ARISTOTLE

Aristotle personified the Greco-Roman idea of wisdom. His impact was broad as well as deep. He characterized the orientation and content of Western Civilization. For 2000 years, Aristotle and the Bible were the two chief sources of wisdom for Europeans. He was the author of an intellectual system that became the vehicle for Christian and Islamic organized religion. His chief accomplishment was to have established the basis for logical thought. After Aristotle, any institution or group wishing to think carefully about a problem would use his approach. More than Plato he understood the need to use language carefully.

Aristotle was born in 384 BCE Stagira, at the northern end of the Aegean Sea, near Macedonia. His father was court physician to Amyntas, King of Macedonia and grandfather of Alexander the Great. As a doctor's son he was likely trained as an apprentice along the lines of a Greek medical tradition about 200 years old. When his father died he was sent to Plato's Academy in 367 BCE, staying there for 20 years until Plato died.

In contrast to Plato, Aristotle placed great importance on observations of natural events. For example in his treatise *On the Generation of Animals* he wrote

"The facts have not yet been sufficiently established. If ever they are, then credit must be given to observation rather than theories, and to theories only insofar as they are confirmed by the observed facts."

In 343 Aristotle was invited by King Philip of Macedonia to tutor his 13 year old son Alexander. He was commissioned to prepare Alexander for his future role as military leader of the (then) united Greek world against the Persian Empire. He used as a model the epic Greek hero as described in Homer's Iliad. Later Alexander was enormously successful militarily, conquering vast areas of the world from Egypt to India. He spread Greek culture among the conquered peoples, but it is not clear how much influence Aristotle's tutoring had on him.

In 335 Aristotle returned to Athens and opened the Lyceum, a school attached to the temple of Apollo Lyceus, in a grove just outside Athens that had been a favorite spot of Socrates.(French high schools are called lycee after Aristotle's school) Lectures were given in a covered walkway called the peripatos, and the school was soon referred to as peripatetic. The Lyceum concentrated on biology and history, in contrast to Plato's Academy with its concentration on mathematics. These were the world's first universities.

ARISTOTLE

Upon Alexander's death in 323 there was an anti-Macedonian agitation in Athens and Aristotle was accused of the capital charge of impiety, just as Socrates had been decades earlier. Aristotle left Athens, reportedly to spare the city from sinning twice against philosophy. He died in 324.

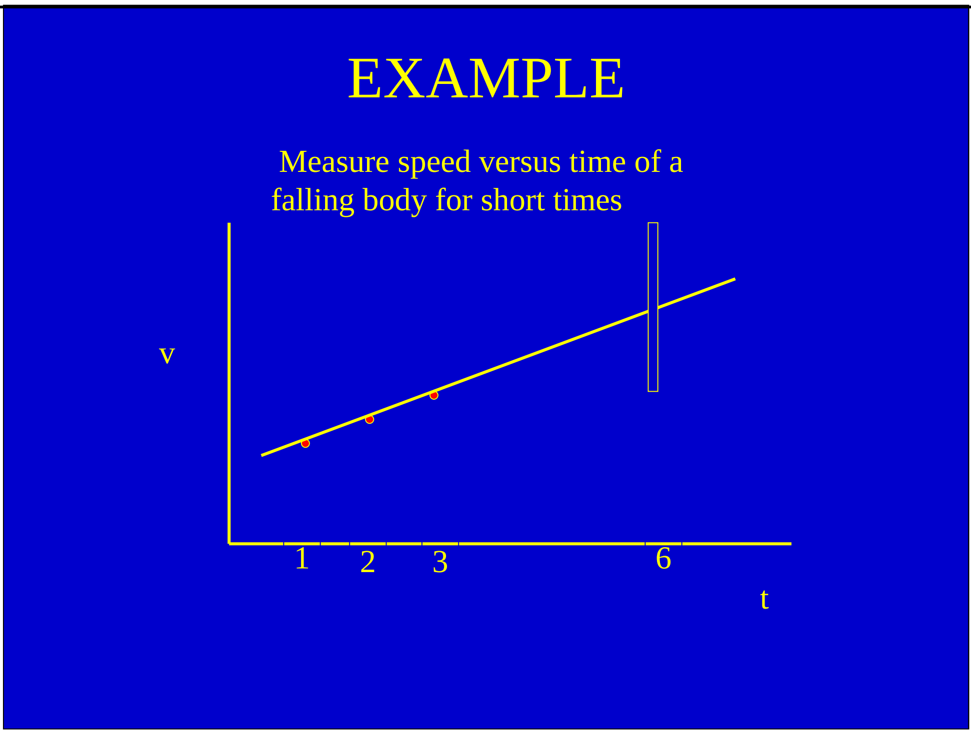
Aristotle believed, in contrast to Plato, that in order to make new discoveries about nature, it was important both to make observations and to think about them. Here is an example illustrating his method. Suppose we know from experience that someone, say Joe, was sick from a particular disease, and became healthy again after taking a particular drug. Then we learn that Sally had the same disease and the same drug cured her. Then we learn of a few more people with the same experience. So far we are just collecting facts, building knowledge based on observation. But then we are "doing science" when we conclude that this drug is generally effective against that disease.

INDUCTION

The drawing of **probable** inferences
from various particulars.

This logical process is called Induction. Its counterpart in logic, as described by Aristotle, is Deduction. Let's describe them both.

Induction is the drawing of probable conclusions from various particulars. The probability that a conclusion is correct depends on the completeness of the particulars. In the example of the drug cited above, the conclusion would be quite tentative.



EXAMPLE: Extrapolation of a line.

Suppose we measure the speed of a falling object as a function of time, but only for a short time. Our results might look like the graph above. We measure the speed after one, two, and three seconds. That is all the data we have. Then someone asks how fast the object was moving after six seconds. Since it looks like we have a straight line variation, we would probably **extrapolate** a line to t = 6 seconds to estimate the speed at that time. This is an example of induction.

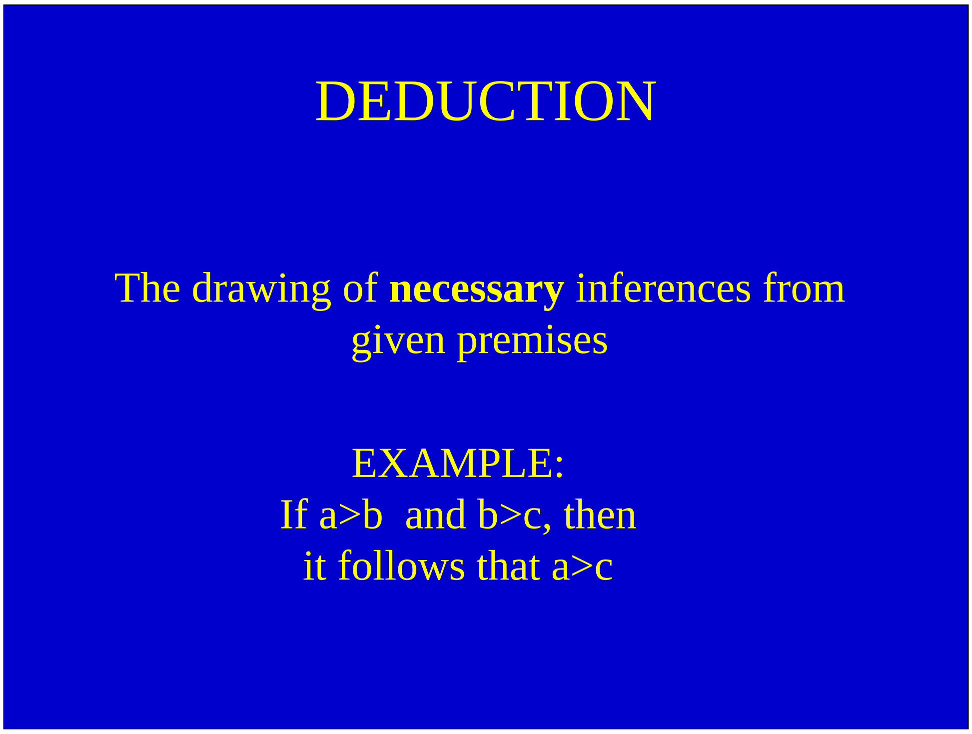
If we also had a value for the speed at 7 seconds, then we would **interpolate** between the measurements to find the speed at 6 seconds. This is also an example of induction, but with greater certainty than for extrapolation.

The reliability of the conclusion depends upon how much data we have. In this example, if we knew the speed at 5.99 sec, and 6.01 sec, we could be quite confident about its value at 6.00 sec.

DANGER: Correlation versus Causality

In collecting data we may observe that one quantity varies with another, i.e. that the two are positively correlated. This does not necessarily indicate that one causes the other. For example, taking the population of the US as a whole, the incidence of smoking is positively correlated with physical stature. Larger people are more likely to smoke than smaller people. Should we conclude that smoking is good for us and promotes growth? Is there another explanation for this correlation?

The strength of induction is that we can use it to approach many different situations. This is how the discovery phase of natural science proceeds. The weakness is that all conclusions are provisional. Additional observations and/or thinking may at some point in the future change them.



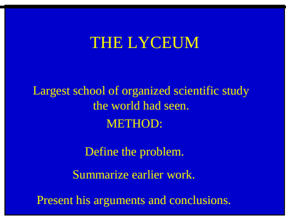
EXAMPLE

The elements of plane geometry were set forth by Euclid in about 300 BCE. He used a deductive logical structure, stating five postulates. All that we know of plane geometry can be deduced from these postulates. How to prove two angles equal, two triangles congruent, the Pythagorean theorem, etc., all necessarily follow from the five postulates.

EXAMPLE

Einstein structured his theory of Special Relativity in a deductive manner. He stated two postulates. All that we know of Special Relativity follows from these two postulates. The fact that moving clocks run slow, meter sticks appear shorter, etc all follows from the two postulates. This is unusual in natural science; new ideas are usually arrived at by induction.

The strength of a deductive structure is that the conclusions are known with certainty. The weakness is that their truth or falsehood depends on the postulates being true.



Aristotle agreed with Plato that the highest human faculty was reason, and its supreme activity was contemplation. In addition to studying what he called “first philosophy”, cosmology and mathematics, the things Plato had worked on, Aristotle also studied “second” philosophy, the world of the senses, from physics and mechanics to biology. He did some of his best work in biology, and was doubtless influenced by the training he received from his father when he was young.

What Aristotle achieved at the Lyceum in Athens was to begin a school of organized scientific inquiry on a much larger scale than had been achieved before at Plato’s Academy. In other words, he invented scientific research as a focused social activity, much as it continues today. After Aristotle, the only comparable professional scientific research institute during the next 2000 years was the library and museum at Alexandria where Ptolemy worked. His work was of such quality that it became accepted by all, and he remained for centuries THE AUTHORITY on nearly all the subjects he treated extensively.

Aristotle’s method of investigation varied from one subject to another depending on the problems encountered, but it usually included:

1, Defining the subject matter.

2. Summarizing the generally accepted views on the subject, and the work of earlier thinkers. He was not trying to achieve historical accuracy here, but to clarify as much as possible the problem to be solved.

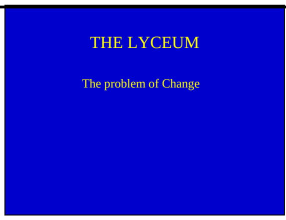
3. Presenting his own arguments and conclusions.

This is the pattern modern research papers follow in the sciences and social sciences. Aristotle was laying down what became the standard approach to scientific research. Also, his summaries of earlier thinkers’ ideas about a topic are often the only window we have today about them.

The arguments he used were of two types: *dialectical*, that is, based on logical deduction, and *empirical*, based on observations or practical considerations. He often refuted an opposing argument by showing that it led to an absurd conclusion. This is called *reductio ad absurdum*, and is the method we used earlier to show that the square root of two is not a rational number. We will see later that Galileo used this kind of argument against Aristotle himself, 2000 years later.

Another possibility was that an argument could lead to a *dilemma*, i.e. an apparent contradiction. However, dilemmas can sometimes be resolved by realizing that there is some ambiguity in a definition of an important term in the argument. Aristotle showed that precision of definitions is essential to productive discussion in any discipline.

Aristotle’s study of nature was a search for “causes”. What did he mean by this? He stated that any object, animate or inanimate, had four attributes: matter, form, moving cause, and final cause. For example, for a shoe, the matter is what the shoe is made of – cloth and rubber, leather, etc. The form is the shape of the shoe. The moving cause is the cobbler or machine that made it, and the final cause is the reason it was made in the first place, for a person to wear.



For people, he thought the matter was provided by the mother, the form was a rational two-legged animal, the moving cause was the father, and the final cause was to become a fully grown human being. It is significant that this approach to studying nature fits very well into religion. The idea that every object is beautifully crafted for a particular function, its final cause in the grand scheme of things, fits naturally with the thought that all this has been designed by a Creator. This is not the way Aristotle saw it, but the structure of his thinking was readily taken over by Christian and Islamic thinkers during medieval times.

Aristotle's most successful scientific work was in biology, in particular, comparative anatomy. Living creatures and their parts provide more numerous and more convincing evidence of final causes in the sense of design for a particular purpose than do inanimate objects. What is the final cause of our eyes? To allow us to see. What is the final cause of our hands? To allow us to pick things up, and throw things. He studied more than 500 different animals, including 120 kinds of fish, and 60 kinds of insect. He was the first to use dissection extensively.

The problem of how change occurs had vexed the Greeks for centuries before Aristotle. How can anything come into existence? It cannot come from what is not, since that is non-existent. And it cannot come from what is, because then it would already have been in existence. Aristotle introduced a distinction between potential and actual existence. A tree, for example, comes from a seed, which itself is not a tree, but is a potential tree.

He agreed with Plato that the highest faculty humans possess is reason, and so the supreme activity of which we are capable is disciplined thinking.

THE ELEMENTS

Fire, Air, Water, Earth
are each a combination of:

Hot or Cold, Wet or Dry

We have seen that Plato described the elements out of which the world is composed as being eternal, and represented by mathematical objects the symmetries of which determined what alchemical reactions could occur between them. Aristotle took a quite different approach. He started with the same four traditional Greek elements: Fire, Air, Water, and Earth. But each of these he took to be a combination of two of four attributes: hot or cold, and wet or dry. His approach is more in touch with the way things appear to our senses, as opposed to abstract mathematical constructs.

Earth is cold and dry, water cold and wet, air hot and wet, and fire hot and dry. So when water boils, becoming air,it changes from cold and wet to hot and wet.

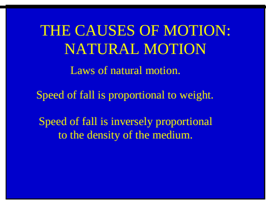
Hot or cold, wet or dry seem natural ways to describe our everyday encounters with things in the world. He thought Plato mistook the nature of the challenge, thinking it a mathematics problem rather than a physics problem. For Plato the distinct properties of different materials was a mathematical problem that would, after sufficient study, be understood quantitatively. Aristotle’s approach was entirely qualitative.

For a long time, Aristotle seemed closer to the truth, since he appealed more directly to our senses. During the past century, however, we have learned that Plato’s identification of mathematics with the elements (or the atoms) of nature was on the right track after all. There is simply a huge gap between the atomic nature of matter and the way our senses perceive macroscopic objects. We do not experience atoms directly in any way whatsoever.

COMPARATIVE ANATOMY

We should approach the investigation of every kind of animal without being ashamed, since in each one of them there is something natural and something beautiful. And the end, for the sake of which a thing has been constructed or has come to be, belongs to what is beautiful.

Aristotle differed so directly with Plato and his followers on the importance of making observations that he defended his position a number of times. Later in life he turned to the study of animals, or what today we would call comparative anatomy. He found it necessary to dissect animals to discover their internal organs and the purposes of those organs. The above statement is representative of his attitude.



Before the industrial revolution, most things that moved in the world were living things. A bird, or rabbit, or person, moves from one place to another for some reason. The animal makes a decision, to seek food, escape a predator, etc, as part of the process of fulfilling its “final cause” of growing into an adult animal. It is in the “nature” of the animal to move as it does.

To account for the motions of inanimate objects, such as a stone that has been dropped, Aristotle suggested that elements tend to seek their “natural” place when released. So dirt and rock move down, to be with the earth; water moves down but less strongly; air moves up, and fire moves up more strongly. These are “natural” motions. There is something animistic in Aristotle’s conception of natural motion. Somehow the rock “knows” that other rocks are below it and wants to join them.

Aristotle’s intuition was based on his experience, starting of course as a young child. When we were very young, we had to learn how to deal with the physical world. Learning how to walk is a mechanical process in which we all developed an intuitive sense that corresponds to keeping our center of gravity over our feet. People who study child development have found that we all go through stages in the development of our understanding of the world. One of those early stages involves the child attributing to inanimate objects a kind of will as in Aristotle’s description. “The book fell on the rug because it wanted to go there”. Through many educational experiences, going to school, seeing cars move that are obviously driven by people, not themselves, we refine this understanding. Aristotle did not have the benefit of these educational experiences.

Violent motion is the motion of an object in any other direction than its natural one. We can throw a stone upward, and for a while it moves “violently” upwards until it overcomes the push we gave it and falls back to earth.

Aristotle’s Laws of Motion

Aristotle thought quantitatively about the speed of natural motion, and made two assertions about how things fall:

1. The speed of fall is proportional to the weight of the object.
2. The speed of fall of a given object varies inversely with the density of the medium through which it falls.

These rules are simple, and agree with many observations about falling objects. A leaf falling from a tree does so much more slowly than a branch from the same tree, for example. And a stone falling through water moves more slowly than the stone falling through air. We do not know for sure whether, when he wrote “density”, Aristotle was referring to what we mean by that term today, i.e. mass per unit volume (grams/cubic centimeter), or viscosity, a measure of the friction forces in a fluid. Indeed these two quantities are confused by many people today.

In either case, he concluded, by extrapolating the second statement above to zero density, that a vacuum could not exist, because in it all objects would travel with infinite speed, which did not make sense to him.

THE CAUSES OF MOTION: VIOLENT MOTION

Violent motion is motion in any other direction than that of natural motion for that object.

Requires an applied force.

Speed is proportional to the applied force.

Examples of violent motion are: A block of wood sliding across a table. You going upstairs. For violent motion, Aristotle stated that a force is required to cause the motion, and that the speed of the moving object is in direct proportion to the applied force. This means that if you stop pushing something, it will come to an immediate stop.

The above ideas of motion are intuitively appealing, and agree with many everyday situations. They are not appropriate for developing a deeper understanding of motion and its causes, however. Aristotle’s problem was that he was dealing with motion in which friction and gravity forces played dominant roles. Not until Galileo was the importance of friction realized, and Newton was the first to understand gravity.

To study the causes of motion, what is needed is a situation in which all forces can be removed from a body. Then forces can be added one at a time to observe their effect. This can be achieved in a weightless environment in space, for example. Without access to such exotic technology, what were earlier scientists to do? We will see later how Galileo dealt with this problem in a very clever manner.

MOTION OF CELESTIAL BODIES

Celestial bodies are made of a fifth element, aether, whose natural motion is circular.

Somewhere between the earth and the moon, terrestrial elements give way to aether.

The various bodies in the heavens evidently move in unending circles, so they must be very different from all bodies here on earth that are always moving to their natural place. Aristotle said they are composed of a fifth element, not found on earth, called **aether**, whose natural motion was circular. This is not very satisfying for several reasons: Somewhere between the earth and the moon a change must take place. What makes this happen, and where does it occur? And if the sun is made of aether only, and does not contain fire, which is, of course, one of the terrestrial elements, why does it appear so much like fire, and seem so warm?

Aristotle had another argument for the fifth element. It was known that the distance to the sun was very large compared with the size of earth (from the work started by Aristarchus). So Aristotle thought that if the celestial bodies were made of terrestrial elements, the volume out there was so great, that there would be no matter left over for earth. He appreciated the smallness of earth compared with the size of the heavens, and felt that the terrestrial elements would be uniformly shared, if allowed to escape earth. This is quite a modern idea, in which “spaceship earth” is seen as tiny and vulnerable in the cosmos.

Aristotle pointed out that his idea of the fifth element fits in with traditional Greek religious beliefs of the divinity of the celestial region. This may have made it easier for others at the time to accept, but the basic reasons for the new element were to solve the serious physical problem of the continuing circular motions of the celestial bodies. They cannot, in Aristotle’s view, be made of the terrestrial elements, because they would then move of their own accord either up of down. They would need a force to cause them to move in circles.