Lecture 10: The Scientific Revolution, 1543-1600

> *Why then do we hesitate to grant [the Earth] the motion which accords naturally with its form, rather than attribute a movement to the entire universe whose limit we do not and cannot know? And why should we not admit, with regard to the daily rotation, that the appearance belongs to the heavens, but the reality is in the Earth?*

---Copernicus, *On the Revolutions of the Heavenly Bodies* (1543)

One of the most important developments in the western intellectual tradition was the Scientific Revolution. The Scientific Revolution was nothing less than a revolution in the way the individual perceives the world. As such, this revolution was primarily an epistemological revolution -- it changed man's thought process. It was an intellectual revolution -- a revolution in human knowledge. Even more than Renaissance scholars who discovered man and Nature (see Lecture 1), the scientific revolutionaries attempted to understand and explain man and the natural world. Thinkers such as the Polish astronomer Nicholas Copernicus (1473-1543), the French philosopher René Descartes (1596-1650) and the British mathematician Isaac Newton (1642-1727) overturned the authority of the Middle Ages and the classical world. And by authority I am not referring specifically to that of the Church -- the demise of its authority was already well under way even before the Lutheran Reformation had begun. The authority I am speaking of is intellectual in nature and consisted of the triad of Aristotle (384-322), Ptolemy (c.90-168) and Galen (c.130-201). The revolutionaries of the new science had to escape their intellectual heritage. With this in mind, the revolution in science which emerged in the 16th and 17th centuries has appeared as a watershed in world history. The long term effects of both the Scientific Revolution and the modern acceptance and dependence upon science can be felt today in our daily lives. And notwithstanding some major calamity -- science and the scientific spirit will be around for centuries to come. (For an excellent overview of the Scientific Revolution see Robert Hatch's The Scientific Revolution Home Page.)

In 1948, the British historian Herbert Butterfield (1900-1979) prepared a series of lectures to be delivered at the History of Science Committee at Cambridge. These lectures became the foundation for his book, *The Origins of Modern Science*. In the Preface to this work, Butterfield wrote that:

> *The Revolution in science overturned the authority in not only of the middle ages but of the ancient world -- it ended not only in the eclipse of scholastic philosophy but in the destruction of Aristotelian physics.*

The key word here, I suppose, is authority. The Renaissance and Reformation also attacked the stranglehold of medieval authority but with quite a different purpose and with decidedly different results. However, Butterfield continues:

> *The Scientific Revolution outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes, mere internal displacements within the system of medieval Christianity.*

Consider the period in which Butterfield makes this statement. It's 1948, just a few years after Hiroshima -- 78,000 men, women and children died within fifteen minutes of the dropping of the atomic bomb. This is what science has given us. And although I doubt whether Butterfield, civilized Englishman that he was, would have gloated over this fact of neat and efficient killing, the fact remains that this was science in action.

There are numerous questions we could ask ourselves about the Scientific Revolution: why it occurred? what forces produced it? why was it so revolutionary? why was it stronger in the Protestant North? But to my mind, before we can even begin to cope with these questions we must ask a much more basic question: What is science?

Science is no doubt with us today -- it surrounds our daily lives to such an extent that we now take it as a given. We expect science to be, to exist. Its effects and products touch the statesman and the soldier, the house husband and the grocer. Science has given us nylon, fluoride, latex paint as well as 747s, ever-faster microchips and PEZ. But science has also given us fluorocarbons, heroin, nuclear waste, dioxin, sarin gas and the atomic bomb. Science can be a mixed blessing -- with much that is good comes much that is clearly bad. But, what do we mean by science?

Science is faith. And the Gospel of that faith was written by Copernicus, Galileo, Newton, Darwin, Einstein and others. We are certainly not all scientists. I know I'm not a scientist. But yet, I'm sure that scientists are busy at work solving problems, the solution to which will help me in some way. Perhaps scientists can improve our situation here on earth, just as the Gospels perhaps did almost two millennia ago. A scientist is an expert and for some reason we have grown to trust experts. The scientists, the technicians, the experts -- they must know the answers to our questions.

We are surrounded by science whether we recognize it or not. Just about everything we see, touch, smell and hear, is a product of science. Furthermore, science has a language all its own, a language which uses expressions like: rational, method, methodological, systematic, rules, laws, behavior, experts, technology and so on.

What I would like to suggest is that for the non-scientist, science is an idea. And this idea -- science -- gives us ways in which to think about and explain our world and ourselves. Science provides a world view, a way of making sense out of the apparently random and meaningless experience of our lives.

The origins of this world view emerged full blown in the Scientific Revolution of the late 16th and 17th centuries. The Revolution itself was European -- it was cosmopolitan. Its short term effects were felt throughout the Continent and in England. And today, barely three or four centuries after the fact, there are few areas on the globe that remain untouched by modern science, whether for good or bad.

In the 16th and 17th centuries, scientists, theologians, philosophers and mathematicians were engaged in a vigorous debate over the natural world. Not so much man, but Nature. After all, the Renaissance had refined the dignity of man as perhaps distinct from the human depravity that the Church had preached. Nature -- the new focus was Nature. But why was this a subject for examination? Why had Nature become the new object of study? The reasons for this are complicated but for now I will suggest that answer lay with the Christian matrix. More specifically, the new focus on Nature was a direct result of the collapse of the Christian matrix, and this was the result of a combination of forces which produced intellectual change. To be brief, these forces were the Renaissance, Reformation (see Lecture 3), the Age of Exploration (see Lecture 2) and the spirit of capitalism. The major obstacle faced by the scientific revolutionaries was one of knowledge -- it was a specifically epistemological question. If an older world view was to break down, then something would have to take its place. A new human identity was required -- it was essential to the changes in the intellectual climate. How could the world be known? Another way of putting this is to say that if the Renaissance had discovered man and Nature, then it was up to the scientific revolutionaries to verify their knowledge of man and Nature.

What did science mean to the scientific revolutionaries? One of the problems inherent in this question is that the revolutionaries rarely used the word science. Instead, they talked and wrote about natural philosophy or the philosophy of nature. Nature, to them, meant the natural world, that is, what was natural, what was not made by human hands. I would suggest that using the expression the philosophy of nature was really a hangover from the medieval world. In other words, questions of science were subsumed under the study of philosophy, and since medieval man called the phenomenal world Nature, then it was quite logical to refer to the study of Nature as the philosophy of Nature.

Above all, science meant astronomy and mathematics. These seemed to be the only two fields of study that embraced both laws and the explanation of those laws. Astronomy and mathematics have their own symbols -- they have their own language. This language, though difficult, is stronger than any other language because of its power to be understood by people who speak different languages. In other words, the language of science is universal. Whereas Charlemagne (742-814) had created a scholarly language -- we call it, medieval Latin -- the scientific revolutionaries created a language of science, and we call this language, mathematics. The legacy of all this to the modern world -- to our world -- was the scientific way of thinking -- it is a process of thought which is technical, mathematical, logical and precise. It's complicated too -- it's difficult for the non-specialist to understand. But perhaps not that difficult. Consider the following definition of man given by R. Buckminster Fuller (1895-1983), the father of the geodesic dome:

> *Man is a self-balancing, 28-jointed adapter-base biped, and electro-chemical reduction plant, integral with the segregated stowages of special energy extracts in storage batteries, for subsequent activation of thousands of hydraulic and pneumatic pumps, with motors attached; 62,000 miles of capillaries, millions of warning signal, railroad and conveyor systems, crushers and cranes, and a universally distributed telephone system needing no service for seventy years if well managed, the whole extraordinary complex mechanism guided with exquisite precision from a turret in which are located telescopic and microscopic self-registering and recording range-finders, a spectroscope, etc.*

This is science gone absolutely crazy. Of course, such a definition of man ignores his nature -- his emotions, dreams, joy, sadness, successes and failures. In fact, Fuller seemed to ignore everything that made the individual fully human. It is a mechanical explanation of man -- man as machine. It is also an explanation of man that would not have been possible had it not been for an intellectual development we call the Scientific Revolution. The irony, however, is that if somehow we could have gotten Galileo and Fuller together over lunch, Galileo would have perhaps found Fuller positively mad (then again, Fuller would have not been the type of person he was without Galileo as a predecessor).

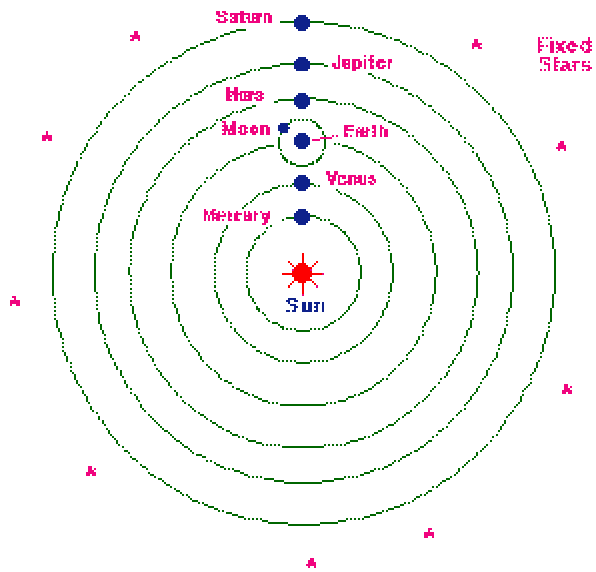
Before we talk about the scientific revolutionaries, the implications of their work and their world view, it is necessary to examine the medieval world view. It was, after all, the world view of medieval man that the scientific revolutionaries made the deliberate attempt to overthrow. The medieval world view -- the linchpin of the Christian matrix -- was fashioned from the ideas of four men. Two of them were from the ancient world -- Aristotle and Ptolemy. And the other two were of the medieval world -- St. Thomas Aquinas (c.1225-1274) and Dante Alighieri, (1265-1321).

According to the medieval world view, Nature was conceived to be kept going from moment to moment by a miracle which was always new and forever renewed. It was God who ordered the universe through these miracles. This entire scheme depended not only upon God, but upon the individual's absolute and unwavering faith in God. If God pronounced it to be so, then it must be so. But after 1350, let's say, by the time of Petrarch (1304-1374), some men became more interested in the form of the miracle. Knowing that the cosmos was of divine origin and moved according to the will of God, some men embraced that Faustian spirit that wanted to know more. It was not enough to simply accept the existence of miracles -- the miracles now had to be explained. These men wanted to know what order, to what hierarchy the miracle conformed. And this brings us to the medieval view of cosmological order. According to the intellectual tradition stretching from Aristotle to Dante, all things in nature -- all phenomena -- are composed of four fundamental elements. These elements were air, fire, earth and water. These elements were believed to follow certain laws -- they were to follow their ideal nature. So, since they are heavy and coarse, water and earth move downward. Likewise, since they are light and airy, air and fire move upward. Each of the four elements is constantly striving to reach its natural center. The striving of all these elements is what kept the cosmos going. In this scheme of things, the elements of air and fire predominated and together they composed a fifth element, more pure than the rest, which the ancients called "the aether." And since the heavenly bodies are "up there," they must be composed of "the aether." (The reader interested in a succinct overview of cosmology should consult the Foundations of Modern Cosmology page.)

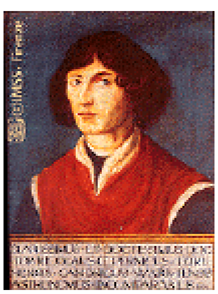
Which brings me to relate a brief story. In 1666, and with the city of London burning down, Isaac Newton left his study at Cambridge and made his way to his mother's home at Woolsthorpe in Lincolnshire. It was here, in his mother's garden, that the great Newton was struck by an idea -- the idea that the force which held the planets in their orbit was the same force which caused an apple to strike him in the head. Such an idea -- we of course know it today as universal gravitation -- would have been absolutely unintelligible even to an advanced medieval thinker. This is so for two reasons. First, medieval man did not see the movement of the heavenly bodies from the standpoint of the mechanics of motion. The heavenly bodies, after all, were composed entirely of aether. Theirs was an organic, living world view rather than our now more familiar mechanical conception. Second, and perhaps of even more importance, medieval man could not understand that the planets or the stars or comets were made of the same stuff as an apple -- matter.

When it came to conceptualizing the universe, the medieval world borrowed its knowledge from the Egyptian geographer and astronomer Claudius Ptolemy (c.90-c.168). The Ptolemaic System put the stars on a fixed sphere around the earth. At the center was an object about which nine concentric sphere were situated. This object was the earth. Beyond the earth, its position fixed, were the Moon, Sun, Mercury, Venus, Mars, Jupiter, Saturn and then the stars, and finally, the Prime Mover, the First Cause, God. The motions of the planets were complicated. Ptolemy said the planets moved in epicycles. The concept of epicycles was used by Ptolemy to explain why planets seemed to exhibit what is now known as retrograde motion, that is, the tendency for planets to move in one direction, then stop, change directions and then continue their original movement. Ptolemy's system was accepted during the Middle Ages but over time it became awkward. As improvements were made in the skills of observation, more and more epicycles were called for to explain the movement of heavenly bodies. A simple, regular, ordered and hierarchical system had, over time, become very complicated. Criticism of the Ptolemaic system began in the mid-16th century. The system which eventually overthrew that of Ptolemy was not based on criticism alone. Instead, another system took its place -- and that system came with the emergence of the New Science.

So monumental were his achievements in cosmology, the Scientific Revolution could almost have been called the Copernican Revolution. Born in Poland in 1473, it was the humble astronomer Nicholas Copernicus (1473-1543) who challenged the geocentrism of Ptolemy with his own heliocentric universe. Ptolemy would never recover -- neither would the Christian matrix. Copernicus studied mathematics at Cracow and managed to obtain a law degree from Bologna as well. In 1500 he was in Rome where he witnessed a lunar eclipse. The following year he studied medicine at Padua and in 1505 he left Italy for Prussia. By 1512 he was settled in Prussia where he not only observed the movement of the heavenly bodies but also worked in various capacities as a bailiff, military governor, judge, tax collector, physician and reformer of the coinage. He was an untypical man, an exceptional man, like one of his contemporaries, Sir Thomas More, a Renaissance man (see Lecture 1).



As we all know, it was Copernicus who determined that the sun was at the center of the cosmos and that the earth moved. Such an opinion alarmed his contemporaries who could not explain that if the earth were spinning then why was it that an arrow shot into the air didn't fly off the face of the earth -- remember, this is well before the idea of gravity had been discovered by Newton. The Copernican system offended the medieval sense that the universe was an affair between God and man. Copernicus knew it too. The ultimate authority, of course, was the Holy Writ. That his contemporaries would be alarmed by the heliocentric theory bothered Copernicus. So, he decided to publish his findings in 1543, the year of his death. It was in that year that Copernicus published his magnum opus, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Bodies*) at Nuremberg. The book was dedicated to Pope Paul III. Aware that he could not persuade the traditional thinking of the time, Copernicus made a specific appeal to mathematicians. It was, he thought, only the mathematician who could understand and appreciate the order and essential simplicity of his system. In the DEDICATION to this most revolutionary of scientific treatises, Copernicus wrote:



> *mathematics is written for mathematicians, to whom these my labors, if I am not mistaken, will appear to contribute something.*

Copernicus never expected that his findings would appeal to the non-specialist. But in 1572 something happened. A new star appeared in the constellation of Cassiopeia. The new star was observed by the Danish astronomer, Tycho Brahe (1546-1601). The star was brighter than any other star for more than two years -- contemporary accounts tell us that the star was so bright that it could be seen in daylight. And in 1600, another star appeared. This star was observed by Johannes Kepler (1571-1630). The heavens seemed to be in flux. Such occurrences made lasting impressions on all men, whether scientist or not. After all, this was an age in which men believed their fate to be written in the stars and now those stars were changing. What Brahe and Kepler had seen were super-novas, the explosions of old stars.

Kepler, even more than Copernicus, was literally carried away by the strange relationship between numbers and the properties of the natural world. In his books, *Mysterium Cosmographicum* (*The*

Mysterious Universe, 1596) and *Harmonice Mundi* (*The Harmonious World*, 1619) one theme is presented repeatedly: "Nature loves simplicity." From his friend Brahe, Kepler learned that it was necessary to take more accurate measurements while observing the movement of the heavenly bodies. In the end, Kepler determined the three laws of planetary motion, which he published between 1609 and 1619. (1) planets move in elliptical orbits. (2) explained the varying speed of the planets and so, retrograde motion, (3) relates the movement of one planet to all the others. With the discovery of these three laws within the framework of the heliocentric universe, the paths of the planets were mapped forever. All that remained would be to see these three laws as part of a single unity -- a single law which held each planet in its orbit about the sun. This of course, would have to wait another seventy years -- this single law would have to wait for the genius of Isaac Newton. But what was needed before Newton could go to work was a more practical and elaborate understanding of the mechanics of motion (see Lecture 11).