History of Science Lecture -- Notes

Spring 2001, Western Civilization I

To summary/handout

Introduction:

What is science?

Science is not merely fact. Merely knowing that at a certain time of year, a certain bright star is just above the eastern horizon after sunset means that soon the Nile will flood is not science. The Babylonians and Egyptians, and indeed any agricultural civilization, must possess a great deal of "scientific" fact, but not science. Science, also known as "natural philosophy" is characterized by organizing these facts, by organized skepticism, by eliminating personification of nature, by disprovability.

Science is inherently at odds with organized religion. Science preaches disbelief, not faith; lack of respect for authority, and respect for the rationality of humanity.

Religions, or at least their conservative elements, attempt to suppress science and scientific thought because science forces religion to either die or change, and both are seen as unacceptable.

By this definition, science begins with the Greeks.

The Greek World:

Classical—

Science begins in the Greek world with the rise of widespread literacy. The Greeks used an alphabetic writing system rather than a logographic system like the Chinese or Egyptians, and this made learning to write significantly easier. This took reading out of the hands of an elite, priestly class and made it widely accessible. Writing allows for the close and repeated examination of arguments and observations, permitting flaws to be more easily uncovered.

The Ionic Greeks who settled in Asia Minor also had exposure to both Babylonian and Egyptian knowledge, pre-scientific mathematics, and engineering. Exposure to these new ideas encouraged the development of scientific thinking.

The first scientists, beginning with Thales in the 6th century BCE, were from the city of Miletus. They began asking questions about mathematical generalizations and the fundamental nature of things. More importantly, they did not invoke religious explanations. They not only state their theories, but attempted to provide a logical defense of them, introducing the idea of a proof.

Science and philosophy did not have clear divisions at this time, and philosophers and scientists typically worked in both fields. Science was far from looking much like what we would consider "modern", and the mystical element would remain long past the Renaissance.

Pythagoras founded a brotherhood in the 6th century BCE after traveling and learning of Egyptian and Babylonia mathematics. His brotherhood was highly secretive, but made many contributions to the development of Greek mathematics, as well as revealing the mathematical nature of music. The mystical characteristic he imbued numbers with—he believed numbers were the only reality—

contributed to the tendency of Greek science to spend a great deal of effort considering nature philosophically rather than observationally.

As we will see again and again, scientists sometimes come upon theories that prove to be far ahead of their time. The atomist theory is one such example from the Greek world. The atomists, Democritus and others, believed that most of the universe was empty space and that matter could only be divided so far. We know that this theory is essentially correct in its broad details today, but we should be careful not to judge early scientific theories by modern standards. The atomists were thinking about the world, but had no evidence they could point to to demonstrate the validity of the atomic theory, so while we can appreciate the visionary nature of atomism and other seemingly anachronistic theories we will encounter later, we should not judge those that rejected these theories too harshly.

Mathematical modeling of science begins with a student of Plato's named Eudoxus. While he did not suggest any actual numbers, he suggested the notion of epicycles used heavily in the later Ptolemaic theory of the solar system—the details of epicycles I'll come back to later. Eudoxus does not seem to have considered the model to reflect reality, only a mathematical construct to capture the motion we see. Another student of Plato's, Aristotle, would take the model to reflect reality.

Aristotle is certainly Plato's best-known student, and the most influential of the Classical Greek scientists. He divided science into several subjects, and his classifications we still largely use today. Among the subjects he wrote on were: zoology, physiology, linguistics, psychology, meteorology, physics, planetary astronomy, geology, optics and chemistry. Aristotle based his writing on observation, but did not believe that experimentation would reveal anything useful. His rationalist approach to science would prove extremely influential when he was rediscovered in the middle ages.

Classical Greek science did not proceed unimpeded, however. Anaxagoras and Socrates were both prosecuted on the grounds of impiety. Socrates was actually put to death for his crime. Greek religion, despite efforts to resist philosophy and science, would eventually be forced to give way to the rationalizing influence of science and philosophy.

Hellenistic—

The Hellenistic period begins with the death of Alexander the Great, and also the death of Aristotle the following year in 322 BCE. This period would begin with a huge flurry of activity in the 3^{rd} century BCE, which would be the most productive period of Greek science.

One of the reasons science found such success in the Hellenistic period was that for the first time scientists began to receive public funding for their studies. The Ptolemaic rulers of Egypt helped found and fund the Library of Alexandria. At its peak, it may have had as many as 700,000 volumes. The Museum both a temple (to the Muses, thus the name) and a place of learning. Most Hellenistic science was in some way associated with the Museum.

Euclid was the earliest of the great Hellenistic mathematicians. He compiled in his book the *Elements* all of the known geometry of his day, putting together a textbook that would be the standard well after the Renaissance. The book was so successful because each concept was laid out clearly, with logical proofs. While most of the material is the books is known not to be his own, he did make original contributions to geometry.

Another great scientist of the 3rd century was Aristarchus of Samos. Aristarchus proposed a heliocentric model of the solar system, probably based on a Pythagorean notion of a central fire around which all the planets (including the sun) would rotate. However, like the Atomist theory, his heliocentric model could not be proved. For one thing, the model predicted that the background stars should wobble slightly over the length of a year caused by the earth's changing angle to them. This motion is called a parallax. While this motion does exist, it was beyond the level of observational accuracy available to the Greeks.

Possibly the greatest mathematical mind of the Hellenistic period was Archimedes. Archimedes was a mathematician, but also concerned himself with science of mechanics. Unlike Euclid who wrote the Elements as a textbook, Archimedes wrote for a very small audience of the most advanced mathematicians of his day, and so few works of his survive. He used a system of proof that presaged the system of limits employed in modern calculus. His mathematics would prove to be extremely influential when his works were rediscovered in the Renaissance. Apollonius, who worked with conic sections—ellipses, parabolas, hyperbolas and circles—would also prove influential in the Renaissance.

There are two distinct periods in Hellenistic science that are divided by the turn of the Common Era. About this time the political instability of the transition to Roman rule disrupted the transmission of science.

Claudius Ptolemy (no relation to the Egyptian rulers of the same name) based his *Almagest* (as it came to be known to the Arabs), largely on the basis of the observations of the astronomer Hipparchus. Hipparchus had been the first to propose that mathematical models of planetary motion have predictive power. The Ptolemaic model takes its name not from its originator, but from the man who wrote the definitive textbook on the subject. In addition to being an astronomer, Ptolemy was a mathematician, geographer and astrologer. Because it is the Ptolemaic model that is so influential in astronomy for the next fifteen hundred years and is finally overthrown with the Copernican system, I want to take a moment to explain a little bit about it.

Uniform circular motion required because it was "perfect", but also because it was the only kind of motion Greeks were capable of modeling mathematically.

During this second period of Hellenistic science, Ptolemy was not alone. Medicine also had its great author, Galen, who not only expanded upon Hippocrates' medical writing, but also attempted to correct some of the flaws. Galen's was the medical text transmitted to the Arabs and upon which they built their medical practices. While primitive by modern standards, Galen made great strides over existing medicine.

Diophantus was also working during this period, and developed an algebraic system, introducing negative and complex numbers. His major work only survives in fragments, and was not rediscovered again until mathematics had passed him. The Arabic developments in algebra were arrived at independent of Diophantus.

Christianity began to take hold politically in the 4th century, and began to have an effect on the practice of science. The atomist theory, for one, would become associated with atheism—questioning Aristotle (who rejected the notion of a vacuum, which atomist required) became tantamount to questioning the existence of god. Christianity had an increasingly deleterious effect on science. Hypatia of Alexandria, a woman mathematician, astronomer and philosopher associated with the Library of

Alexandria in the late fourth century-early fifth century CE. Hypatia not so much important for being a woman scientist at a time when women were confined to the role of wife and mother, but rather that she was a martyr for science. She was dragged into a church and dismembered by a Christian mob of followers of the Christian bishop Cyril (later made a saint). Conservative members of the Church like Cyril believed that science was "pagan", even "atheistic". Led many scientists after the death of Hypatia and the closing of the Academy in the following century to flee to Persia (Gondeshapur) where Islam would later absorb much Greek science. Attitudes like Cyril's led to the decline of science both in Byzantium and in western Europe.

Islam:

At its height, the Islamic world held territories from India to Spain. Arab scholars included Muslims, but also Jews, Christians and pagans writing in Arabic. Islamic science always struggled with a very fragile balance between conservative clerics, and the protection of powerful rulers. Those sciences perceived as most useful to Islam, allowed others to survive as well: particularly astronomy, mathematics and medicine. Astronomers were needed especially for timekeeping, and determining location for facing Mecca, and eventually made official part of Islam faith, and even practiced at mosques. Under this system, Arab astronomers surpassed everyone else in the world: 13^{th} century saw them hired as imperial astronomers in China over native Chinese, and remained the best until Europe overtook them in the 16^{th} century.

The sources of Islamic science were widely varied. They adopted the scientific traditions of the Indians, Persians, and Greeks whom they conquered. Early dynasties were dominated by foreign civil servants, and this helped speed assimilation of foreign sciences and encouraged translation efforts.

Religious law considered most sacred. Those pursuing "foreign" sciences could be taken as impious, regardless of whether it disagreed with Koran or used to support. Physicians most likely to gain notoriety, but this did not imply acceptance of philosophical views. Physicians, like other scientists, studied more than one science at a time, and promoted the power of reason. This brought them into conflict with religion, because Islam denied power of reason without revelation.

Like their Greek predecessors, secrecy/elitism on intellectual subjects was widespread. There was a reluctance to apply science to everyday problems. The fear of persecution for their studies certainly did not engender a feeling of openness about science. However, there was also a fear that information might fall into the "wrong" hands, from a strong distrust of the common man. So great was this fear, that when the printing press made its way into Islamic lands, it was banned, in some places as late as the early 1900's.

On the opposite end of this extreme, however, large public libraries were often endowed by wealthy patrons and associated with mosques. These libraries could house not only books on Islam but also the sciences. However, spasmodic sectarian intolerance led to book burnings or the confiscation of the libraries contents. This ambivalence about the dissemination and pursuit of knowledge could be seen in the Koran and other religious writing. A quote from Mohammed goes: "He who pursues the road of knowledge, God will direct to the road of Paradise…" However, he is also to have distrusted novelty and equated it with heresy. Despite these problems, science found a sometimes precarious handhold in the Islamic world with the support of powerful rulers, and was able to flourish in comparison to the Christian West.

One of the developments that occurred in Islam that promoted the spread of learning was the *madrasa*. These were essentially Islamic colleges, endowed typically through the wills of wealthy patrons to study the Islamic "sciences", such as theology and law. Foreign sciences were generally forbidden subjects of study in the *madrasa*s, but the libraries did house books on these subjects, and study sometimes went on *sub rosa*. Those discovered studying subjects considered forbidden, however, could be threatened with death. All subjects were taught through a process of strict memorization and reliance on authority; even the sciences were taught without correcting weaknesses of texts or working problems. Scholars who began quite knowledgeable in Greek sciences risked conservative clerics issuing *fatwa* against them if it became well-known. There was no separation of religious and secular spheres as would occur in the West because the *madrasa* were endowed under Islamic law, and not permitted to deviate from the terms of their endowments. It was not until after the 11th century that the rare medical *madrasa* was set up which helped to push for the standardization of medical training. These became associated with the development of hospitals from which our modern hospital descend.

One of the great scientists to come out of the Islamic world was al-Khwarizmi. He is considered the father of Algebra, and the first to used the term *al-gebr*, meaning 'restoration', referring the restoration of balance in an equation by adding or subtracting from both sides. His name is also the source of the word 'algorithm'. Despite the work of Diophantus which preceded him, al-Khwarizmi is created with inventing our modern notion of algebra because Diophantus' methods seem to have been unknown to the Arabs, and all later Arabic mathematicians would follow the methods laid down by al-Khwarizmi. In his book, he introduced the decimal notation, apparently borrowed from the Indians, including the digit zero, which had been unknown to the Greeks.

Astronomy was one of the sciences Islam came to find more or less useful, and it was permitted to flourish with the support of powerful rulers—their interest was generally in astrological predictions. Advances in astronomy served as impetus for developments in mathematics: plane & spherical geometry, trigonometry, computational methods and algebra. By the 11th century, astronomy, with its used for keeping calendars and finding the exact location of Mecca from village mosques, became an official part of Islamic religious practice and were given official sanction in the person of the timekeeper or *muwaqqit*. This gave astronomers some level of acceptance within the community, but conservative clerics strove to restrict the investigations of these astronomers. This did not prevent complicated philosophical and mathematical debates from arising. The most important of these was over Ptolemaic astronomy. There were a large number of scientists that objected to Ptolemaic astronomy, and they fell into two camps: those with philosophical problems with the model (mostly incapable of producing satisfactory models) and those who had scientific or mathematical problems (objected for observational reasons); corresponding roughly to west vs. east. Various non-Ptolemaic models were proposed, the details of which do not concern us here, but the most influential would arise in the 13th century around the great observatory at Maragha.

Maragha Observatory was built in Persia by Mongol conquerors who converted to Islam. Their principal interest was in astrology, but Maragha became a haven for serious astronomical research as well. They were concerned with the predictability of the Ptolemaic model, but also with what they perceived to be a lack of scientific consistency in it. They went so far as to reject the Ptolemaic model even without a satisfactory replacement. While none of the models generated at Maragha rejected geocentricity, their mathematical methods pioneered here would find their way into the model of Copernicus. Maragha only lasted 60 years, as long as religious leaders could be placated, but would be a haven for intellectuals of all kinds while it survived and boasted a library of perhaps 400,000 volumes, and large astronomical instruments.

In addition to these advances in mathematics and science, Arabs advanced science in other fields as well. A few highlights: advancements in trigonometry; medicine took great stride forward: hospitals, medicinal herbs, effects of stress on health, rejected appeals to "evil spirits", medical ethics emphasized, even barbers who extracted teeth were required to pass period inspection, first apothecary shops; a theory of evolution was proposed (and ignored); another heliocentric planetary model was proposed (and ignored); elliptical orbits were proposed for planets (no math available to model); optics advanced; (al)chemistry; map-making.
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Medieval Europe:

There are few positive things that can be said about the history of science in Byzantium or the early medieval period. Science was undergoing a slow process of loss or barely holding to what it possessed. The Byzantines were a little better off because of slightly greater political stability, and because they did not face the linguistic barriers to Greek science that western Europeans faced. It was not until the 11th and 12th centuries that things began to look bright once again for science in the West. About this time the population of Europe increased dramatically, urbanization which is associated with advanced learning began, and with political stability came the increased opportunity for trade bringing Europe finally into contact with science again.

The 12th and 13th centuries saw the rise of European universities like Paris, Bologna and Oxford. The previous educational system had been bases largely on private schooling or monastery schools. The universities that developed sprung largely from such schools, and while they were early on associated with the Church, they were not controlled by the Church. This was an important difference between the university and the Islamic *madrasa*. In addition, Roman legal traditions helped assure the independence of these secular organizations, and were legally treated much like Guilds. This made it possible for universities to resist the pressure of the Church when conflict would eventually arise. Another difference of the European system over the Islamic one is that university "masters" were created as a sort of intellectual knighthood. They received certain civil protections and exemptions that were never afforded their Muslim counterparts. A third difference was that Church fathers studied science and logic. The tradition of Biblical criticism in the West supported humanity's ability to reason, and helped pave the way for the reintroduction of science into Western Europe.

By 12th century, Aristotle, Euclid and Ptolemy were central parts of university curriculum. Medieval astronomers compiled a *corpus astronomicus* of instruments, observation tables and other data that allowed for prediction of eclipses, etc., and formed the basis of the Copernican revolution. The spread of Arabic and Greek science back into Europe came largely from Spain and through Italian merchants.

Things did not proceed very smoothly. The Church attempted to ban the study of certain ideas or texts it felt ran contrary to Scripture. Their efforts were not entirely successful. Universities under local bans tended to ignore them for fear of losing ground to foreign universities. So great was the fear of "rational" philosophy that even Thomas Aquinas, who was eventually named a saint, had his works banned for a time. The backlash to science could be quite severe, and at times those who showed any aptitude for creative genius in science or technology were frequently accused of selling their souls to the devil.

The late Middle Ages also saw the beginnings of standardization of medical training, and education generally; and at least one brilliant mathematician, Leonardo of Pisa, or Fibonacci, who brought the algebraic system to Europe in early 13th century. Perhaps the only great mathematician in Europe until the Renaissance. He also attempted to import the Arabic numerals, but this met with considerable resistance.

Renaissance:

The Renaissance saw science take off again in Europe, but I want only to mention a couple of things about the beginning of the Renaissance here. With the Renaissance, it became important for models to be physically true; scientists fought for the *truth* of the world, even when it contradicted Scripture, even risked their lives.

Nikolaus Copernicus (d. 1543) was attempting to reform the calendar for the Church when he developed his heliocentric model for the solar system. It is nearly identical mathematically to the Arabic models proposed by the Maragha school, though the debate continues about whether he knew of their work or not. In his book, he cites deficiencies in the Ptolemaic model that are not shared by his model, however, so fearful was he of the reaction of the Church to his model that he refused to release it until after his death. Copernicus was right to be concerned. In 1586, Giordano Bruno was burned at the stake for heresy for being a heliocentricist. Because mysticism was tied to science until the Age of Enlightenment, men would be murdered by the Inquisition in the name of protecting the Church from science and the black arts.

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History of Science: Islam and the West

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For Western Civilization I, Spring 2001, Daniel-James Thornton

Introduction:

What is science?

The Greek World:

Classical—

Thales of Miletus (625-545 BCE)
Pythagoras (582-500 BCE)
Anaxagoras (488-428 BCE) (persecuted for impiety)
Democritus (c. 420 BCE)
Socrates (470-399 BCE) (executed for impiety)
Hippocrates (460-377 BCE)
Eudoxus (408-355 BCE)
Aristotle (384-322 BCE)

Hellenistic—

Euclid (330-260 BCE)
Aristarchus of Samos (310-230 BCE) (persecuted for impiety)
Archimedes (287-212 BCE)
Apollonius of Perga (260-200 BCE)
Hipparchus (190-120 BCE)
Ptolemy (85-165 CE)
Galen (129-199 CE)
Diophantus (2nd cent CE)
Hypatia (died c. 414 CE) (killed by Christian mob)

Islam:

Officially begins 622 CE.

Al-Khwarizmi (8th century CE)
Maragha School (13th century)
Al-Tusi (13th century)

madrasa: Islamic college
fatwa: legal judgment
al-gebr: the restoration
muwaqqit: timekeeper

Medieval Europe:

Universities begin twelfth century.

Leonardo of Pisa, Fibonacci (13th century)

Renaissance:

Copernicus (d. 1543) (would not release heliocentric model until after his death for fear of persecution)

Giordano Bruno (d. 1586) (burned at stake by Inquisition for heresy)

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