

# Chapter 2

## Pre-Galilean Science

### 2.1 Deep Roots

The roots of science are within the roots of philosophy because until relatively recently science was not distinguished from philosophy; it was considered to be natural philosophy. This lack of separation is reflected throughout Greek science. Proceeding historically from ancient Greece into the Eighteenth Century there is a continuing, although not necessarily progressive, untangling of reason, science, metaphysics, and faith. It is important to recognize the growing demarcation of science, as a subject in its own right, over the centuries if one is going to acquire a deep understanding of the Twentieth Century developments, in particular, the role of uncertainty and the lack of absolute objectivity.

This chapter begins with Aristotle's epistemology and outlines the evolution of reason and science prior to the birth of modern science in the Seventeenth Century. There were outstanding Greek scientists before Aristotle, of which we mention three: (i) Thales (624–546 BC), who first used deduction to prove geometric theorems, studied astronomy independently of astrology, and predicted the eclipse of the sun on May 28, 585 BC; (ii) Empedocles (492–432 BC), who expounded a theory of evolution in which all higher forms develop from lower forms and there are no sharp distinctions between species, with Nature producing monstrosities that perish on account of maladaptation and organisms that propagate by meeting the conditions of survival; and (iii) Democritus (460–370 BC), who proposed an atomic theory of matter governed by necessity via natural causes and who postulated the preservation of matter, it being neither created nor destroyed, with only atomic combinations changing. The roots of science go very deep.

### 2.2 Aristotle: Causality as the Ground of Knowledge

Aristotle (384–322 BC), a Macedonian, put into place the basic tenets of logic and scientific epistemology that remained dominant for two thousand years. His fundamental aim was to analyze the process and technique of reasoning. What is reason? What is the domain of reason? His major logical treatise, the *Organon*, served as the major logic text for two millennia.

### 2.2.1 Plato: Allegory of the cave

For Aristotle's mentor Plato (428–348 BC), the path to true knowledge lies beyond the material world. In *The Republic*, Socrates tells Glaucon the famous allegory of the cave, in which prisoners sit chained with their heads bound straight ahead. Behind them a fire is burning. Between the fire and the prisoners is a raised way with a low wall behind which men move about carrying statues and other structures, held above the wall, so that their shadows appear on the cave wall opposite the fire. These shadows constitute the world observed by the prisoners. We are the prisoners condemned by the human condition to see only the ephemeral shadows of sensibility that are thin reflections of a deeper reality, one that is permanent and, unlike the shadow world, not always passing away.

True knowledge is knowledge of the *forms* that constitute that deeper reality and these can only be reached by reason. Empirical knowledge is shadow knowledge and leaves us in perpetual darkness. Mathematics, which to the ancient Greek mind meant geometry, is unchanging and independent of the senses. As a mathematical entity, a triangle is a form that has permanence and mathematical knowledge of triangles is true knowledge, whereas any physical instance of a triangle is only a crude shadow of a real triangle and knowledge of physical triangles is a vulgar kind of knowledge. Like mathematics, metaphysical knowledge is not transient and concerns the truly real, not shadows. It is not surprising that Plato took so little interest in natural science.

As to a demarcation between science and metaphysics, Windelband writes,

The general questions which concern the actual taken as a whole are distinguished from those which deal with single provisions of the actual. The former, viz. the highest principles for explaining the universe, and the general view of the universe based on these principles, form the problems of *metaphysics*.... The special provisions of the actual are Nature and History. [Windelband, 1958]

Natural science comes under the province of Nature.

The grand issues that concern explaining the universe as a whole form the problems of metaphysics. Metaphysical explanations go beyond explanations of individual conditions (provisions) within the world to a unity of all individual conditions, not simply as a collection of conditions, but integrated within the context of the whole. Metaphysics does not concern this or that scientific principle but rather the deeper reality governing scientific principles in general. From Plato onward it has been a perpetual struggle to keep science and metaphysics demarcated.

Plato's placing the physical below the metaphysical has had great impact for over two thousand years. The metaphysician is enlightened; the physical scientist is not. In deprecating the natural sciences in favor of metaphysics, Plato has had the effect of encouraging the infusion of metaphysical speculation into science, a problem still with us today.

### 2.2.2 Aristotle's epistemology

For Aristotle the basic axiom of logic is the law of contradiction: “ $X$  and (not  $X$ )” is always false. Logical arguments are based on syllogisms, such as the classical example: All men are mortal; Socrates is a man; therefore, Socrates is mortal. Aristotle put great emphasis on definitions as they pertain to the class of an object and the differences between objects in a class. The defining attribute of a class is called a *universal*; for instance, the class of all triangles is characterized by certain properties that define an abstract triangle, the latter being a universal. Only individual objects exist in the material world. For Plato, a universal exists as a form in a deeper reality, but for Aristotle, a universal is simply a concept, or general idea. This conceptual view is in line with his empirical view that the senses are the only source of knowledge and observation is necessary for science.

While the issue of universals might appear abstruse, one's attitude towards universals is closely related to his view of reality. There tends to be three general positions. In the *realist* view, universals (man, truth,...) are real. “Man” is more than simply the set of individual men. In the *nominalist* view, which is common today, universals are simply names of sets and only the elements are real. In the *conceptualist* view, a universal refers to a general idea in the mind.

Aristotle diverged from Plato by paying serious attention to the physical world, in particular, biology. He made many observations and made serious efforts to record and explain them; however, he lacked the notion of a model-based designed experiment. Although he emphasized observation, Aristotle placed the authenticity of knowledge in metaphysics. In Book III of the *Physics*, Aristotle writes, “Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the ‘why’ of it (which is to grasp its primary cause).” [Aristotle, 335 BC] By insisting on an answer as to why, he points to a deeper reality (cause) beyond the phenomena (shadows). Whereas Plato left the deeper reality to the abstract, mystical world of forms, and therefore had little impact on actual scientific enquiry, Aristotle related the ‘why’ to the phenomena via causality, thereby having a huge impact on the future development of science. As described by Aristotle, causality has to do with providing categories of explanation. Knowledge is explanation surrounding the question of why and is based on four causes.

The four causes are defined in the *Physics*. A *material cause* is “that out of which a thing comes to be and persists.” It is “the bronze of the statue, the silver of the bowl, and the genera of which the bronze and the silver are species.” A *formal cause* is “the form or the archetype, i.e. the statement of the essence, and its genera,...and the parts in the definition.” An *efficient cause* is “the primary source of the change or coming to rest; e. g. the man who gave advice is a cause, the father is the cause of the child, and generally what makes of what is made and what causes change of what is changed.” A *final cause* is “the end, or that for the sake of which a thing is done, e. g. health is the cause of walking about.... The same is true also of all the intermediate steps that are brought about through the action of something else as means toward the end.” The same analysis is provided by Aristotle in the *Metaphysics*.

An efficient cause seems most in accord with our ordinary understanding of causality, but what does it mean to be “the primary source of the change or coming to rest?” Perhaps if one thinks of a moving billiard ball hitting another billiard ball at rest, then a casual observer might say in the vernacular that the moving billiard ball is the “cause” of the motion of the previously stationary billiard ball. But this everyday appeal to causality lacks any quantitative description. The latter would involve velocity, impact angle, elasticity, friction, air resistance, etc. Note that we have avoided trying to define “causality” in its current usage, instead allowing the reader to simply recognize the obvious difference or agreement with Aristotle. As we proceed, it will become apparent that defining causality in any meaningful sense is problematic.

The metaphysical nature of Aristotle’s notion of cause is revealed by his use of it to prove the existence of God. He argues that there must be a first cause, uncaused, and that first cause is God. He is the prime mover, after which all movement is imparted.

Our primary concern with the epistemology characterized by Aristotle’s conception of causal knowledge is the orientation towards the science of Nature engendered by it and the resulting impact on the future development of scientific epistemology. Three points are fundamental to Aristotle’s epistemology: (1) to know is to explain; (2) explanation must involve a causal relation; and (3) there is no demarcation between physics and metaphysics. The evolution of scientific epistemology has involved the demolition of these three pillars of Aristotelian epistemology and the removal of their retarding effect on scientific advancement.

### 2.3 Evolution and the Argument from Design

Empedocles expounded an evolutionary theory, but a more significant and modern articulation of *natural selection* was put forth by Lucretius (99–55 BC) in *De Rerum Natura (On the Nature of Things)*, one of the greatest treatises of Roman society. He writes,

Many were the monsters that the earth tried to make... It was in vain; Nature denied them growth, nor could they find food or join in the way of love.... Many kinds of animals must have perished then unable to forge the chain of procreation...for those to which nature gave no protective qualities lay at the mercy of others, and were soon destroyed.  
[Lucretius, 56 BC]

As framed by Charles Darwin (obviously without the genetic knowledge available today), organisms possessing different variants of a trait may have environmental advantages, thereby enhancing their survivability relative to other variants and thus facilitating greater reproduction. This natural selection occurs at the phenotypic level but the reproductive advantage (or disadvantage) shows up at the genetic level, the result being that populations evolve. This evolution is broken down into two general categories: (1) *microevolution* refers to changes within a species; and (2) *macroevolution* refers to the emergence of new species.

For this categorization to be meaningful, the definition of a species must be tight and universal, not something vague like a class of organisms possessing many similarities; otherwise, it will be subjective, not inter-subjective, and what for one person is microevolution may be macroevolution for another. Although Lucretius lacked mechanistic understanding of evolution, his analysis in terms of natural selection was sophisticated.

The *argument from design* was also discussed during the Roman period. In fact, it goes back to the Greek Stoics with little change. Cicero (106–43 BC), in *De Natura Deorum* (*On the Nature of the Gods*), writes, “When you see a sundial or a water-clock, you see that it tells the time by design and not by chance. How then can you imagine that the universe as a whole is devoid of purpose and intelligence, when it embraces everything, including these artifacts themselves and their artificers?” [Cicero, 45 BC] This *teleological argument* relates to purpose, or final cause, and not, as is more popular today, an argument based on complexity.

Both Lucretius’ theory of evolution and Cicero’s argument from design depend on reason operating on observations. The degree to which they are or are not scientific depends on the epistemology of science.

## 2.4 The Fall and Rise of Reason

Since our interest is primarily in the nature of scientific knowledge, we shall skip to the beginning of the Middle Ages, which we take to be 325 AD, marked by the Council of Nicaea, where the Christian creed was codified under the watchful eye of the emperor Constantine. Much great work was done during the period between Aristotle and the commencement of the Middle Ages, for instance, in geometry and in the studies of Archimedes, but this is not our interest.

We leave it to historians to decipher the factors leading to the abandonment of reason in the Roman world as Rome entered what was perhaps its final great phase under Constantine. Very likely the decline in reason and the move to faith were inextricably interwoven, with the failure of reason to bring material well being and spiritual contentment. For our purposes it is important to mention some markers in the fall and rise of reason.

### 2.4.1 Believe that you may understand

The fundamental problem was to reconcile reason with faith in the Age of Faith. St. Augustine (354–430) of Hippo and a Doctor of the Church, argued that the intellect is weak and there are many paradoxes that human reason cannot resolve. Therefore, do not try to ground faith upon reason. Augustine advises, “Seek not to understand that you may believe, but believe that you may understand.” Put another way, faith precedes understanding. Augustine did not come to this view because his reasoning was weak; rather, his reason was strong but it could not lead him to the certainty of faith. Since faith is primary for Augustine, it must lead the way to understanding. If reason does not agree with faith, then reason must yield.

Regarding the Bible, Augustine applies the same basic argument: “Dispute not by excited argument those things which you do not yet comprehend, or those which in the Scriptures appear...to be incongruous and contradictory; meekly defer the day of your understanding.” [Augustine, in Durant, 1950]. The Bible is not to be taken literally. It cannot be an arbiter of theological disputes. These must be settled by Church councils.

### 2.4.2 Islamic transition

Although dormant in Europe, reason was far from dead. It had earlier migrated into areas that were to be conquered by Islam and there it was preserved and prospered for some time.

Avicenna (Ibn Sīnā, 980–1037) was a Persian Aristotelian for whom reason is the arbiter of knowledge and knowledge of the natural world is obtained via observation. Like Aristotle, he argued that contingent beings require a first cause; hence, God must exist. He aimed to reconcile Islamic dogma with Aristotelian reason. Regarding the existence of universals, he argued that they exist as real entities in the mind of God, like Plato’s forms, and they exist as concepts in the human mind, in agreement with Aristotle. Regarding religious dogma, parables are needed to ensure the moral order, but for philosophers, reason must ground knowledge. Avicenna influenced medieval European philosophy, including Thomas Aquinas.

It is a common sequence in history for reason as queen to give way to faith when reason proves unable to arrive at truth or to provide answers to the deepest questions men pose: on freedom, on immortality, on God. We have seen this turn with Augustine. His was part of a great millennial metamorphosis into the medieval mind. Following the heights of reason in Plato and Aristotle, it was only a few short years to the skepticism and return to religion of Pyrrho, and more generally of the path trod by the Skeptics and Stoics. An analogous move will play a key role in the Enlightenment during the Eighteenth Century and affect the course of science.

The Enlightenment conflict was foreshadowed in Islam at the end of the Eleventh Century by one of Islam’s greatest philosophers, al-Ghazali (1058–1111). In his critique of reason, he anticipated David Hume by arguing that reason depends on causality and causality is merely temporal regularity. He anticipated Immanuel Kant by contending that reason cannot prove the existence of God or immortality, without which there is no moral order, without which civilization cannot survive. The only option is to return to the orthodoxy of the *Quran* and *Hadith*. Al-Ghazali’s influence was conclusive: reason and science began to wane in Islam. His argument is powerful, not too dissimilar from that of Augustine and Martin Luther. Kant will attempt to preserve both science and faith by limiting “pure reason” to science and basing faith on “practical reason.”

Following a long hiatus of almost a thousand years, reason would return to Europe. A key factor in the process was the attempt of Christianity to regain control of the Holy Land with the Crusades. It was during this period, 1095–1291, that the contact and mixing between a mature Islamic civilization that had

preserved the science and philosophy of ancient Greece and an adolescent European civilization that had suffered through the Dark Ages facilitated the movement of knowledge to Europe, including the translation from Arabic into Latin of ancient Greek texts. The Crusades also facilitated the integration of Europe under the Catholic Church, an integration that would break down with the emergence of monarchies.

Averroes (Ibn Rushd, 1126–1198), born in Cordoba, present-day Spain, was a major figure, perhaps the most important, in this movement of knowledge from Islam to Europe. He was an Aristotelian and, contra al-Ghazali, accepted that philosophy may risk atheism, but potentially there can be harmony between religion and philosophy. Indeed, religious dogma as symbol can be harmonized with philosophy by minimizing dogma to reconcile it with reason. Philosophers should be free to think and speak amongst themselves. They do not take the Bible or *Quran* literally but they recognize that the general public needs myths. Taking a view that in several hundred years would be held by many scientists, Averroes believed that natural law rules the world without any interference by God—a position unwelcome by Islam and Christianity. Indeed, Averroes had negligible influence in Islam, which had turned towards orthodoxy following al-Ghazali, but his philosophical thinking swept the educated circles in France and England, where secularism was beginning to contend with orthodox Christianity. It might not be too strong of a statement to say that Averroes brought Aristotle to Europe.

### 2.4.3 The Thirteenth Century: an age of reason

When Aristotle's *Physics* and *Metaphysics* arrived in Paris during the first decade of the Thirteenth Century, the European mind was roused. All the old conflicts between reason and faith took on new fervor. Out of these disputes arose the great Doctor of the Church, Thomas Aquinas (1225–1274). Contra Averroes, he aimed to make Aristotle consistent with Christianity. Contra Augustine, he elevated the intellect over the heart. Like Aristotle, for Aquinas truth is equivalence, in some sense, of thought with the thing. This view is a form of naïve realism and will be demolished with the coming of modern science.

Yet Aquinas cannot be neatly fit into rigid positions. He agrees with John Locke that there is nothing in the intellect that is not first in the senses, except the intellect itself, which agrees with Kant. Knowledge of Nature is acquired via the senses; metaphysical knowledge, including God, is obtained by analogy; and knowledge of the supernatural world comes only by faith. Taking this as a whole, Aquinas recognizes the roles of faith, reason, and the senses. In his balanced view, reason has its domain but must in some places yield to faith. In the *Summa Theologica*, a treatise that stands as an outstanding testimony to human reason, Aquinas writes, “Man is directed to God as to an end that surpasses the grasp of his reason.” [Aquinas, 1485]

Just as al-Ghazali counteracted the reason of Avicenna, John Duns Scotus (1266–1308) followed quickly on the heels of Aquinas to confront reason on behalf of faith. As a forerunner of Kant, Duns Scotus emphasized that reason applied to religion leads to contradictions (Kant's antinomies of pure reason) and,

since religion is necessary for morality, dogmas of faith should be accepted as a practical necessity (Kant's practical reason). A battle between faith, the Franciscans (Duns Scotus), and reason, the Dominicans (Aquinas), took place within the Church. Even before Duns Scotus, it appeared that orthodox dogma would prevail. In 1277, three propositions of Aquinas were declared heresies and the Archbishop of Canterbury condemned Thomism.

Aquinas quickly recovered, being canonized as a saint in 1323. The Catholic Church had to some extent legitimized reason and this would have huge effects going further, including for science. Six centuries later in 1921 the Church went so far as to declare Thomism its official philosophy. Much happened during the intervening centuries. In the Sixteenth Century, the Protestant Reformation attacked reason (Martin Luther, "That whore reason."), looking to return to Augustine, and the Catholic Church took an antagonistic view towards both reason and science when they were perceived to threaten the Church—or perhaps more accurately, perceived to threaten powerful interests in the Church. Fall-out from the conflict between reason and faith (or its secular substitute, ideology) always affects science.

Not only was modern philosophy foreshadowed in the Thirteenth Century but so too was modern scientific epistemology. Roger Bacon (1214–1294) asserted the two most fundamental aspects of that epistemology: first, scientific theory takes mathematical form, and second, experiments provide final proof of a theory. It would take many centuries before the meaning and application of these statements would be clarified, but the ground had been seeded with the mental form of theory and the requirement of an empirical connection.

Those living today often possess the distorted view of the days before the Age of Reason as a period containing nothing more than an arid and tedious scholasticism in which theologians argued amongst themselves as to how many angels can dance on a pin head. Certainly there is much truth to this view; however, the Thirteenth Century was itself an age of reason in which great intellectual battles were fought whose outcomes would shape the Western World for centuries, up into the modern period. In the *Age of Faith*, Will Durant writes, "We must see the Thirteenth Century not as the unchallenged field of the great Scholastics, but as a battleground on which, for seventy years, skeptics, materialists, pantheists, and atheists contested with the theologians of the Church for possession of the European mind." [Durant, 1950]

#### **2.4.4 William of Ockham: the razor**

The Fourteenth Century produced a remarkably modern mind whose name may be forever linked with the demand for concise theory. In addition to requiring an empirical basis for knowledge, William of Ockham (1287–1347) called for parsimony in reason. The famous *Ockham's razor* states that a plurality (of entities, causes, or factors) is not to be posited without necessity. Aquinas and Duns Scotus had desired parsimony, but they were less rigorous in application. Ockham wanted it applied everywhere, to metaphysics, science, and theology, the latter presenting a particularly thorny domain in which to apply the razor.



Ockham adopts a host of modern positions: philosophical and theological truth are different; nothing can be an object of thought without having been an object of the senses (Locke); universals are abstractions useful for thought, existing only in the mind; reason's conclusions are only meaningful as pertaining to experience; our knowledge is molded by our perception (Kant); and there is no objective truth. And Ockham was a theologian!

Beginning in antiquity we have come to the end of the Middle Ages, having moved at lightning speed, hitting only the highest points; however, in doing so we have touched upon the major issues facing reason and science heading into the modern period by viewing them in terms of their greatest protagonists. This provides a background for the epistemological eruptions to come in the Seventeenth Century and hopefully has given the reader a sense that the big ideas with us today have precursors running back through history.

## 2.5 Copernicus Moves Man from the Center of the Universe

The geocentric theory of Claudius Ptolemy (90–168), in which the earth is fixed at the center of the universe with the sun and planets revolving around it, had been generally accepted into the Sixteenth Century. The basic orbits are circular but they require complex epicycles within the basic orbit and eccentrics that move the basic orbit off center. The geocentric theory fit the existing data fairly well, did a respectable job at predicting planetary motions for astronomical charts, and had the metaphysically (theologically) pleasing consequence that humanity held a very special place in the universe.

In 1543, Nicolaus Copernicus (1473–1543) in *De Revolutionibus Orbium Coelestium* (*On the Revolution of the Celestial Orbs*) proposed the heliocentric theory. It contained one of the most striking claims in European history: the sun is fixed and the planets, including Earth, move in circular orbits about the sun. Orbital predictions from the heliocentric theory were no better than those from the geocentric theory; however, the heliocentric model was less complex, so that based simply on predictive capacity and parsimony (Ockham's razor) it was superior. Nonetheless, it was not generally accepted; indeed, Tycho Brahe, the greatest astronomer of the time, did not accept it.

The heliocentric theory of Copernicus was not completely novel. The idea went back to Aristarchus of Samos (310–230 BC) and had been followed up in more recent times by Nicole Oresme (1330–1382), Nicholas of Cusa (1401–1464), and Leonardo da Vinci (1452–1519). Nonetheless, it was Copernicus' theory that got attention and ushered in a new conception of the human condition.

How important was it? In *The Story of Civilization*, Will and Ariel Durant state what they consider to be "The basic events in the history of modern Europe." These events are three books: *De Revolutionibus Orbium Coelestium* by Copernicus, *Philosophiae Naturalis Principia Mathematica* by Isaac Newton, and *The Origin of the Species* by Charles Darwin. These books have driven the philosophic, religious, and political evolution of Western Civilization.

Was the theory claimed to be true? Sounding very modern, the preface of *De Revolutionibus* states:

Many scientists, in view of the already widespread reputation of these new hypotheses, will doubtless be greatly shocked by the theories of this book.... However...the master's hypotheses are not necessarily true; they need not even be probable. It is completely sufficient if they lead to a computation that is in accordance with the astronomical observations.... Let us grant that the following new hypotheses take their place beside the old ones which are not any more probable. Moreover, these are really admirable and easy to grasp, and in addition we shall find here a great treasure of the most learned observations. For the rest let no one expect certainty from astronomy as regards hypotheses. It cannot give this certainty. He who takes everything that is worked out for other purposes, as truth, would leave this science probably more ignorant than when he came to it. [Copernicus, 1543]

Truth is not claimed; only that when used in computations, the new theory predicts the astronomical observations as well as any competing theory.

In fact, the statement was not written by Copernicus but by an assistant, Andreas Osiander, apparently with the aim of keeping Copernicus out of the hands of the Inquisition, and without the permission of the author. Nonetheless, Osiander's preface showed prudence of the kind necessary in science, where final demonstrations are impossible. It is as though a Twentieth Century scientist had stepped back in time to clarify the epistemological ground of the theory.

The Copernican theory suffers on account of the assumption of circular orbits. Johannes Kepler (1571–1630) dropped this assumption and during the period from 1609 to 1619 formulated three laws based on elliptical orbits:

- I. Each planet moves in an elliptical orbit for which one focus is the sun.
- II. Each planet moves faster when nearer the sun and a radius drawn from the sun to the planet covers equal areas in equal times.
- III. The square of the time of revolution of a planet around the sun is proportional to the cube of its mean distance from the sun.

In addition to using elliptical instead of circular orbits to fit the data, Kepler's theory is structurally different than that of Copernicus because it involves formulae for various aspects of planetary motion. The next step would await Isaac Newton: derivation of planetary motion from a general theory of gravitation, that is, from fundamental physical laws.