History of Science in Late Antiquity – Lecture Notes

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Handout

The history of science in Late Antiquity very much follows the fortunes of the Library of Alexandria. By this time, the Library had passed its apogee and even in the period of the Greek Renaissance in the second century, it could not match the impressive work of its early scholars. We are going to talk today of principally four people: Ptolemy, Galen, Diophantus and Hypatia, whose lives and works form the broad outline of the history of science in Late Antiquity. But let me begin with a brief overview of where science and the Library stand when the second century opens.

The Library of Alexandria was founded upon the death of Alexander the Great by the first Ptolemaic ruler of Egypt. It was based on the great publicly funded libraries of the Persian kings Alexander conquered. The Library was founded not only as a storehouse of books, but also as a university where scholars could come and pursue knowledge, share ideas and teach others. Because of generous public funding, Alexandria quickly became the dominant intellectual center of the Hellenistic world. While other libraries were also started in Pergamum and Ephesus, neither were able to match the wealth the Ptolemies afforded to their Library. The Museum attached to the Library was both a shrine to the Muses and the university itself. It is felt that the shrine was necessary to give the Library legal standing, as had been the case with the Academy in Athens. Over the next 300 years, all the great scientific minds of the Greek world would have some affiliation with the Library and Museum, either as students, scholars, or the Librarian himself.

By the time Caesar saw the Library in the last century BCE, it was already struggling with a lack of originality in the work emanating from it. And it was Caesar's visit to Alexandria that would coincide with the first devastating blow to the supremacy of Alexandria's Library. In 47 BCE, it burned. It is not known how much of the Library suffered. The Library at this time is believed to have held between 400,000 and 700,000 books in the main Library, with smaller satellite libraries scattered around the city, the largest at the Serapeion (The Temple of Serapis). By 30 BCE Egypt fell to the Romans and with the political instability inherent in a change of government, scholarship at the Library became almost non-existent. Scholarship at the Library would continue to languish until the rise of the Greek Renaissance in the second century.

The first great scientist to rise out of Alexandria in the second century was Claudius Ptolemy. We know very little about the life of Ptolemy—as is true of most of the scientists of antiquity—but we do know he was not a relative of the Ptolemaic kings of Egypt who founded the Library; we know that he was a Roman citizen, and that he was a Hellenized Egyptian, non-Greek by birth. This last fact is characteristic of all the scientists we will discuss today, and of the period in general. Exact dates for his life are not known, but he did his observations between 125 and 151 CE.

Ptolemy's great genius was in applied geometry, for it is through geometry that all of his known works find a common thread. He wrote treatises on optics, astronomy, astrology, geography and mechanics. Of the last, only the title is known, but such was the strength of Ptolemy's work, that all the others are extant in either Greek or Arabic versions. His book on geography used geometrical techniques to improve map-making ability, and to show how using the sun and stars, one could fix one's location on the earth. His book on optics made great improvements in our understanding of refraction and reflection, and was one of the most important works on optics until Newton. But his best work, and that which defined the field of astronomy for 1500 years, is his *Syntaxis Mathematica*, better known as the *Almagest*, from the Arabic word for 'the' tacked onto a corruption of the Greek adjective *megiste* for 'greatest'. It says something about what both the Greeks and the Arabs thought of the text.

The *Almagest* is the book against which all later theories of planetary motion would be judged. The *Almagest* attempts to lay out a theory of the solar system (and thus the universe) that will account for all the motions that were then known, based on astronomical observations of Hipparchus—perhaps the greatest observational astronomer of antiquity—and other records dating back another 900 years to Babylon. Ptolemy's genius was in his ability to convert observations into a workable theory—no one would be better at it until Johannes Kepler. Ptolemy's system was a marvel of using circular motion to account for complex behaviours. So powerful is such a system that modern mathematics has a field dedicated to essentially the same methods called Fourier analysis. The great power of this method is that it makes calculations easy—and for a subject like astrology in which accurate predictions of planetary positions are necessary, Ptolemy's methods were adopted quickly by high-end street fortune-tellers.

Despite the relative ease with which calculations could be made, and despite accounting for many known behaviours of the planets, Ptolemy's model had serious flaws that would engage astronomical debate even after the model was overturned. I want to take a moment to look at Ptolemaic astronomy in a little more detail.

Ptolemy's model conformed to prevailing Aristotelian views of the universe in his time. The model is geocentric—that is the earth is at the center—all of the motions are supposed to be uniform circular motions as the heavens are perfect and only circular motion was perfect (how convenient it is that circular motion was also practically the only kind of motion that Greek mathematics could accurately describe). However, the planetary motion as seen from Earth does not seem simple. The planets Mercury and Venus never stray far from the Sun, and the others, Mars, Jupiter and Saturn, show retrograde motion on a periodic basis. (EXAMPLE) To account for both of these motions, Ptolemy, as his predecessors had suggested, employed the notion of an epicycle.

In Ptolemy's geocentric system, planets did not only move in circles around the Earth, but to account for the retrograde motion, he had the planets moving around a point which went around the Earth. This secondary circle is the epicycle. By varying the speed that the planet moved on the epicycle, Ptolemy could match the motions of the planets as seen from the Earth. Additionally, he also moved the Earth from the exact center of the planetary circles, a first attempt to approximate the true elliptical motion of the planets. (An ellipse has two foci, and the Sun, in a heliocentric model is not at the center, but at one focus.) For the outer planets, Mars, Jupiter and Saturn, the orbit represents the orbit of the planet around the sun, and the epicycle the motion of the Earth, while for the inner planets, Mercury and Venus, the reverse is true. Ptolemy and later writers would attempt to improve the accuracy and predictive power of this basic model by incorporating additional epicycles to account for the true elliptical nature of both orbits and other corrections. One of the principal reasons Copernicus argued for the heliocentric model over the geocentric one is that it eliminated one epicycle per planet, making a by then overly complex model somewhat simpler. Wedded as the Hellenized world was to the geocentric model, such a proposition—even having been made by the astronomer Hipparchus—would not have been accepted. Ptolemy himself confronts the notion of a heliocentric solar system, but rejects it, not so much because he had evidence specifically against it, but rather he didn't feel sufficiently justified in rejecting what was more philosophically acceptable.

Besides these complications, Ptolemy's model also suffered from other problems that he chose to gloss over. It predicts, for instance, that the apparent size of the moon should differ by a factor of two between quarter moon and full moon, and it does not. Ptolemy's model did beautifully account for the *position* of objects, and for the popular astrologers this was all that was needed, and because it complied with Aristotelian views of the universe, it became the standard model for astronomy and a symbol of our place in god's universe upon pain of death under Christian rule.

The second great scientist of the Greek Renaissance was the physician Galen of Pergamum. That Galen came out of Alexandria's rival intellectual center is one of the first significant signs that the

Library of Alexandria's fortune's had changed. About Galen's life we know a great deal more than is usual for scientists, but Galen felt medicine was a very personal and experiential science and often related experiences in his writings. As with Ptolemy, the Muslims who eventually took over Hellenistic science in the seventh century and after respected Galen immensely and preserved most of his work. Galen began his medical career as a field surgeon for gladiators in Pergamum in Asia Minor. He spent time in Rome trying to build his reputation as a physician in what was a largely corrupt medical practice. He was summoned to attend Marcus Aurelius in the field against the Germans, but after spending the winter of 168 tending to plague-stricken soldiers in the field alone, he requested to be withdrawn from the front and was appointed personal physician to the emperor's son Commodus. Galen stressed in his writing the need for physicians to be logical, knowledgeable about natural philosophy and ethical. He also felt that the key to be good at diagnosis was a keen knowledge of anatomy and physiology gained from careful observations of both living patients, and when possible, through dissection. However, human cadavers were not generally available in Rome as they were in Alexandria, so Galen was forced to make analogies based on his dissections of other animals, particularly monkeys, being most similar to humans. Indeed, many of the mistakes on his anatomical assessments are based on faulty analogy with the Barbary ape in particular. And while Galen did perform vivisections—that is live dissections—of animals, he chastised one predecessor, a scholar at the Library of Alexandria during the reign of Ptolemy Philadelphus (II) who was granted the privilege of vivisecting criminals from the king's prisons as unethical and barbarous.

At the time Galen was writing the medical field was divided up into sects that constantly argued back and forth about whose approach to medicine was the correct one and the most effective. Galen belonged to the *rationalist* camp. The rationalists were highly speculative theoreticians, and Galen based his on the philosophy of Plato. The principal rivals of the rationalists were the *empiricists*, who, despite their name, felt physiological knowledge was a waste of time. Late in the life of Galen two more groups appeared on the scene: the *methodists* and the *pneumatists*. The methodists felt that anyone could perform medicine (a concept which Galen strongly opposed) because disease was based on the tenseness or laxness of the body; it was a practice that would become quite popular among Roman aristocrats. The pneumatists repudiated humoural theories like those Galen based his work on and instead argued for a more atomist doctrine (a doctrine those of us in the 21st century would find more in common with then we would with Galen).

Galen's contribution to medical knowledge, besides his improvement on our knowledge of anatomy and physiology, are very much based on his ethics and beliefs about the hands-on-training of physicians. He is a far better model upon which to base medieval and Islamic medicine than many of his other contemporaries; and it would be his treatises and techniques that would guide medical students well into the Renaissance when artists like Leonardo da Vinci and Michelangelo would at last surpass Galen's knowledge of anatomy.

The Greek Renaissance would close but science would still have one more great original thinker in the second half of the third century and beginning of the fourth. Diophantus of Alexandria introduced for the first time a non-geometrical, quasi-symbolic algebra. Until this time, algebra had been done either with the use of words embedded in standard Greek syntax, or with geometry (limiting multiplication to being done on only three things at once, because, of course, what is the fourth dimension?). Greek mathematicians had been slowly taking steps away from its dependency on geometry, but Diophantus introduced symbolism and a methodology to approach these problems. When we look at an example of his equations, even people with familiar with math still feel a little confused, but consider doing math with whole words… (EXAMPLE) Diophantus did not invent a true algebra. He lacked the systematicity we would like to see in an algebra. His method of solving problems was essentially a trial and error method, though his method of analysis is still used today for some problems in higher mathematics where a systematic method has not yet been developed. A true symbolic algebra would not come along for almost a millennium, but he was so far ahead of his contemporaries that his innovations to the field of mathematics were negligible. Within a century, over half of his revolutionary book *Arithmetica* would be lost, and he exerted little or no influence on the history of mathematics. By the time he was rediscovered among the Arabic texts filtering back into Europe, his innovations had already been re-innovated and surpassed.

The question of why his work was lost so quickly remains something of a mystery. In his lifetime Diophantus would witness the second burning of the entire district of Brucheion where the mail Library was found in 272 when Caracalla sacked the city, and before his death the conversion of the Emperor Constantine to Christianity.

From the 3rd century onward, with the sole exception of Diophantus, originality in Hellenic science ground to a halt. The works coming out of the Library of Alexandria were predominantly commentaries on old authors; invaluable for preserving ground-breaking work, but also crushing originality and contributing to a tendency to appeal to authority. Even gifted scholars of their time, like Theon of Alexandria and his daughter Hypatia, would find themselves trapped in the mold of copying and explaining past authors, sometimes unquestioningly and without revision or addition.

I will leave to Mr. Thornton, the details of the Roman world in the late fourth century CE, but I want to give you an idea of the world our last scientist found herself in, in the period leading up to her death.

Hypatia of Alexandria was an extraordinary woman. We need not fall into the trap of turning her into an eternally youthful angel to admit this. Hypatia was a woman of great intellect. The daughter of Theon of Alexandria who was himself affiliated with the Library, she was likewise held in high esteem, apparently unmarried, a philosopher, mathematician and astronomer. In her youth she worked with her father on editing the text of the *Almagest*, and on her own wrote commentaries on the extremely difficult *Arithmetica* of Diophantus. She would be remembered for no other reason than that she was a woman at a time when women were valued very little, but unluckily for her, we remember her for a far more tragic reason.

In the late fourth century, the patriarch of Alexandria was Theophilus. While consolidating power after the Empire nominally became Christian, Christianity was extremely hostile toward all forms of learning, but particularly so with science. Christians in power tended to view science as pagan and therefore a product of the devil, and deserving of destruction. We can see this attitude in the writings of famous Christians like Tertullian and Augustine. We can also see it played out in the events in Alexandria beginning in the late fourth century. Emperor Theodosius outlawed cult practices in 391, and Theophilus took this moment to attempt to rid Alexandria of all things pagan, and to seize the pagan temples so that they could be made into Christian churches. Clearly, this did not go over well with the educated pagans of the day, and they made a stand at the Serapeion, the Temple of Serapis. Besides the Temple, this had once been the largest of the Library of Alexandria's satellite libraries, and perhaps since the fire in Brucheion, most of what remained of the Library's books. The pagans were besieged and defended the Temple, and they were met by civil and military forces they could not withstand. The Temple was destroyed, and the Christians who died in destroying it were named martyrs.

Theophilus died in 412, and was succeed by his nephew Cyril. Pagan sources describe him as power-hungry and much opposed within Egypt. Cyril felt that Christian authority also needed strengthened in the city. He began by expelling the unorthodox Christians like the Novations, and likewise began purges of the Jews in 414, converting their synagogues into churches just as his predecessor had done with the pagan temples. Cyril also attempted to extend his authority into more secular spheres and was opposed by the moderate Christian governor of Alexandria, Orestes. One could make a whole lecture out of just these events, but to make a long story shorter, Orestes resisted, even when radical Christians loyal to Cyril threatened his life. Hypatia, a friend of Orestes, was blamed by the

Christians for casting a spell on him. It seems as though rumours about her were spread around the city that she performed black magic because of her association with astronomy, and thus astrology. In 415, during the month of Lent, a mob of Christians led by a young monk named Peter, captured Hypatia and slew her. The details of how are not entirely clear, but all the sources acknowledge the method was quite gruesome. Some say she was slain in a church, her body cut apart with pieces of tile and then burned. Or another says that she was taken to the church and "disgraced", then dragged through the streets behind a chariot, and then burned. In either case, her death was violent in the extreme. Hypatia was 60 years old. John of Nikiu, a Christian writer, would call the leader of this mob "a perfect believer in all respects in Jesus Christ."

Upon the death of Hypatia, pagans were understandably afraid. Orestes asked the Emperor to reassign him. Pagan scientists fled to other cities, inside the Empire like Athens, and outside the Empire in Persia, fearful for their own lives as Cyril went largely unpunished. Science would continue in the East, in Athens, until Justinian closed the Academy in 529. Pagan science in the East would melt away into the Persian and Arab world. In the West, Romans had for centuries considered science and philosophy a leisure pursuit rather than a career, and under invasion from barbarian hordes, there was little leisure time. In the West, all that would remain of the great legacy of Greek science would be handbooks, and the barest bones of "practical" knowledge. In the East, the Arabs would conquer Alexandria in 642, and find little left of its great Library, but the knowledge that fled with the pagan scientists to Persia would thrive in the Islamic Classical Period until at last it would find its way back to Europe nearly a millennium later.

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Where Science Stands 30 BCE:
Mathematics: Euclid is the standard; greatest to date is Archimedes.
Astronomy: Hipparchus; suggests heliocentric universe but no one else agrees.
Medicine: Hippocrates.
Natural Philosophy: Aristotle.
Center of Science is the Ancient World: Library and Museum of Alexandria

The "Big Four" in Late Antiquity:
Claudius Ptolemy (c. 125-151 CE)
Galen of Pergamum (129-210 CE)
Diophantus of Alexandria (246-330 CE)
Hypatia of Alexandria (355-415 CE)

Texts:
Almagest (Syntaxis Mathematica) (Ptolemy)
Optics (Ptolemy)
Arithmetica (Diophantus)

Other People:
Caracalla
Theon of Alexandria
Theophilus, Patriarch of Alexandria
Cyril, Patriarch of Alexandria
Orestes

Places:
Library and Museum at Alexandria
Serapeion, Temple of Serapis
Pergamum
Ephesus
Brucheion

Terms:
epicycle
retrograde
geocentric/heliocentric
rationalist
empiricist
methodist
pneumatist

Epigram on the tomb of Diophantus:

His boyhood lasted 1/6 of his life; his beard grew after 1/12 more; after 1/7 more he married; five years later his son was born; the son lived to half his father's age and the father died four years after his son.

How old was Diophantus when he died? When he married?

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Primary Sources:

See list of references in back of secondary sources. There are too many to list here.

Webpage:

http://www.betsymccall.net/edu/CLAM/greek for link.

For a brief outline of the history of science through Copernicus see:

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