relevant for recording astronomical observations. The Babylonians kept meticulous astronomical records over many centuries, mainly for astrological purposes, but also to maintain and adjust the calendar. They had tables of squares they used to aid multiplication, and even recorded solutions to word problems which were a kind of pre-algebra, a technique broadened and developed millennia later in Baghdad, as we shall see.

The Egyptians developed geometry for land measurement (that's what it means!), the land being measured for tax assessment.

The Greeks, beginning with Thales then Pythagoras, later Euclid, Archimedes and Apollonius, greatly extended geometry, building a logical system of theorems and proofs, based on a few axioms. An early result of this very abstract approach was the Pythagoreans' deduction that the square root of 2 could not be expressed as a ratio of whole numbers. This was a result they didn't want to be true, and that no-one would have guessed. Remember, they believed that God constructed the Universe out of pure numbers! Their accepting of this new "irrational" truth was a testimony to their honesty and clear mindedness.

The development of geometry took many generations: it could only happen because people with some leisure were able to record and preserve for the next generation complicated arguments and results. They went far beyond what was of immediate practical value and pursued it as an intellectual discipline. Plato strongly believed such efforts led to clarity of thought, a valuable quality in leaders. In fact, above the door of his academy he apparently wrote: "let no one who cannot think geometrically enter here."

Over this same period, the Greeks began to think *scientifically*, meaning that they began to talk of natural origins for phenomena, such as lightning, thunder and earthquakes, rather than assuming they were messages from angry gods. Similarly, Hippocrates saw epilepsy as a physical disease, possibly treatable by diet or life style, rather than demonic possession, as was widely believed at the time (and much later!).

The geometric and scientific came together in analyzing the motion of the planets in terms of combinations of circular motions, an approach suggested by Plato, and culminating in Ptolemy's

Almagest. This Greek approach to astronomy strongly contrasted with that of the Babylonians, who had made precise solar, lunar and planetary observations for many hundreds of years, enough data to predict future events, such as eclipses, fairly accurately, yet they never attempted to construct geometric models to analyze those complex motions.

Why did Mathematics and Science Grind to a Halt?

Why did the development of science on the ancient world pretty much end after 800 years, around 200 AD or so? For one thing, the Romans were now dominant, and although they were excellent engineers, building thousands of miles of roads, hundreds of military garrisons, and so on, they did very little science. And, *the Greeks themselves lost interest*: Plato's Academy began to concentrate on rhetoric, the art of speechmaking. Perhaps this had been found to be more valuable for an aspiring leader than the ability to think geometrically or scientifically—or perhaps better for winning elections and persuading people. Furthermore, with the conversion of the Roman empire to Christianity around 300 AD, saving souls became a top priority in the Catholic church. As St. Augustine put it,

"Nor need we be afraid lest the Christian should be rather ignorant of the force and number of the elements, the motion, order and eclipses of the heavenly bodies, the form of the heavens, the kinds and natures of animals, shrubs and stones ... It is enough for the Christian to believe that the cause of all created things, whether heavenly or earthly, whether visible or invisible, is none other than the goodness of the Creator, who is the one true God."

It's a little puzzling to put this together with Botticelli's picture, showing Augustine looking prayerful but with scientific instruments in plain sight!   (Augustine *was* very interested in science and many other unholy things earlier in life.)

St. Augustine by Botticelli (Wikipedia Commons).

But Some Christians Preserved the Classical Knowledge…

Actually, the story of the treatment of the Greek mathematical and scientific knowledge by the early Christian church is complicated, like the church itself. Recall that mathematics and science effectively ended in Alexandria with the murder of Hypatia in 415 AD, ordered by the Patriarch Cyril. This same Cyril engaged in a violent theological quarrel with the Patriarch of Constantinople, Nestorius. The question was the relative importance of the Virgin Mary. Cyril demanded that she be referred to as the Mother of God, Nestor would only accept Mother of Christ. This was all part of a debate about the nature of Christ: did he have two natures, human and divine, or one nature? Nestor thought two, of which only one, the human, died on the cross. Getting this right was very important: it was believed that salvation depended on it. However, the dispute was also (and perhaps principally) a struggle for power. At the Council of Ephesus in 431, Cyril arrived early with a large group of strong men, handed out bribes, and got the assembled bishops to condemn Nestor as a heretic. (Further complications ensued at later Councils, see for example *The Closing of the Western Mind*, Charles Freeman, Knopf, 2002, page 259 on, but it was all bad news for Nestor and his followers, who became known as Nestorians.)

How the Nestorians Helped Science Survive

What has this got to do with science? It is a crucial link in the chain. In contrast to most of the rest of the church, the Nestorians preserved and read the works of Aristotle, Plato, etc., and translated many of them into Syriac. They felt that clear thinking was useful in theology. Being declared heretics meant that it was no longer a good idea to stay in the Roman Empire, and, in fact, they were expelled.

Let's briefly review the extent of the Roman Empire to understand what expulsion implied. The maps below are from:
http://www.roman-empire.net/maps/empire/extent/augustus.html

At its greatest extent, in 116 AD, pictured above, notice that the Empire included almost all of present-day Iraq, including the port of Basra (bottom right, on the Persian Gulf). However, this

didn't last long—the Romans' most powerful enemy, the Persians (now known as Iranians), recaptured the territory after a short Roman occupation.

At the time of the death of Constantine, 337 AD, the Empire was officially Christian. The eastern part of the Empire, ruled from Constantinople and Greek speaking, became known as Byzantium. The Empire's total extent is shown below:

The Nestorians found temporary refuge with Syriac speaking sympathizers in Edessa (see Google map below, 37 10 N, 38 47 E. Istanbul (top left) is of course Constantinople):

(Nestor was a pupil of Theodore of Mopsuestia in Antioch, Syria. When Nestor was condemned, these Arab Christians broke with the Byzantine church, forming the Assyrian Church of the East, see Wikipedia.)

On into Persia

This was all during the time of the second Persian Empire (226-651), the Sassanid Empire. The Sassanid Persian kings saw an opportunity to handle their own considerable number of Christian subjects better. They granted protection to Nestorians in 462, then in 484, they executed the Bishop of Nisibis (37 04 N, 41 13 E) (who was anti Nestorian, pro Byzantine) and replaced him with a Nestorian. (This is from Wikipedia.) The Nestorians settled in the Persian Empire, moving eventually to Gundishapur (near modern Dezful, at 32 25 N, 48 26 E). These Nestorians sent out many missionaries, for example reaching China in 635, and even Korea, and founding many churches, races still remain today. (However, foreign religions were suppressed in China in the 800's.)

The academy at Gundishapir had Syraic as the working language. Under a Sassanid monarch, Khosrau I, 531 – 579 AD, it became famous for learning.   Although Khosrau I was a Zoroastrian, the dominant Persian religion, he was tolerant of all religions, in fact one of his sons became a Christian. He greatly improved the infrastructure, building palaces, strong defenses, and irrigation canals. He encourages science and art, collecting books from all over the known world, and introducing chess from India. (*Trivial Fact*: "Checkmate" is a corruption of the Persian shah mat, meaning the king is dead.) He had Syriac and Greek works translated into Persian. He also sent a famous physician Borzuyeh to India to invite Indian and Chinese scholars to Gundishapur.

The Advent of Islamic Rule

In 622, the prophet Muhammad left hostile Mecca to found his own theocratic state in Medina (just over two hundred miles to the north, both in western Saudi Arabia). He readily attracted converts, and built an army that captured Mecca eight years later. He died in 632, but his armies continued to conquer. Both Romans and Persians were by this point rather weak militarily, having spent decades fighting each other. The Sassanid dynasty fell to Muslim Arab armies in 638 AD. Alexandria was conquered in 642. These Muslims, although at war with Byzantium, were tolerant of their ethnic brethren, the Arab Christians. The first dynasty, the Umayyad (660 – 750), centered in Damascus, included Hisham ibn Abd as-Malik, who encouraged the arts, education, and "translation of numerous literary and scientific masterpieces into Arabic" (Wikipedia). (The Muslim Empire was now vast: a Hindu rebellion in Sindh was subdued; at the same time Umayyad armies went north from Spain, but were defeated at Tours, France, in 732. It has been argued that if the Arab armies had won at Tours, all Europe would have become Islamic, and still would be.)

In 749, a second dynasty, the Abbasid caliphate, began. In 762 the Abbasid Caliph al-Mansur built a magnificent new capital: Baghdad. Al-Mansur emulated the Persian rulers, building a palace library like the Sassanid Imperial Library, except that now everything was to be translated into Arabic. Harun ar-Rashid, Caliph from 786 to 808, sent agents to buy Greek manuscripts from Constantinople, to be translated into Arabic. At the same time, the *Siddhantas* wrrived

from India: a set of Indian astronomical works, including trigonometric tables that likely originated with Hipparchus, and had then found their way to the Greek cities in India and Afghanistan founded by Alexander. (It's worth noting that the first paper mill outside China was built in Baghdad in 794, the secret having been given by prisoners of war from a battle against the Chinese in Central Asia. In fact, the cheap availability of paper made the complex Abbasid bureaucracy reasonably efficient.)

Meanwhile, Gundishapur wasn't far away: generously funded court appointments drew physicians (including al-Mansur's personal physician) and teachers to Baghdad.

Later, under the Abbasid Caliph al-Ma'mun (813 – 833), the *House of Wisdom* was founded (in 828): a large library and translation center into Arabic: first from Persian, then Syriac, then Greek. Many works were translated from Syriac into Arabic, including some Archimedes and all Euclid. Hunayn, a Christian, from Jundishapur, redid many translations to make them more readable.
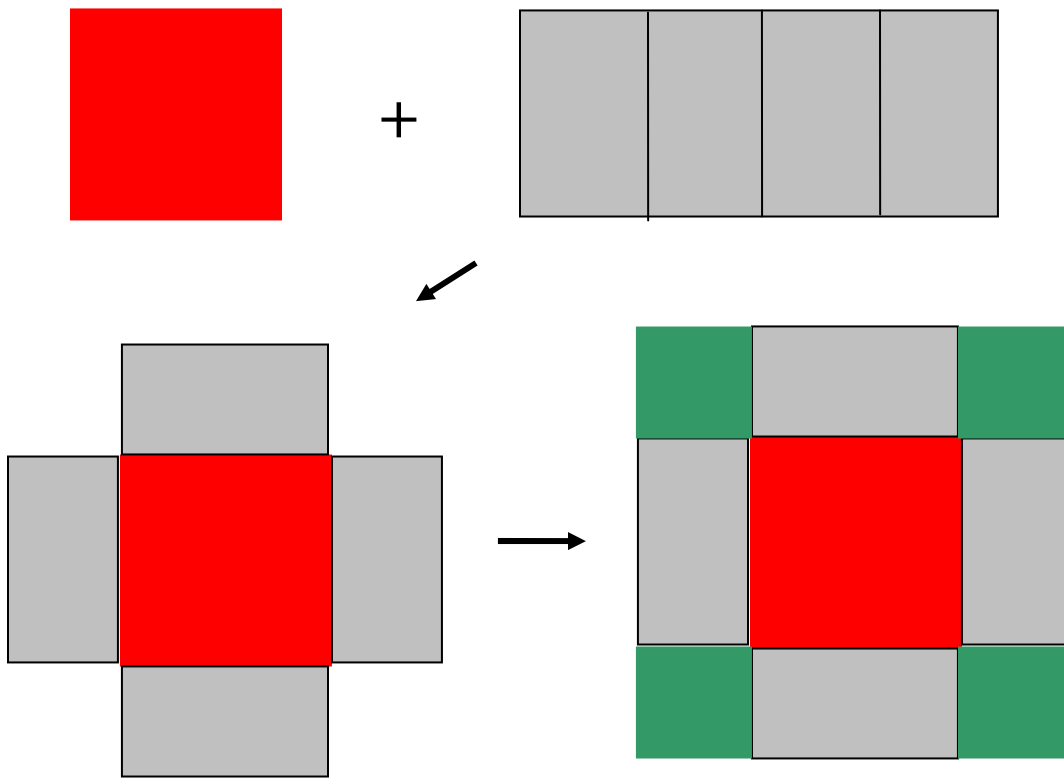
The House of Wisdom: al-Khwarismi

Perhaps the most famous scholar from the House of Wisdom is Al-Khwarismi (780 – 850). The word *algorithm*, meaning some kind of computational procedure, is just a mangling of his name. This is because he wrote the book that introduced the Hindu numbering system (now known as Arabic) to the Western world, and medieval scholars used his name to refer to routines for multiplication using Arabic numbers, far more efficient than anything possible with the previously used Roman numerals!

He also wrote the book on algebra: that word is actually "al-jabr" meaning completion. (We'll see below why this is an appropriate term.) Actually, he didn't use symbols to denote unknown quantities, now the essence of algebra. Ironically, such symbols had been used by the Greek Diophantus, in Alexandria, in the 200's AD, but that work was apparently unknown to the Arabs. Instead, al-Khwarismi stated algebraic problems as word problems, as the Babylonians had over two millennia earlier, but he also gave geometric representations of his solutions.

Let's look at one of his examples: $x^2 + 10x = 39$. (OK, I've cheated by using x: he wrote it all out in words, but his thought process was as outlined below.)

This he thought of in terms of equating *areas*: a very natural approach to something beginning with a square! On the left we have a square of side x and a rectangle of sides x and 10.

His strategy is to add area to this to make it *one big square*—he takes the rectangle and divides it into four equal rectangles each having sides x and $10/4 = 5/2$. He then glues these to the x square:

al-jabr: completing the square

The next step is to extend this to give just one square, by adding the green bits. But to keep the equation valid, the same amount must of course be added to the other side. That is, 5/2×5/2×4 is to be added to each side. We can see that on the left we now have a square of side x + 5. on the right hand side, we have 39 + 25 = 64 = 8×8. Therefore, x + 5 = 8, and x = 3.

So by adding to both sides we have "completed the square", and _al-jabr_ is this adding to get completion. Negative numbers were not in use at that time, so quadratics like $x^2 = 10x + 39$, for example, were treated separately, and several distinct cases had to be explained.

It's not clear that al-Khwarismi's own contribution, by which I mean really new mathematics, was great, but his influence was tremendous: his presentation of algebra, and of the Arab numerals, sparked much further mathematical development, both in Baghdad and, later, in the West, as we shall see.