**TRADITIONS OF ANCIENT SCHOLARSHIP**

In this course we will deal with ideas about the physical world around us, finally leading to quite fundamental issues, namely, space and time. It will be useful to look at these ideas from an historical point of view – when and where did these ideas appear, and who contributed to our present understanding of the world? The short answer to this question is people from nearly all over the world, stretching over a very long time span.

Science is a quantitative subject so we need some amount of mathematics to deal with it. Where did our math come from? The earliest recorded significant work in mathematics comes from Mesopotamia about 3500 BCE where the Sumerians developed the place value system in arithmetic. We use this system today. For us the number 1997 means 1*1000 + 9*100 + 9*10 + 7*1. The Sumerians did not use a decimal system, but a mixture of decimal and sexigesimal: For them the number 1997 would equal 1*600 + 9*60 + 9*10 + 7*1 (=1237 in our notation, a completely different number).

The important thing is that they developed the place value system, allowing addition, subtraction, multiplication, and division, just as we do these things. Using Roman numerals, with no place system, these operations are so complex that they were regarded as magical.

The oldest recorded long division problem appears on a Sumerian clay tablet written 4600 years ago. It probably came from a training school for Sumerian priests, who played the role of accountants and lawyers among other things in their society. In this problem someone wants to pay workers to do a job. They will be paid seven volumes of rice apiece, each volume being about 0.7 modern liters. He has 1,163,242 of these volumes. So the question he has is, how many workers can he pay? Clearly we need to divide 1,163,242 by 7, as we all learned how to do in grade school. The Sumerian student was using a mixed decimal and sexigesimal system, but the process is the same, and there it is, all worked out on the clay tablet with the answer 166,177 with a remainder of 3.

Clay tablets are the only traditional writing medium that is not destroyed by fire, and today we have about half a million of them in the basements of museums around the world (most untranslated) as well as unknown numbers still buried in ruins in Iraq.

Indian mathematicians developed our number system. We call our numbers 0, 1, 2, 3, 4, 5, 6, 7, 8, 9 Arabic numerals, since Europeans got them from Arabs, but the Arabs got them from Indians. The integer 0 was and still is, a harder nut to crack. It first appears on counting boards in India in the 1st Century. The Maya invented 0 at about the same time. It was not accepted in Europe until the 12th or 13th Century.

Even today 0 strikes many people as being different from the other integers. For example, one of the rules of the College of Arts and Sciences is that entering first year students whose social security number ends with an even integer should take ENWR in the fall. Those whose number ends with an odd number should take it in the spring. A few years ago some students, and some faculty were puzzled about what a student whose social security number starts with 0 should do. This was discussed at a meeting of faculty advisors, and the correct conclusion was obtained: 0 is indeed an even integer. This year's student handbook separately specifies 0 and even integer endings.

Our calendar begins with the year 1. Should it have instead begun with 0? The Maya used year 0 and day 0 to restart their calendar whenever a new king was installed. The Babylonians knew there was a problem, but they did not have a 0, so they called the first year of a king's reign the accession year, and the next year was year 1. With our calendar if we go from year –1 to year +1, we have skipped a year, which clearly did not happen at the time.

Astronomy will play an important role in the ideas we will discuss in this course. It certainly has roots more ancient than arithmetic. People have been looking at the night sky and wondering about it ever since we could consciously wonder. Early astronomy in all ancient societies was mystical and religious, something like astrology today. The Sun, Moon, Stars, and Planets are so majestic and move with such grand regularity (with the possible exception of the planets) that they cannot help but impress us.

In the new world the Maya, during the period 200 – 900, created a historical calendar millions of days in extent showing phases of the Moon, Venus, Mars, the Zodiac, and eclipses. Only a few of the thousands of texts they created survived the Spanish book burnings, so we know little of what they actually understood. (We do know that they realized the evening and morning star were the same object (Venus)).

All the Mesoamericans built astronomical alignments into their architecture. They were oriented towards special rising and setting points of the Sun, Moon, Venus, Mars, and the Pleiades.

In the old world, in Mesopotamia astronomical records go as far back as the $18^{th}$ C BCE. They were interested in predicting eclipses for divination purposes. They developed a 12-month calendar with 360 days per year. Egypt is the place of origin of the 365-day year and 24 hour day. They may have been aided by the fact that the flooding of the Nile in spring averages to a 365-day year. The old pyramids built during 2600 – 2100 BCE faced precisely north, with entrance hallways sloping down as you go in so the North Star could always be seen from within at night.

In India astronomy was advanced by Indian mathematics more than by observations. In 499 Aryabhata proposed that Earth rotates on its axis, causing the apparent daily motions of the celestial objects. This idea was not advanced in Europe for another thousand years.

From the $10^{th}$ to the $15^{th}$ centuries, Muslim astronomers were the best in the world. In 1420 they built an observatory in Samarkand with the largest sextants ever built. They developed the trigonometry needed to calculate the direction towards Mecca from all over the Muslim world.

China has the longest unbroken record of astronomical observations of any ancient civilization, going back 5000 years. In 1500 BCE they knew that the year was 365 ¼ days long. Kan Te in the 4th C BCE reported sunspots, at a time the Greeks thought the sun was a perfect uniform sphere. All astronomical knowledge in ancient China was a state secret. It was thought to be a divine comment on the emperor’s fitness to rule. In the $2^{nd}$ century BCE Chang Heng invented quantitative cartography. He applied a grid system to maps allowing distances to be measured between points. This was used both for the Earth and the stars.

This summary of ancient accomplishments could ago on and on. It is clear that people in nearly every ancient civilization contributed to what we call science today. Not all their achievements survived to influence others. The Maya remained isolated until European contact for example. The curiosity and energy and ability were present all over the world.

Among these ancient civilizations the Greeks stand out in a peculiar way: It was only here that objective thinking about the world around us came about, eventually leading to science, and by direct extension, to today's science and technology. This is remarkable. Is it just a matter of chance? Were the Greeks better at this than other people? The above summary suggests not. The key idea here is *objective* thinking about the world. Objective means without ideological constraint. We just saw that in ancient China all astronomical observations were a state secret, because they were thought to be a divine comment on the Emperor's fitness. This does not lead to objectivity. Similar political and religious constraints prevented astronomers and mathematicians in other parts of the world from thinking freely about what they were doing. Objective thought simply was not popular among kings and priests. It is too dangerous to the survival of the current rulers. How then, did objectivity arise in Greece?

Let us begin by describing some important cultural attitudes of Greek civilization. A good place to begin is with Homer, the great poet who wrote around 700 BCE, just as Greece was beginning its golden age. Homer writes of some traditional legends and stories from the Mycenaean civilization of Crete some 700 years earlier. Did Homer just make up these stories? Perhaps, but clay tablets found on Crete, written in an initially mysterious script referred to as Linear B, were eventually translated to reveal a people interacting with the gods of classical Greece: Zeus, his wife Here, Athena, Poseidon, Hermes, and others. So Homer's stories are plausibly based on fact.

Homer's two great epic poems are the Iliad and the Odyssey. The Iliad is the story of the siege of Troy, and depicts the futility of war. The Odyssey is a sea yarn filled with fantastic events, as Ulysses makes his way back home from Troy. These two poems have come to define important aspects of ancient Greek culture, illustrating that their highest values were skill in battle, and skill in debate. In the opening scene of the Iliad a meeting of an assembly is depicted. The meeting was called to discuss what to do about a plague that has appeared. What is interesting about the assembly is the diversity of people who attend. The king, Agamemnon is present, along with nobles, merchants, and soldiers. People of all stations in life. And they all feel free to speak, even insulting the king. The tradition of free debate as a way to solve problems is clearly deeply rooted in Greek history. We do not know whether this tradition goes all the way back to the Mycenaeans or whether Homer used it as part of the story because people of his own time would understand it. In either case, it was a well-established part of Greek culture.

Ancient Greece was a seagoing nation. They traded south across the Mediterranean to Egypt, and north all around the Black sea. This helped prevent them from becoming isolated from the surrounding peoples. In addition this made it relatively easy to move around from one seacoast town to another, enabling adventurous people to escape political oppression. Indeed, Pythagoras is said to have left Samos, his island of berth, for just such a reason. In addition the trade produced a merchant class that could afford to educate their children, creating the need for a teaching profession. Following is a list of characteristics of Greek culture that may have played a role in leading to objective thought about the world:

1. The assembly, where people first learned to persuade one another by rational debate.

2. A maritime economy helping to prevent parochialism.

3. The existence of a widespread Greek-speaking world around them through which travelers and scholars could wander.

4. The existence of an independent merchant class that could hire its teachers.

5. The literary masterpieces Iliad and Odyssey that are the epitome of liberal rational thinking.

6. A pantheistic religion not dominated by priests.

7. The persistence of these factors for many centuries.

It is remarkable that all these factors came together in one great civilization. This did not happen twice.

For comparison let us briefly review some characteristics of ancient China. In addition to the accomplishments listed above in astronomy, we can only be impressed with their technical achievements: Chinese sailors used battens on their sails to improve efficiency in the first century, 1800 years before Europeans. They built ships with separate watertight compartments to help prevent sinking in the $5^{th}$ C, 1200 years before Europeans. And they used the magnetic compass for navigation in the $12^{th}$ C, 200 years before Europeans. The invention of paper, the use of block printing, and many other impressive achievements could be added to this list.

In many ways Confucius (551 – 479 BCE) can play the role of Homer as an indicator of the style of Chinese thinking. He was primarily concerned with human relations and the creation of good government. He traveled around China hoping to be appointed to a government post, and failed at this, but as he traveled, he spoke and wrote. And he was tough. For example in the Analects, is written:

The Master said, “The essentials of good government are sufficient food, sufficient arms, and the confidence of the people.”

“But”, asked Tzu Kung, “if you have to part with one of the three, which would you give up?”

“Arms,” said the Master.

“But suppose,” said Tzu Kung, “one of the remaining two has to be relinquished, which would it be?”

“Food,” said the Master. “From time immemorial, death has been the lot of all men, but a people without confidence is lost indeed.” Political leaders today know that confidence is paramount, but few would be so brutally direct about it.

Confucius taught loyalty to family and community as the highest values. There is no mysticism here, or superstition, and there is a commitment to education. These ideas were built into the Chinese governmental system, and for 2000 years China had the best government in the world. Over time however the system came to be more and more bureaucratic. The governmental officials, chosen for their knowledge of the writings of Confucius came to be the most powerful group in the country, known as the mandarinate, and jealously guarded their power. Edicts were passed forbidding trade with foreign countries, presumably to prevent the possible rise of a merchant class.

Chinese thinking can be characterized as group-centered, and evolved into a bureaucratic governmental system that brought great stability, but foreclosed China’s future. In spite of the absence of superstition and the commitment to education, the climate of thought did not give rise to independent objective thinking about the world.

Each of the ancient cultures listed above was of course unique, a product of its history and environment. In each there was a tradition of scholarship. In most cases the scholars studied the history of their people, or the words of an ancient wise man, such as Confucius. And succeeding generations of scholars went on doing the same thing. In other words, a scholarly tradition lasting even thousands of years does not guarantee progress. Usually succeeding generations studied the same things the past generations had studied. In Greece things happened differently – let us now see how this began to take place.

## The Milesians

In sixth century BCE Greece, the most vital city was Miletus, near the mouth of the Meander river (hence our word meander) in what is now Turkey. Thales lived here and was active around 585 BCE. He is often described as the first philosopher-scientist, and sometimes as the person who “discovered nature”. This does not mean that he or others of this era developed a complete description of the natural world. Indeed all we have from most of the pre-Socratic philosophers of ancient Greece are fragments, collected and numbered by classical scholars. Nothing remotely approaching a complete text exists.

What is meant by the “discovery of nature” is the idea that natural processes take place on their own and do not involve supernatural forces. For example, in Homer’s poems, an earthquake would usually be attributed to the anger of Poseidon. Thales’ model for the cause of earthquakes was this: He said that the (flat) earth floated on water, and every now and then waves occurred on the water that caused the earth to crack just as a ship is rocked and stressed by waves. This is remarkably close to the modern explanation, except that the Earth’s crust does not float on water, but on the semi-solid mantle and liquid core beneath it. Since Poseidon was the god not only of earthquakes, but also of storms, this model is only a step removed from the traditional Greek supernatural explanation of earthquakes. But the step is a big one. Poseidon’s anger is not involved. The psychological difference is enormous. When an earthquake occurs near us we do not need to feel that we may have done something wrong to anger the gods. We were just unlucky to be near the crack when it occurred.

Thales and the other Milesians were the first in recorded history to “leave the gods out” in their explanations of events in the natural world around us. In addition while

Homer's poems would describe a particular earthquake, the Milesians dealt with earthquakes in general. This is an important step in objectifying nature. An earthquake in our hometown can be a stressful and emotional event. Thinking about earthquakes in general, however, makes it easier to step back and be more rational about the question.

Thales was regarded as one of the 7 wise men of the ancient world. Following him in Miletus was Anaximander around 555 BCE, and Anaximenes around 535 BCE. It is thought that they continued the tradition of discussion and debate used in the Greek assembly. The evidence for this is indirect. Prior to this time many speculations had been put forward about the world around us. For example Egyptians had several models of how the sky is held up. One was that it was held up by posts, another that it was a god, and another that it was a cow. But someone describing one of these pictures need pay no attention to the others. These conflicting stories were not in competition with each other – they were simply different ways of viewing the same thing.

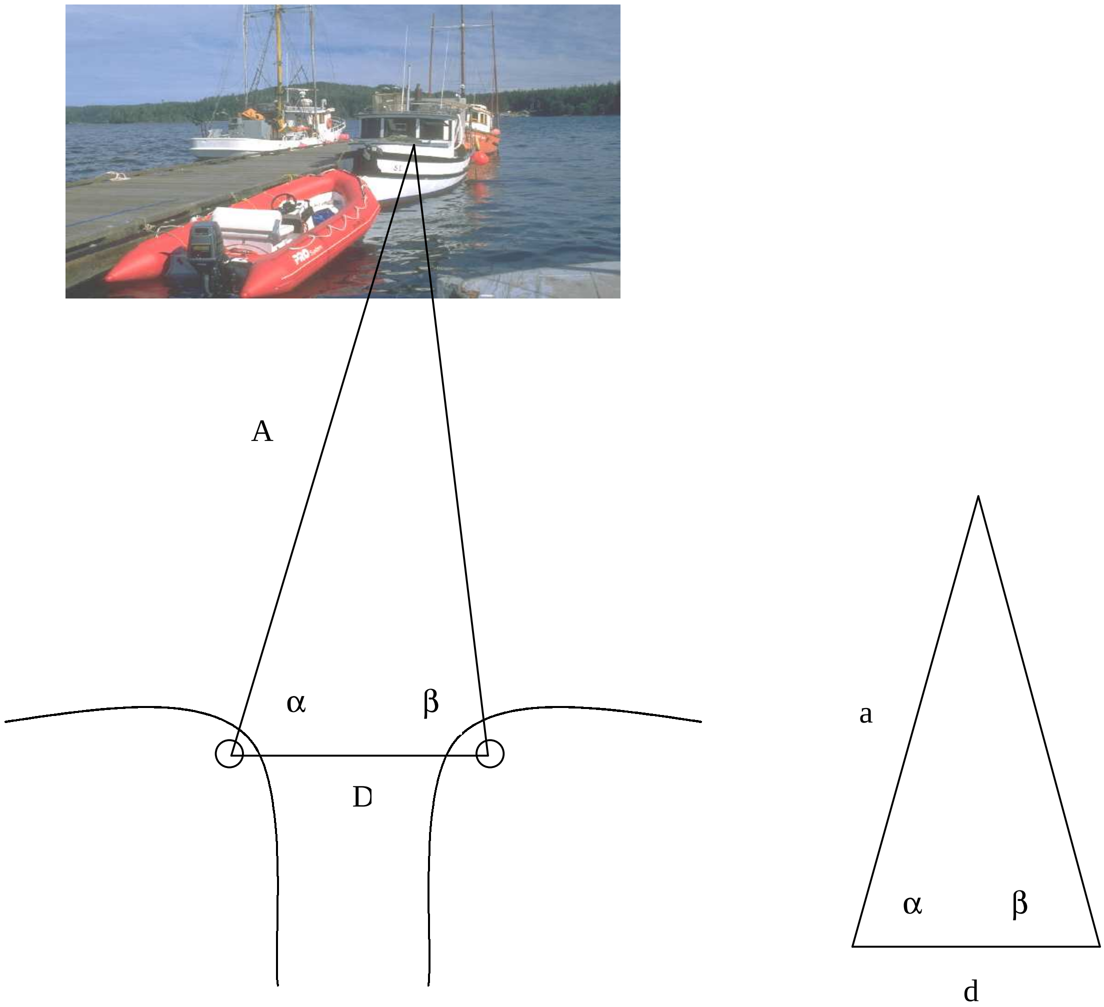
With the Milesians, there is a sudden difference in style. They tended to attack the same problems, and it is tacitly assumed that different models are in competition with one another. There is a desire to express the strongest grounds for the model being proposed, find the best evidence for their idea and expose the weaknesses in another proposal.

They all struggled for example with the origin of the universe, and what things are made of. Thales suggested that in the beginning all was water. This is a reasonable beginning point because water was the most common substance for which all three phases of matter (solid, liquid, gas) were known as part of everyday life. As water evaporates or boils, it becomes a gas, and when if freezes it becomes a solid. Anaximander did not like being tied down to a specific substance, so he said that in the beginning there was boundless chaos. Out of this the universe grew as from a seed. This is qualitatively similar to today's big bang model for the origin of the universe. Anaximenes argued that in the beginning all was air, and other substances were formed by condensation. All three models describe a formless initial state for the universe with the things we see around us evolving through natural processes. This is a remarkable modern picture, although of course nowhere near complete. (The same can be said of today's models of the origin of the universe).

One of Thales' important accomplishments must be singled out. While on a trip to Egypt (probably a business trip), he noticed the way the Egyptians were surveying the land to reestablish boundaries after the annual flood of the Nile in the spring. This was necessary from the Pharaoh's point of view because he assessed taxes in proportion to the land area cultivated by each farmer. If the river took land from a farmer, he should not be required to pay as much tax. What the Egyptians had discovered were some of the properties of similar triangles. Thales observed what they were doing, understood it, and brought these ideas back to Miletus. There he amazed his friends by showing them how he could measure the distance offshore of a ship approaching the mouth of the Meander river.

Here is the idea: On each side of the river near its mouth, establish an observation post and measure the distance D between them. Then as a ship approaches, an observer at each post measures the angle between the ship and the other post.

Call the two measured angles $\alpha$ and $\beta$ and the distance from one observation post to the ship A. This is what we want to know. Now draw a small triangle on a flat surface with base d and the same base angles $\alpha$ and $\beta$, and label the left side a.




The drawn triangle is similar to the triangle created by the lines of sight of the observation post observers. This means the two triangles have the same shape; they just differ in size. The size difference can be enormous, that makes no difference. The shapes are the same, and so the ratios of corresponding sides must be the same. That means:

$$A/D = a/d$$

So $A = D(a/d)$. So if we use a ruler to measure a and d for our drawn triangle we can evaluate $a/d$. This ratio is about 2 for the triangles drawn above. Then since the distance D is known, we know A. For example, suppose D is one mile, then in this case, A would be about two miles.