The Renaissance and the scientific revolution

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 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. 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 Hipparcos (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. Apollonius of Perga gave us our modern understanding of conic sections (circle, ellipse, parabola, hyperbola), Euclid systematized geometry more than any of his predecessors, and Strato of Lampsacus (the third director of Aristotle's institute the Lyceum) had very modern-sounding approaches to empiricism in physics. For example, he argued that objects must accelerate when they fall, because a stone dropped from a finger's-breadth above a surface will land softly whereas a stone dropped from a hundred feet will hit hard.

Progress was also made in the life sciences, although this was more difficult because of the complexities of the systems involved. Some decent observations were made, but the conclusions drawn were often far off the mark. A good example of this is Galen, the most famous physician of ancient times. Galen had to base most of his observations on dissections of monkeys, because dissection of human cadavers was strongly opposed (largely on religious grounds). Based on this he produced an account of the heart, arteries, and veins that was the standard until Harvey in the 1600s, and he also had good observations of the function of the brain. However, he made innumerable mistakes and had theoretical ideas based on

bodily humors (blood, phlegm, and black and yellow bile!). More damaging in the long-term sense was that his works were so prolific and authoritative that for centuries after his death the impression was left that there was nothing left to learn; why experiment yourself when you could just consult Galen?

From the perspective of science, Europe was a dead zone for most of the AD period. A convenient marker for the final demise of knowledge in this sense was the murder in 415 AD of Hypatia, a women who was generally considered the most accomplished scientist and philosopher of her time and was the head of the Platonist school at Alexandria when she met her demise. A rumor spread that she was the reason for the existing discord between the imperial prefect and the archbishop at the time, and she was dragged from her chariot and killed. The library of Alexandria itself was also destroyed, although there is dispute about whether the final destruction happened as a general anti-pagan measure ordered by the Christian emperor Theodosius in 391, or whether this was a consequence of the sack of Alexandria by Arabs in 642. In any case, the result was that nothing of the greatest library of antiquity survived.

The rediscovery of Greek texts via Arabic sources

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. The first books to be rediscovered were those of Aristotle, with the result that for a couple of centuries his ideas dominated the thoughts of the period. A good example of this is the writings of Thomas Aquinas (1225-1274), who was and is one of the most influential of the fathers of the Catholic church. In a very simplified sense, Aquinas viewed theology as a science, and believed that faith and reason were both necessary to obtain true knowledge of the divine. His approach to reason was largely informed by Aristotle, indeed so much so that three years after his death some twenty of his propositions were officially condemned as violating the omnipotence of God. Fifty years later, however, he was made a saint and he has been considered the definitive word on many aspects of Catholic theology since.

With this in mind, Aristotle acquired enormous influence. Although some early European scholars (notably Roger Bacon, a contemporary of Aquinas) emphasized empiricism, most in that period relied on ancient texts rather than their own observations. The gradual rediscovery of works by other Greek authors eventually made it clear that Aristotle was not the only ancient authority. For example, Aristotle felt that mathematics was essentially irrelevant to explanations of physical phenomena, because it was not physical itself and therefore did not explain effects with causes. In contrast, Plato felt that mathematics could help explain the universe (maybe going a bit too far himself; he didn't believe much

in observation or experimentation!).

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 addition, Aristotle did *not* make mistakes in everything. For example, his observations of marine life are legitimate to this day, even if the conclusions he drew are not. Even so, after the infusion of information from Arabic translations of Greek texts, Europe slowly moved in its scientific thought closer to our current approach.

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.

One realistic-sounding suggestion from many people is that because China is one giant country and has been for much of its existence, there has been little motivation to innovate (why would a government want change when it already has dominion?). To a degree this may have been caused by the lack of major geographic barriers within China (see *Guns, Germs, and Steel* by Jared Diamond for a discussion of the geographical influence on civilizations). In

contrast, Europe was not at all politically united, and its fragmentation into many relatively small countries meant that innovation could give one country an important advantage over others.

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. Even when Europeans started making significant contact, the Chinese were dramatically superior in various ways. For example, the admiral Zheng He made trips to Africa as early as 1421 (bringing back giraffes!), but the voyages were discontinued due to their expense and inobvious return. This superiority, combined with anti-European sentiment stemming from the apparently subversive activities of missionaries and (in the 19th century) the Opium Wars, probably dissuaded China from copying European scientific and industrial approaches.

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. Much of this persists today in traditional Chinese medicine, which is based on the idea that causative principles operate on all scales. What we mean by this is that if you have a disease, it is not necessarily true that one can look for its cause in a local way (e.g., in just the area affected, or just the individual affected). Instead, the whole universe is connected, hence large-scale "energy fields" or whatever might have to be addressed to cure the disease. In contrast (goes an argument from Joseph Needham), the Christian culture of Europe was strongly predisposed to think that the universe is driven by a rational personal being, hence the laws of this being should indeed be comprehensible. Additional subtleties in this argument have also been proposed, e.g., that the embrace of manual labor in Protestantism led to new examination of nature and then to scientific discoveries.

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). As an example of this although as stated earlier Chinese astronomers did know that the Moon was spherical, they did not accept the concept of a spherical Earth until contact with Europeans in the 17th century. One would speculate that without overarching general ideas, each new discovery would be isolated and there would be no particular reason why one would expect to follow them up with related developments.

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. The Black Death in Europe (peaking around 1350), which was obviously catastrophic for the individuals at the time, may have stimulated gradual rethinking of many aspects of society including the approach to knowledge. In addition, the contact with previously unsuspected cultures starting with Columbus' 1492 voyage may have made many people question their assumptions as well. None of these events happened in China to the same extent if at all.

Islamic science

Starting in the early 600s, Muslim culture swept over the near and middle east. As we have already discussed, Arabic translations of Greek texts served as a major stimulus to European science after the Crusades. 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 scientific method, and especially their empirical and quantitative approach to inquiry. They also introduced many specific institutions, including the first (1) public hospital, (2) psychiatric hospital, (3) public library and lending library, (4) academic degree-granting university, and (5) astronomical observatory as a research institute. They made many advances in mathematics, and "The Book of Optics" by Ibn al-Haytham (1021 AD) radically changed our understanding of light. 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. Therefore it is not orthodoxy itself, or religion itself, that is to blame. Indeed, as indicated above, some prominent researchers attribute the scientific revolution to monotheism.

Another suggestion for the decline of Muslim science has to do with various conflicts. These include conflicts between Sunni and Shia faiths, Crusader invasions, and most importantly Mongol invasions. The Mongols were not known for their appreciation of learning or science of any sort, and they destroyed Muslim libraries, observatories, hospitals, and universities (including the destruction of Baghdad, the intellectual center of the Abbasid

empire, in 1258). By comparison, Europe (which would have been felled quickly by the Mongols) caught a break when Mongke Khan, conqueror of China, died in 1259 and the Mongol contingent that was in the process of conquering Poland and other parts of eastern Europe returned to take part in the succession battles. Therefore, Europe was essentially unaffected by a major chapter in the histories of both China and the Muslim world. 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. Indeed, science in the Middle Ages prior to about 1450 reminds me of a standard in fantasy literature, which is that in the old days individuals and civilizations had far greater power than they do now (as an example, read the Lord of the Rings trilogy). 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.

In the next two classes we will discuss specifics of some of the ways that European science managed to cast off the prejudices of its ancestors, leading to remarkable advances in all fields (although the physical sciences saw that fastest improvements). Now, however, we will set the stage for our debate question: was religion a net positive or a net negative in

the development of the ideas that led to the scientific revolution?

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 ones, 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, the prominence of Aquinas and his emphasis that understanding of the universe required reason as well as faith had a strong influence. 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?