

The scientific revolution and Kepler

http://en.wikipedia.org/wiki/Johannes_Kepler

In this lecture we will move on with our historical survey and discuss the process of science and its relation to culture after the classical Greek period and through the scientific revolution. There are some organizing questions about the scientific revolution that you should bear in mind as we go through the first part of this class:

1. Why did the scientific revolution occur in western Europe as opposed to elsewhere?
2. Would the scientific revolution have occurred in Europe without the Protestant Reformation?
3. How much of the scientific revolution was driven by immediate practical applications, as opposed to the idealized search for knowledge?
4. Why was Kepler's model of the solar system not widely accepted until decades after his death?
5. How did the emphasis on experiment transform science?
6. Did religion had a net positive or a net negative effect on the scientific revolution?

In the last 40-45 minutes of class we will have our first official debate, and it will be on the last of these four topics.

Science after the classical Greek period

After Aristotle there was certainly a continuation of scientific investigation in the Greek world. In some ways, in fact, the peak of Greek science came in the following century or two. Highlights include the astronomical discoveries of Hipparchos (who found that the Earth's axis precesses over thousands of years, and who put together the first detailed map of the stars) and the remarkably modern mathematical developments of Archimedes, who almost reached calculus 1900 years before Newton.

But this soon dropped off, and from the perspective of science, Europe was a dead zone for most of the AD period. A small fraction of Greek texts did persist, however, and during the Muslim golden age (roughly 632-1200 AD) these books were translated into Arabic. Some of these books fell into the hands of Europeans as a consequence of the Crusades (1095-1291 AD), and interest in science began to be rekindled. Aristotle's works had particular impact, especially due to Thomas Aquinas' attempted synthesis of Aristotelian philosophy with Christian theology.

But over the next two to three centuries, one experiment after another demonstrated that Aristotle and other ancient authors often got things wrong. This was true in physics, astronomy, and medicine among other fields. One may, therefore, ask why it was that his influence held on so long (until the 1700s in some fields!). A simplified answer is that the corrections to Aristotle and others were independent of each other, so rather than overturning Aristotle's largely common sense based framework, little bits were changed.

In the rough period 1450-1750, Europe underwent what is commonly called the scientific revolution. This is a period that has been studied in great detail, and as one might expect there is disagreement about many of the major and minor causes. One of the big persistent questions is why the scientific revolution happened there, and at that time, instead of other places and earlier. To explore this we will look at some aspects of Chinese science and Arabic science, and the disputed reasons why these cultures did not have a scientific revolution before Europe did.

Chinese science

For a period of more than a thousand years after the fall of Rome, China was arguably the most powerful nation on Earth. Yes, it got conquered on occasion, but its level of technology and its sheer size and continuity were remarkable. Among its many innovations were the development of the compass, gunpowder, paper, and printing. Book printing existed as early as the 7th century AD in China, Korea, and Japan, and movable type was also invented by the Chinese and used as early as 1048 (although soon abandoned because of the number of characters needed in the Chinese pictographic system). They had sophisticated and well-kept astronomical records, suggested the correct explanations for eclipses and phases, and understood that the Moon was spherical.

It is clear, therefore, that there were periods where the Chinese were centuries ahead of Europeans in terms of technology. Why, then, did they not have a technological revolution? Many ideas have been proposed, so let's go through some of them.

- China is one giant country and has been for much of its existence, hence there has been little motivation to innovate (why would a government want change when it already has dominion?). In contrast, Europe was not at all politically united.
- Another possibility is what Mark Elvin has called a "high level equilibrium trap": given the size of China and its large population, workers were cheap enough, and agricultural productivity was high enough, that mechanization was not needed. If necessity is the mother of invention, therefore, invention was not as driven in China as it was in Europe.
- It has also been argued that Taoist principles (which addressed nature more than the also-influential Confucianist principles) suggested that although there might be order in nature, this order was not ordained by a rational personal being. There is, therefore,

no reason that we should be able to spell out the laws of the universe.

- The final suggested reason that we will discuss has to do with the lack of generalizations by Chinese scientists. To quote the mathematician Yang Hui (1238-1298): “The men of old changed the name of their methods from problem to problem, so that as no specific explanation was given, there is no way of telling their theoretical origin or basis.” (from the Wikipedia page http://en.wikipedia.org/wiki/History_of_science_and_technology_in_China).

In addition to these major potential causes, it seems likely that various aspects of luck entered. For example, all European writing is alphabetical instead of pictographic, which ultimately meant that (unlike for Chinese) movable type was an efficient way to disseminate information. In addition, the contact with previously unsuspected cultures starting with Columbus’ 1492 voyage may have made many people question their assumptions as well.

Islamic science

Starting in the early 600s, Muslim culture swept over the near and middle east. A particular question that is often asked of the Muslims is whether they were mainly preservers of knowledge, or whether they produced significant innovations themselves.

The most recent views appear to be that Muslim scientists laid the foundations for experimental science with contributions to the scientific method, and especially their empirical and quantitative approach to inquiry. They also introduced many specific institutions, and made many advances in mathematics and optics. However, these developments and the emphasis on empiricism did not flower into modern scientific inquiry.

Why, then, did the scientific revolution not develop in the Muslim world? Several reasons have been cited, most of which are disputed.

- One proposal is that orthodox theology, rather than rational theology, rose and choked off investigations. Against this we note that many great Islamic scholars were orthodox, just as all major figures in the scientific revolution (Galileo, Kepler, Newton, etc.) were devout believers.
- Another suggestion for the decline of Muslim science has to do with religious conflicts and Mongol invasions. In comparison, Europe was never invaded by the Mongols. On the other hand, even after the sack of Baghdad scientific activity did continue in the Middle East, and in fact there were multiple writings of encyclopedias.

The scientific revolution itself

Despite its name, the scientific “revolution” was not an abrupt event. It gathered steam gradually starting around the middle of the 1400s, and has accelerated ever since.

Some of the motivating factors were technological. The development of mass-produced movable type by Gutenberg in 1439, followed by his invention of the printing press in 1454, made books available to a vastly larger number of people than ever before. Early microscopes appeared around 1590 and early telescopes around 1608, and both of these inventions facilitated remarkable discoveries.

Other factors were cultural or stemmed from new viewpoints. The voyages of Columbus, Magellan, and others revealed people and customs that were alien to the Europeans. The power of the Catholic church in Europe was challenged in multiple ways, from the Protestant Reformation to Henry VIII's separation of the Church of England from the Vatican. The competition for new resources between many countries, combined with the lack of the strong unifying hand of the Church, produced an environment in which innovation was rewarded. It has also been suggested that aspects of Christianity, or more specifically Protestantism, encouraged exploration of nature.

To me, whatever the causes of the scientific revolution its most important effect was to move people away from what was essentially ancestor worship (i.e., a sense that ancient scientists such as Ptolemy and Galen knew far more than we do, hence study of their works should predominate over new investigations) to a feeling that we could do better, and learn more, by ourselves. The transformation of viewpoint that this represented, which is in some sense giving ourselves permission to disagree with our ancestors, strikes me as a profound shift.

Kepler, Brahe, and the motion of the planets

To my mind, the story of Johannes Kepler is remarkable because in him we have a mystical figure who was driven by aesthetic considerations but who nonetheless placed agreement with observations above all such considerations. This uncompromising position led, after many tortuous months, to one of the most remarkable breakings of a mental block in the history of science.

Kepler was born in 1571 in Germany, into a family whose fortunes had fallen. His father left when he was five years old, and his mother was weird enough that late in her life she was tried for witchcraft (a charge against which Johannes successfully defended her). He demonstrated early aptitude in mathematics, and in 1594 became a teacher of mathematics and astronomy at a school in Graz, Austria. One of his duties was to make astrological forecasts, and he was quite successful at this: he predicted a cold winter and an invasion of the Turks, both of which happened. However, he never fully bought into astrology, referring to it as the foolish daughter of a wise mother (astronomy), and chafing at its imprecision compared to astronomical calculations.

As a theology student at the University of Tübingen, Kepler had become a committed

Copernican. He therefore accepted that the orbits of the planets were circles centered on the Sun (modulo epicycles and whatnot), but the radii of the orbits seemed arbitrary. Then, on July 19, 1595, while teaching in Graz, he had a dazzling epiphany: if one inscribed a circle in a regular polygon, then circumscribed a circle around the same polygon, one had a unique ratio of the radius of the inner circle to the outer. Perhaps this would provide the reason for the particular ratios of the solar system. The problem was that there are an infinite number of regular polygons, but that even so there was no arrangement he could find that would give ratios consistent with observations. Later, he had an even better idea. There are five regular polyhedra, and six planets were known then (Mercury, Venus, Earth, Mars, Jupiter, and Saturn), and he discovered that starting with an inner sphere and doing the inscribe/circumscribe bit with, successively, an octahedron, icosahedron, dodecahedron, tetrahedron, and cube would yield the radii within the accuracy limits at the time. To the end of his life, Kepler considered this to be his greatest contribution to astronomy.

That's an odd thought from the modern perspective, because it is completely wrong. For one thing, two more major planets are known (Uranus and Neptune). For another, many other planetary systems are known that don't come close to following this arrangement. In addition, with our much more precise measurements the system doesn't even work for the inner six planets. To Kepler, however, the system seemed so right, so perfect, that it had to be true. To me, this is a lesson about how easy it is for our aesthetic predilections to get the best of us. However, Kepler's later work suggests to me that if he had been confronted with what we know now, then he would have given up his cherished idea. His ability to abandon concepts that do not fit the data was truly remarkable.

In the next few years, Kepler published his work and corresponded with various astronomers. Fortunately, Tycho Brahe invited Kepler to visit him in Prague, and Kepler set off on January 1, 1600. Tycho was the greatest observational astronomer of his day, and his story is interesting in its own right, but in the interests of time we'll focus on Kepler's use of his data.

Kepler with Tycho's data

Kepler's main duties, in addition to the casting of horoscopes, involved the completion of the Rudolphine Tables, which would replace existing astronomical tables.

Kepler went to work, but found small but persistent discrepancies that bothered him. Tycho had suggested that Kepler analyze Mars in particular, and Kepler found that no matter how he adjusted his equants and other complications, the data didn't quite fit. The deviation was small; the maximum discrepancy was eight minutes of arc, which is the angular size of a penny at a distance of eight meters. Most people in history would have dismissed this as of no consequence, but Kepler was agitated by the difference because he knew that Tycho's observations were much better than this (the median error was about 1.5 arcminutes,

the angular size of a penny at more than forty meters). He therefore obsessed about this for years.

His first breakthrough was to consider that perhaps the speed of the orbit varies with the distance from the Sun. This has similarities to the known properties of magnetism and the intensity of light, so these served as motivation. He found, empirically, that planets sweep out equal areas in equal times, and formulated this law (now known as Kepler's second law) in 1602.

The next question was the shape of the orbit. He thought about egg-shaped orbits, and made more than 40 attempts to fit Tycho's data until finally in 1605 (and after multiple arithmetic errors) he came to the possibility of an ellipse. An ellipse is one of the classic conic sections (i.e., it is a shape that can be produced by the intersection of a plane with a cone), and Kepler had assumed that this was too simple to have been overlooked by other astronomers. Instead, no one previously had had the insight needed to consider ellipses, and (equally importantly) no previous astronomer had access to such precise data. With this, Kepler produced what is now called his first law: all planets move in ellipses, with the sun at one focus. In 1619 he added his third law: the period of an orbit is proportional to the three-halves power of the semimajor axis. He finally completed the Rudolphine tables in 1623, publishing them in 1627, and died in 1630. In his last twenty years he also wrote what is now considered to be the first science fiction novel, successfully defended his mother against witchcraft charges, and performed sundry other investigations into optics and mathematics.

As a side comment, from the perspective of history I find it a little strange that no one came up with the idea of elliptical orbits prior to Kepler. Comets moved in obviously noncircular orbits, and indeed this led Tycho to conclude that there could not be literal celestial spheres, as the comets would puncture them. However, no one thought that the planets might move similarly.

To restate Kepler's laws in a concise form:

1. Planets move in ellipses, with the Sun at one focus.
2. The line from the planet to the Sun sweeps out equal areas in equal times.
3. The square of the period of the orbit is proportional to the cube of the semimajor axis.

Reception of Kepler's astronomy

The agreement of Kepler's three laws with the most precise data of the time, including subsequent telescopic data, was so spectacular that one might suppose that astronomers were immediate converts. This was, however, far from the case. A contributing factor was undoubtedly that Kepler was renowned for the impenetrability of his prose (and of

his oral delivery as well; he was apparently a horrendous lecturer). This may have been a reason that Galileo, his senior by just seven years, disappointed Kepler by never responding to his astronomical works even though the two corresponded on other matters and even though Galileo recommended Kepler for a position as mathematician at Padua when Galileo departed in 1611. In addition, there were some missed predictions: for example, the transit of Venus across the Sun in 1631 was predicted incorrectly because of some mistakes in the Rudolphine table. Finally, in addition to the bare-facts astronomical model presented by Kepler he added many physical and metaphysical elements, some of which really were weird (such as the magnetic soul of the Earth). It took several decades, indeed until the ascendancy of Isaac Newton, before people were sufficiently confident of being able to sort out the useful from the useless that Kepler's planetary model was accepted fully.

Discussion, and the role of religion

There were many factors that entered the scientific revolution. These include the existence of many small countries instead of one large one, and external influences such as importation of Greek texts from the Arabs, insulation from the Mongols, and contact with new cultures. There is vigorous argument about the relative importance of these various factors. My personal feeling is that China and the Muslim world might have had their own scientific revolutions within no more than a few centuries after it actually happened. However, Europe got there first, and global interdependence rapidly emerged.

Let us now return to the role of religion. Specifically, you will debate whether this was been a net positive or a net negative in the development of the scientific revolution. On the positive side, monotheism has been proposed as a driving force behind searches for rational explanations of phenomena. If an individual, personal deity had not been thought to be behind the universe, what reason would ancients have had to look for organizing principles? In addition, Aquinas had a strong influence with his emphasis that understanding of the universe required reason as well as faith. On the negative side, religious prohibitions against dissections were problematic, and one can argue that prior to the Protestant Reformation the Catholic Church in Europe played the same role as a large empire did: basically, change was bad for the empire, therefore it slowed down progress. In addition, we argued that some aspects of religious belief such as Taoism actually served as arguments against an ordered universe with specific causes.

What do you think?