

Chapter 3

The Birth of Modern Science

3.1 The Seventeenth Century

We shall define the Age of Reason to be the period between 1620, publication of the *New Organon* by Francis Bacon, and 1750, publication of *A Discourse on the Moral Effects of the Arts and Sciences* by Jean-Jacques Rousseau. As discussed in the previous chapter, reason was well ensconced in European thought by the end of the Thirteenth Century, but with the publication of the *New Organon*, it took on an empirical flavor, the aim no longer being to reconcile reason with faith, but to use it independently of faith to understand the world. With his rejection of both reason and civilization, Rousseau ushered in the Romantic Period, where sentiment and feeling take preference over reason.

During the Seventeenth Century, which is the focus of the present chapter, Bacon propounded the central role of designed experiments, Galileo advanced the notion that scientific knowledge must take mathematical form, Isaac Newton formulated physics in terms of general mathematical laws, and, both Galileo and Newton put aside the requirement of causal explanation, thereby dropping the Aristotelian epistemology.

3.2 Francis Bacon: Empirical Method

Spurred by growing wealth and commerce, and the cross-pollination of ideas engendered by increasing contact and communication, the Sixteenth Century had witnessed a great increase in scientific investigation, capped by Copernicus' heliocentric theory; nevertheless, Francis Bacon (1561–1626) saw progress being hindered by pointless disputation lacking utility. Laying the blame on Aristotle, he made the first major overt effort to break with *The Philosopher*. In distinction with Aristotle's *Organon*, he wrote the *Novum Organum (New Organon)*.

In the first aphorism of the *New Organon*, Bacon states emphatically that knowledge is rooted in experience: “Man, being the servant and interpreter of Nature, can do and understand so much and so much only as he has observed in fact or in thought of the course of Nature. Beyond this he neither knows anything nor can do anything.” [Bacon, 1620] Empiricism is the ground of knowledge. There will be no sterile speculation.

3.2.1 Idols of the mind

Bacon identifies two key impediments to scientific progress. First, certain prejudices in thinking impede objectivity and, second, efficient knowledge discovery requires a formal method with which to approach and comprehend Nature instead of haphazard observation and undisciplined imagination.

Regarding prejudice, Bacon identifies four “idols of the mind.” *Idols of the tribe* are fallacies common to humanity in general that one holds simply by being human. Our observations are necessarily filtered through our senses and our perceptions are necessarily relative to the structure of our minds. Bacon explicitly recognizes the formative role of the human understanding:

The Idols of the Tribe have their foundation in human nature itself, and in the tribe or race of men. For it is a false assertion that the sense of man is the measure of things. On the contrary, all perceptions as well of the sense as of the mind are according to the measure of the individual and not according to the measure of the universe. And the human understanding is like a false mirror, which, receiving rays irregularly, distorts and discolors the nature of things by mingling its own nature with it. [Bacon, 1620]

Idols of the cave are personal or parochial prejudices. Arguments can be twisted and turned to fit one’s prejudices and data can be selectively sought:

The Idols of the Cave are the idols of the individual man. For everyone (besides the errors common to human nature in general) has a cave or den of his own, which refracts and discolors the light of nature, owing either to his own proper and peculiar nature; or to his education and conversation with others; or to the reading of books, and the authority of those whom he esteems and admires; or to the differences of impressions, accordingly as they take place in a mind preoccupied and predisposed or in a mind indifferent and settled. [Bacon, 1620]

Idols of the marketplace are fallacies arising from language, specifically, the use of language to communicate ideas; everyday talk and fanciful story telling distort rigorous scientific investigation:

The Idols of the Marketplace are the most troublesome of all — idols which have crept into the understanding through the alliances of words and names. For men believe that their reason governs words; but it is also true that words react on the understanding; and this it is that has rendered philosophy and the sciences sophisticated and inactive. Now words, being commonly framed and applied according to the capacity of the vulgar, follow those lines of division which are most obvious to the vulgar understanding. [Bacon, 1620]

Idols of the theater involve the uncritical acceptance of dogma and popular theories, in part because they are philosophically delightful or satisfy human desire:

Idols of the Theater, or of Systems, are many, and there can be and perhaps will be yet many more.... For as on the phenomena of the heavens many hypotheses may be constructed, so likewise (and more also) many various dogmas may be set up and established on the phenomena of philosophy. And in the plays of this philosophical theater you may observe the same thing which is found in the theater of the poets, that stories invented for the stage are more compact and elegant, and more as one would wish them to be, than true stories out of history. [Bacon, 1620]

The deleterious effect of the idols on scientific research leads Bacon to desire a universal method that avoids the temptations of the idols. The method he proposes stems from his understanding of causality, which involves a re-examination of Aristotle's four causes.

3.2.2 Forms as law

Bacon agrees with Aristotle that causality is the ground of knowledge; however, he separates Aristotle's four causes as to whether they apply to physics or metaphysics: material and efficient causes to physics, formal and final causes to metaphysics. Bacon does not demarcate science from metaphysics. While he sees no place for final causes in science, his preference for authentic scientific understanding lies with formal causes. He writes,

It is a correct position that 'true knowledge is knowledge by causes.' And causes again are not improperly distributed into four kinds: the material, the formal, the efficient, and the final.... The efficient and the material (as they are investigated and received, that is, as remote causes, without reference to the latent process leading to the form) are but slight and superficial, and contribute little, if anything, to true and active science.... For though in nature nothing really exists besides individual bodies, performing pure individual acts according to a fixed law, yet in philosophy this very law, and the investigation, discovery, and explanation of it, is the foundation as well of knowledge as of operation. And it is this law with its clauses that I mean when I speak of *forms*.... Now if a man's knowledge be confined to the efficient and material causes (which are unstable causes, and merely vehicles, or causes which convey the form in certain cases) he may arrive at new discoveries in reference to substances in some degree similar to one another, and selected beforehand; but he does not touch the deeper boundaries of things. But whosoever is acquainted with forms embraces the unity of

nature in substances the most unlike, and is able therefore to detect and bring to light things never yet done. [Bacon, 1620]

Bacon separates himself from Plato by noting that forms do not give existence and only individual bodies exist in Nature. These bodies act according to a fixed law and “investigation, discovery and explanation of it” is the foundation of knowledge. This law, which by Bacon is called a “form,” is not within Nature; rather, it is metaphysical and governs Nature. It is in the domain of metaphysics where “true and active science” resides. Knowing the material out of which something comes to be or the source of change for a body’s change of motion is “superficial” in comparison to knowledge of form. Efficient and material causes do not touch “the deeper boundaries of things.”

Bacon distinguishes physics and metaphysics, and science intersects both, with the more important aspect of science, that being formal cause, lying within metaphysics. While the language of Bacon might appear muddled, one should not overlook the advance in scientific perspective. Bacon drops final cause and regards efficient and material causes as superficial. Suppose we go a bit further than he and drop all reference to efficient and material causes. Then we are left with only what he calls a formal cause. Let us examine this formal “cause.” First, it is not within Nature. Second, it represents “true science.” Third, it corresponds to a law governing natural behavior. Fourth, it allows the scientist “to detect and bring to light things never yet done.” Thus, if we drop the word “cause,” drop the appeal to explanation, and drop the characterization of a natural law as being metaphysical, then it would be seen that Bacon has taken a significant step towards modern science: the business of science is to discover natural law. We are not saying that Bacon dropped Aristotle’s efficient and material causes, nor that he disagreed with Aristotle regarding explanation, nor that by law he meant anything beyond simple cause and effect, nor that he put aside metaphysics, but we are saying that one can see in his thinking the beginning of the transformation from Aristotelian to modern science.

3.2.3 Experimental design

Bacon desires a method to ascertain scientific knowledge via experiment, not simply abstract reasoning. He recognizes that more is required than Aristotle’s unplanned observations. Given that true knowledge rests upon causality, the form of knowledge and its acquirement should conform to the causal relation. Thus, causality becomes inextricably linked to induction: when we observe that event B follows whenever event A is observed, then a cause-and-effect relation is in some (unspecified) sense “logically” induced between A and B . For Bacon, this relation is a formal cause and goes beyond the list of observations to a deeper knowledge of reality. For Bacon, scientific knowledge is causal knowledge and this knowledge is reached by the “logical” process of induction upon observing one event, the effect, repeatedly following the other, the cause, without exception.

Think of billiard ball A repeatedly sent into billiard ball B . Each time, ball B begins to move when hit by ball A , the latter being the efficient cause. For Bacon,

a deeper relation, one possessing true scientific knowledge, is induced in the relation that any moving body A hitting a stationary body B will always result in the stationary body moving. This more general relation about bodies would constitute a formal cause. It is metaphysical and is induced from repeated observations.

Bacon's attempt to form logical machinery to infer law from data was doomed to fail because it involved metaphysical confusion with science and assumed a very simple physical world that somehow conformed to human logical thinking. Nonetheless, his recognition that haphazard observation will not yield the kind of structured observations that lead to knowledge discovery led Bacon to his greatest contribution, articulation of the experimental method:

There remains simple experience which, if taken as it comes, is called accident; if sought for, experiment. But this kind of experience is no better than a broom without its band, as the saying is — a mere groping, as of men in the dark, that feel all round them for the chance of finding their way, when they had much better wait for daylight, or light a candle, and then go. But the true method of experience, on the contrary, first lights the candle, and then by means of the candle shows the way; commencing as it does with experience duly ordered and digested, not bungling or erratic, and from it educing axioms, and from established axioms again new experiments. [Bacon, 1620]

Looking back over a century and a half since the *New Organon*, in the *Critique of Pure Reason*, Immanuel Kant commented on the essence and importance of Bacon's call for rational experimental design:

It is only when experiment is directed by rational principles that it can have any real utility. Reason must approach nature with the view, indeed, of receiving information from it, not, however, in the character of a pupil, who listens to all that his master chooses to tell him, but in that of a judge, who compels the witnesses to reply to those questions which he himself thinks fit to propose. To this single idea must the revolution be ascribed, by which, after *groping in the dark* for so many centuries, natural science was at length conducted into the path of certain progress. [Kant, 1781]

Mind is inextricably embedded in the experimental method. Scientific knowledge is not obtained via abstractions conjured up in thinking isolated from data, nor from the blind collection of data absent a driving mental construct; rather, it is a product of both reason and data, the latter being obtained according to a plan of reason and then digested by reason in its theorizing. Bacon states the matter metaphorically:

Those who have handled sciences have been either men of experiment or men of dogmas. The men of experiment are like the ant, they only collect and use; the reasoners resemble spiders, who make cobwebs out of their own substance. But the bee takes a middle course: it gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own. [Bacon, 1620]

Kant beautifully summarizes the ants and spiders in the *Critique of Pure Reason*: “Perception without conception is empty; conception without perception is blind.” This insight has been validated many thousands of times during the progress of science; nevertheless, there are still many more ants and spiders than there are bees.

3.3 Galileo: The Birth of Modern Science

While Francis Bacon was formulating the experimental method in England, in Italy, besides making contributions to physics and astronomy, Galileo Galilei (1564–1642) was articulating a behavior-oriented mathematical formulation of scientific theory independent of causality. Modern science arrives with Galileo, because he recognizes that science should concern itself solely with quantifiable relations among phenomena. Galileo does not deny causality; rather, he brackets it—sets it aside—and proceeds with the mathematical description of relations between phenomena. In *Dialogues Concerning Two New Sciences*, Galileo puts these words into the mouth of Salviati:

The present does not seem to me to be an opportune time to enter into the investigation of the cause of the acceleration of natural motion, concerning which various philosophers have produced various opinions, some of them reducing this to approach to the center; others to the presence of successively less parts of the medium [remaining] to be divided; and others to a certain extrusion by the surrounding medium which, in rejoining itself behind the moveable, goes pressing and continually pushing it out. Such fantasies, and others like them, would have to be examined and resolved, with little gain. For the present, it suffices our Author that we understand him to want us to investigate and demonstrate some attributes of a motion so accelerated (whatever be the cause of its acceleration) that the momenta of its speed go increasing, after its departure from rest, in that simple ratio with which the continuation of time increases, which is the same as to say that in equal times, equal additions of speed are made. [Galileo, 1638]

There would be “little gain” in examining the kind of “fantasies” put forth by philosophers to explain acceleration in terms of causality. It is more beneficial to “investigate and demonstrate some attributes of motion.” Galileo does not deny causality; rather, he rejects it as a requirement for knowledge, thereby radically breaking with Aristotle.

Galileo is dissatisfied with words, Bacon's idols of the marketplace. These constitute ersatz knowledge, the result being both an illusion of knowledge and an impediment to actual knowledge owing to satisfaction with empty phrases. In *Dialogue Concerning the Two Chief World Systems*, when the Aristotelian Simplicio comments that everyone knows that bodies fall on account of gravity, Salviati responds,

You are wrong, Simplicio; you should say that everyone knows that it is called 'gravity.' But I am not asking you for the name, but the essence of the thing. Of this you know not a bit more than you know the essence of the mover of the stars in gyration. We don't really understand what principle or what power it is that moves a stone downwards, any more than we understand what moves it upwards after it has left the projector, or what moves the moon round. [Galileo, 1632]

Observation shows that bodies fall, and perhaps something called "causality" is operating here, but to simply say that there is a cause and to name it provides no knowledge. A name tells us nothing about the object being named or if such an object exists. Moreover, understanding the power that moves a stone downwards is not a prerequisite for providing a quantitative relation between the stone and the earth. In general, cogitating on words can lead one away from the phenomena rather than towards a characterization of their attributes.

Galileo contends that the book of Nature is written in mathematics. He writes,

Philosophy is written in this grand book, the universe, which stands continually open to our gaze. But the book cannot be understood unless one first learns to comprehend the language and read the letters in which it is composed. It is written in the language of mathematics, and its characters are triangles, circles, and other geometric figures without which it is humanly impossible to understand a single word of it; without these, one wanders about in a dark labyrinth. [Galileo, 1623]

In arguing that mathematics is the language of the universe, Galileo mixes metaphysics with science. While science may be written in mathematics, that is, grounded in human epistemology, the extension of human epistemology to the actual nature of Nature lies outside the realm of scientific knowledge and constitutes a metaphysical argument.

3.3.1 Trial of Socrates

There have been two great trials pertaining to science and philosophy: Socrates in 399 BC at the beginning of the greatest period of ancient Greek philosophy and Galileo in 1616 at the dawn of modern science. Tension between science and society exists because political forces are often unhappy with a scientific theory or wish to co-opt scientists to support a pseudo-scientific theory favorable to

some ideology. Thus, scientists can find themselves under pressure to keep quiet or bend the epistemological rules. While both political interference with science and acquiescence to such interference certainly deserve disapprobation, it should be recognized that science and philosophy have the potential to threaten the state.

The Peloponnesian War between the Athenian empire and the Spartan led Peloponnesian League lasted from 431 BC to 404 BC and ended with the defeat of Athens. Sparta imposed an Athenian government run by the “Thirty Tyrants.” Their rule was brutal with many opponents being killed and they were ousted after ruling for little more than a year. This was the atmosphere in 399 BC when Socrates was brought before an Athenian court on the dual charges of corrupting the youth and impiety. Athens was under dire threat.

In essence, the trial concerned the relationship of philosophy (science) to the state. Where does the freedom to speak cross a line that the state cannot tolerate? It would be facile to argue that there is no line. One cannot expect the freedom to call for the assassination of the king. In effect, Socrates was accused of undermining the viability of the civil society. He was impious because he did not acknowledge the gods of the city. He claimed the right to let his own reason be the arbiter and that he be allowed to promulgate his views. We see again the problem of al-Ghazali: should philosophy be allowed to undermine the moral order, and ultimately the civil order? This is a recurring theme and in 399 BC the problem was exacerbated by the imminent danger faced by Athens.

Plato understands the dilemma. In the *Apology* the case is made for Socrates and in the *Crito* it is made for the state. Socrates is clearly guilty and does not deny it, arguing only that he is following the direction of “the god”—not a god of the city. The profound issue is not whether Socrates is guilty but where the line prohibiting philosophic and scientific enquiry should be drawn, or should there be a line at all? Would not any line stifle free enquiry and ultimately distort human knowledge of Nature? And would it not be inherently fuzzy, thereby inviting abuse by those whose ambitions might be frustrated by such knowledge?

3.3.2 Trial of Galileo

The trial of Galileo is often misunderstood and misrepresented in the popular media. On March 20, 1615, Tommaso Caccini delivered to the Congregation of the Holy Office (the Inquisition) a letter stating that the Copernican heliocentric theory is incompatible with the Bible and informing the Inquisition that Galileo had advocated the theory. Later in the year, Cardinal Robert Bellarmine explained the Church’s position at the time:

To say that on the supposition of the Earth's movement and the Sun's quiescence all the celestial appearances are explained better than by the theory of eccentrics and epicycles is to speak with excellent good sense and to run no risk whatever. Such a manner of speaking is enough for a mathematician. But to want to affirm that the Sun, in very truth, is at the center of the universe and only rotates on its axis without going from east to west, is a very dangerous attitude and one calculated not only to

arouse all Scholastic philosophers and theologians but also to injure our holy faith by contradicting the Scriptures.... If there were a real proof that the Sun is in the center of the universe,...then we should have to proceed with great circumspection in explaining passages of Scripture which appear to teach the contrary. [Bellarmine, 1955]

Bellarmino is clear: should Galileo take the hypothetical view in Copernicus' preface, then he would be at no "risk whatever;" however, to affirm the theory as true would be "very dangerous." But even should Galileo insist on the truth of the heliocentric theory, if there were "real proof," then the Church might have to change her position. Bellarmine's viewpoint was communicated to Galileo by Piero Dini in a letter stating, in reference to Copernicus, that "with a similar precaution you may at any time deal with these matters."

Galileo decided to play a perilous game with the Inquisition. Still in 1615, he wrote, "I mean to submit myself freely and renounce any errors into which I may fall in this discourse through ignorance of matters pertaining to religion.... But I do not feel obliged to believe that that same God who has endowed us with sense, reason, and intellect has intended us to forgo their use." [Galileo, 1615] He will admit to errors owing to ignorance of religion, but theology must be wrong when it contradicts reason. Like Socrates, he will not submit to the state in matters of religion when his reason disagrees with the state.

The Inquisition responded: "The view that the sun stands motionless at the center of the universe is foolish, philosophically false, and utterly heretical, because [it is] contrary to Holy Scripture. The view that the earth is not the center of the universe and even has a daily rotation is philosophically false, and at least an erroneous belief." [Congregation of the Holy Office, 1616] Whereas the heliocentric theory had been acceptable as philosophy, following Galileo's challenge that compromise was withdrawn.

On February 26, 1616, the Inquisition ordered Galileo "to abstain altogether from teaching or defending the said opinions and even from discussing them." Galileo submitted to the decree and avoided prison. But he never really accepted it and continued to advocate the heliocentric theory, albeit, with less fanfare. Eventually, on June 22, 1633, the Inquisition pronounced Galileo guilty of heresy and disobedience. He spent three days in prison and was released by order of Pope Urban VIII. In December, he was allowed to return to his own villa, still a prisoner and confined to his own property, but free to continue his research and host visitors.

Scientifically, Galileo's position was specious. He was affirming truth when the new science that he was in the process of creating, one absent causality, had yet to establish a theory of knowledge. Moreover, he was supporting Copernicus' theory rather than Kepler's theory, of which he was well aware. The Inquisition's position lacks even a semblance of plausibility. Based on passages in the Bible and the theological desire to have man situated at the center of the universe, it rejected a scientific theory based on empirical observation in favor of another theory that possessed no discernable empirical advantage over the one it was

rejecting. As in the Athens of Socrates, the political situation in Europe was not conducive to tolerance. Most of the ordeal between Galileo and the Church took place during the Thirty Years War in Europe, which lasted from 1618 to 1648, during which time great swaths of territory were laid waste and a large portion of the population died from war, famine, and disease.

3.4 Isaac Newton: *Hypotheses Non Fingo*

Owing to our focus on epistemology, we go directly to Isaac Newton (1642–1727), who in 1687 published the greatest scientific work and one of the Durants' three most important events in modern European history, *Philosophiæ Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*). Newton not only satisfies Galileo's requirement of a strictly mathematical theory; he also formulates the theory of motion in three compact statements from which the quantitative behavior of bodies in motion can be developed via the infinitesimal calculus.

Newton's three laws of motion:

- I. Every body continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it.
- II. The change of motion is proportional to the motive force impressed, and is made in the direction of the straight line in which that force is impressed.
- III. To every action there is always opposed an equal reaction.

Using the laws of motion and the inverse square law, Newton mathematically derived a planetary theory. He grounded his theory in laws that generate an observable theory. The theory is not specific to the planets, as is the strictly descriptive theory of Kepler. The laws are general and apply to planets, billiard balls, and stars.

The epistemology of modern science begins to mature with Newton. The structure is relational, its form is mathematical, and its propositions are ideal, in the sense that relations between phenomena are characterized abstractly with the recognition that in practice they will be affected by other conditions. The theory is connected to the phenomena via its predictive capacity.

Consider gravity. Newton formulates a mathematical law of gravitation that relates distance, mass, and acceleration. The gravitational law is mathematical, relational, idealized insofar as when put into practice it ignores confounding effects such as air resistance, and it can be related to phenomena via experiment. The gravitational law mathematically characterizes a relation in such a way that the relation can be used to make predictions, thereby providing a means for validation and application. The mathematical structure represents a precise, inter-subjective, and operational form of knowledge.

The gravitational law contains no reference to some physical process behind the relations and there is no mention of a cause of acceleration. Regarding causality, Bertrand Russell (1872–1970) states,

In the motions of mutually gravitating bodies, there is nothing that can be called a cause, and nothing that can be called an effect; there is merely a formula. Certain differential equations can be found, which hold at every instant for every particle of the system, and which, given the configuration and velocities at one instant, or the configurations at two instants, render the configuration at any other earlier or later instant theoretically calculable.... But there is nothing that could be properly called ‘cause’ and nothing that could be properly called ‘effect’ in such a system. [Russell, 1913]

Like Galileo, Newton does not deny causality; he brackets it and formulates knowledge independent of it. Newton signals his intent near the beginning of the *Principia* when he writes, “For I here design only to give a mathematical notion of these forces, without considering their physical causes and seats.” [Newton, 1687] Near the end of the *Principia* he leaves no doubt that he is creating a new scientific epistemology:

Hitherto I have not been able to discover the cause of those properties of gravity from the phenomena, and I frame no hypothesis; for whatever is not deduced from the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phenomena, and afterward rendered general by deduction. Thus it was the impenetrability, the mobility, and the impulsive forces of bodies, and the laws of motion and of gravitation were discovered. And to us it is enough that gravity does really exist, and acts according to the laws which we have explained, and abundantly serves to account for all the motions of the celestial bodies, and of our sea. [Newton, 1687]

“*Hypotheses non fingo*”—“I frame no hypotheses.” In three words, Newton changes man’s perspective on himself and the universe, a change more profound than the one brought about by Copernicus because it is a fundamental change in what it means to know.

When speaking of gravity, Newton adds,

But our purpose is only to trace out the quantity and properties of this force from the phenomena, and to apply what we discover in some simple cases as principles, by which, in a mathematical way, we may estimate the effects thereof in more involved cases: for it would be endless and impossible to bring every particular to direct and immediate

observation. We said, in a mathematical way, to avoid all questions about the nature or quality of this force. [Newton, 1687]

There are two critical points in this statement. First, Newton is “to avoid all questions about the nature” of gravity. As he said earlier, “it is enough that gravity does really exist.” Something exists, but as Galileo had said, we know nothing of its substance—a basic category of Aristotle that now disappears from science. Second, the mathematical system is not meant to include all factors, but is of sufficient predictive power that it can “estimate” effects in a more general setting. Owing to its predictive nature, the mathematical system can be empirically tested independently of the reasoning leading to it.

Galileo and Newton widen the scope of knowledge to include mathematical systems that relate phenomena, while bracketing “questions about the nature” of the phenomena. The physical substance behind the mathematical relations is bracketed so that physical knowledge is constituted by mathematical knowledge, with the proviso that the mathematical knowledge be explicitly related to observations. Neither Galileo nor Newton explicitly deny causality; nevertheless, they engender a radical epistemological transformation by describing relations among phenomena in terms of mathematical formulas independent of causal or physically intuitive explanations that can lead to “fantasies,” to use Galileo’s terminology.

3.5 Determinism

Newton’s theory is deterministic: given an initial state (set of initial conditions) it will evolve so that a unique state is reached at each point in time. If the universe is causal, then its movement through time would be determined, each event caused by some set of events, these having been in turn caused by preceding events, the causal chain moving endlessly backwards and forwards in time. Newton’s determinism is consistent with causality but does not imply causality. As discussed previously, causality plays no role in Newton’s theory.

It was just such causal reasoning that led Aristotle to conclude that there must be a first cause, uncaused, that being God. In *The Leviathan*, Thomas Hobbes (1588–1679) states the implication of causality as it pertains to man’s freedom:

Because every act of man’s will, and every desire and inclination, proceedeth from some cause, and that from another cause, in a continual chain (whose first link is in the hand of God the first of all causes), they proceed from necessity. So that to him that could see the connection of those causes, the *necessity* of all men’s voluntary actions would appear manifest. [Hobbes, 1651]

The world is a machine governed by law, and so is man, whose desires and actions proceed from necessity. As a consequence, free will is an illusion. Since free will is required for man to be a moral being, he has no moral nature.

Pierre-Simon Laplace (1749–1827), who is among the founders of probability theory and a great physicist, recognizes the uncertainty in making predictions but attributes this uncertainty to ignorance. While he sees the practical need for a probabilistic approach to Nature, he holds on to causality as existing in Nature. In the following famous passage from *A Philosophical Essay on Probabilities* he formulates a complete determinism:

We ought then to regard the present state of the universe as the effect of its anterior state and the cause of the one which is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of the beings who compose it—an intelligence sufficiently vast to submit this data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present in its eyes. [Laplace, 1814]

By conditioning deterministic knowledge on a “sufficiently vast” intelligence, Laplace does not claim that human beings can achieve a completely deterministic theory of Nature; nevertheless, he postulates determinism in Nature based on causality in Nature. This causality is not merely temporal contiguity. His words, “the present state of the universe as the effect of its anterior state and the cause of the one which is to follow,” clearly suggest that there is more to cause and effect than anterior to posterior.

Laplace’s statement makes it clear that determinism is a metaphysical, not a scientific concept: it concerns a grand issue explaining the universe as a whole. It does not concern this or that scientific principle but a deeper reality governing scientific principles in general. Laplace speaks of an intelligence that can grasp the movements of all bodies, but does not claim that the intelligence exists. Laplace prefaces his determinism with causality but this need not have been the case. He could have hypothesized a vast intelligence that knew all the laws of physics and could at one instant make all the necessary measurements, and that Nature is completely described by these laws.

3.6 Dissenting Voices

Newton’s *Principia* leaves us with a science that is both rational and empirical. Reason supplies the laws but they are arrived at and validated empirically. If one rejects either reason or the senses as being too unreliable to serve as a source of knowledge, then science must be rejected. In the allegory of the cave, Plato rejects the empirical as a source of certain knowledge and argues that only reason can provide certain knowledge. This section considers two French philosophers of the first half of the Seventeenth Century, one who distrusts the senses and turns to rationalism, and another who distrusts reason and embraces faith.

3.6.1 René Descartes: *Cogito ergo sum*

René Descartes (1596–1650), French philosopher and mathematician, employed the principle of methodological doubt in his *Meditations on First Philosophy* to arrive at certainty by wiping the slate clean of his prior beliefs, which rest on uncertain grounds, and by thinking of some underlying certainty upon which to ground his beliefs. Such an undertaking would seem to be in accord with Bacon’s criticism of the idols of the mind; however, whereas Bacon looks to observation, Descartes rejects observation: “Everything which I have thus far accepted as entirely true and assured has been acquired from the senses or by means of the senses. But I have learned by experience that these senses sometimes mislead me, and it is prudent never to trust wholly those things which have once deceived me.” [Descartes, 1641].

Descartes postulates a situation in which he doubts all and only accepts that which cannot be doubted. He does this by distrusting his senses, because these sometimes mislead him and he distrusts all things that have ever deceived him. But he trusts his reason. Whereas Bacon adopts an empiricism filtered by reason, Descartes turns to a strict rationalism.

He assumes the existence of an evil spirit who is using all of his guile and power to deceive him, so that it is possible that all his senses have been put there to trick him. He will assume himself to possess neither hands, nor eyes, nor flesh, nor blood, nor senses, but will assume that he has been tricked into believing that he has all of these. Even in the face of this powerful, tricky, and perpetual deceiver, Descartes concludes,

There can be no slightest doubt that I exist, since he deceives me; and let him deceive me as much as he will, he can never make me be nothing as long as I think that I am something. Thus, after having thought well on this matter, and after examining all things with care, I must finally conclude and maintain that this proposition: *I am, I exist*, is necessarily true every time that I pronounce it or conceive it in my mind. [Descartes, 1641]

This is the famous “*Cogito ergo sum*” (“I think, therefore I am.”). In doubting there is thinking, there must be a thinker doing the doubting. As stated long before by Augustine, “Who doubts that he lives and thinks?... For if he doubts, he lives.”

Descartes concludes that he is a thinking being. He writes, “Thought is an attribute that belongs to me; it alone is inseparable from my nature.” He goes on to claim that it is inherent in a thinking being that he understands, conceives, affirms, denies, wills, rejects, imagines, and perceives. He argues that these are parts of thinking and it is “obvious that it is I who doubt, understand, and desire.”

In the *Meditations*, certainty is not rooted in any kind of concrete existence, be it spiritual or corporeal; instead, it is rooted in the isolated thinking ego. Existence must be demonstrated by a rational proof from within the isolated ego, without recourse to the world in which actual existence takes place.

To prove the existence of God, Descartes invokes a form of the *ontological argument*. The thinker has a clear and distinct idea of God that includes perfection, and existence is a necessary attribute for divine perfection. Descartes conceives of a perfect, existing being. Were that being not to exist, then his mental conception would be in error, and this cannot be since he has a clear and distinct understanding of divine perfection. He writes,

That which we clearly and distinctly understand to belong to the true and immutable nature of anything, its essence or form, can be truly affirmed of that thing. But after we have with sufficient accuracy investigated the nature of God, we clearly and distinctly understand that to exist belongs to His true and immutable nature. Therefore we can with truth affirm of God that He exists. [Descartes, 1963]

Descartes goes on to argue that, since God has now been proven to exist and He is perfect, God cannot be a deceiver because Descartes' idea of Him includes that He is perfect and Descartes' idea of perfection includes the attribute that a perfect being cannot be a deceiver. Hence, Descartes is not being deceived into believing something exists that does not exist when he has ideas of corporeal objects. Descartes can now re-visit his doubting of ideas originating in his senses.

For Descartes, God's existence depends on his having an idea of Him. Other truths can be reached by his having clear and distinct conceptions. He writes,

Whenever I restrict my volition within the bounds of my knowledge, whenever my volition makes no judgment except upon matters clearly and distinctly reported to it by the understanding, it cannot happen that I err. For every clear and distinct conception is without doubt something real and positive, and thus cannot derive its origin from nothingness, but must have God for its author — God, I say, Who, being supremely perfect, cannot be the cause of any error — and consequently we must conclude that such a conception or such a judgment is true. [Descartes, 1641]

Ultimately, the ground of truth lies in the thinking being's clarity of thought. Any judgment of Descartes based on a clear and distinct idea cannot be in error.

What if I have a clear and distinct conception that statement X is true and Descartes has a clear and distinct conception that X is false? Unless Descartes is going to argue that only his clear and distinct conceptions are true, both X and not- X must be true. As for the ontological argument, which long preceded its use by Descartes, suppose I clearly and distinctly understand that immortality belongs to the true and immutable nature of a *cat*. *Ipsa facto*, cats are immortal.

Descartes' rationalism is anti-scientific because scientific knowledge is rooted in the phenomena and must be tied to it, not do Descartes' clear and distinct ideas. In Bacon's metaphor, Descartes is a spider making cobwebs according to his own fancy. Furthermore, whereas science aims to be inter-

subjective, so that concepts can be shared and agreement reached as to why a proposition is acceptable or not acceptable, even though there might not be agreement on whether to accept or not accept, Descartes engages in a radical subjectivism. No one but Descartes can judge the clearness and distinctness of his conceptions.

One might be tempted to dismiss the *Meditations* as an absurd amusement, but this would ignore the enormous impact of Descartes on Western thinking; indeed, during the first two decades of the Twenty-first Century, the view that truth is a private matter based solely on one's internal thoughts has become widespread. Such thinking is anathema to science. A major motivation in the development of scientific epistemology has been to eliminate spider-cobweb thinking.

3.6.2 Blaise Pascal: the eternal silence

Francis Bacon envisioned unending progress as scientific knowledge would allow man to control Nature and extract the benefits. His maxim: "Nature, to be commanded, must be obeyed." Man shall obey Nature to learn her secrets but once they are known he will command her. A utopia will ensue in which scientists provide all the benefits to mankind. Blaise Pascal (1623–1662) had doubts. Looking into the night sky at the dawn of modernity, he remarked, "The eternal silence of those infinite spaces frightens me." Philosopher William Barrett comments that Western civilization is split in two by Pascal's thought: before there was Nature, a gift of God in which man was at home; after, man is homeless and alienated within the cosmos.

Pascal is one of the most subtle thinkers the world has known. His *Pensées*, although a collection of notes and fragments, reveals a mind that cuts everywhere to the quick. He was a scientist and great mathematician. He built the first mechanical calculator and, along with Pierre Fermat, founded the calculus of probabilities. He was among the greatest writers of French prose. Lastly, but not least, he was a defender of faith in the Age of Reason.

Rather than like Descartes extolling the ability of reason to provide certain knowledge or Bacon hoping that a new form of logical reasoning along the lines of the inductive methods presented in the *New Organon* would reveal the causality driving the physical world, Pascal saw reason to be weak and very limited. Sounding like Immanuel Kant almost 150 years later, he argues that reason cannot ground morality, reason cannot grasp the real nature of the world, and reason cannot comprehend God, prove His existence, or prove immortality. Portending the Romantic Period, Pascal exclaims, "The heart has its reasons, which reason does not know."

Pascal puts the deepest question of man before us:

When I consider the short duration of my life, swallowed up in the eternity before and after, the little space which I fill, and even can see, engulfed in the infinite immensity of spaces of which I am ignorant and which know me not, I am frightened and I am astonished at being here

rather than there; for there is no reason why here rather than there, why now rather than then. Who has put me here? By whose order and direction have this place and this time been allotted to me? The eternal silence of those infinite spaces frightens me. [Pascal, 1986]

Pascal is not speaking here of rational analysis, propositions, and logical proofs. Perhaps he wrote these lines in the hours after midnight, after having lain in the grass on his back gazing up at the stars on a moonless night. Billions of stars, light years away, appear at every angle above him. He imagines the mass of all these stars measured against his own mass, which at once becomes nothing. He imagines the light years and age of the universe measured against his own time on earth, which is infinitesimal in comparison. Nothing! All of his mathematical and scientific learning, and he knows nothing.

His advice: “Know then, proud man, what a paradox you are to yourself. Humble yourself, weak reason; be silent, foolish nature; learn that man infinitely transcends man, and learn from your Master your true condition, of which you are ignorant. Hear God.” [Pascal, 1670]

So, in the Seventeenth Century, in which science emerges as a colossus to transform man’s thinking and his place in the world, two of the greatest minds of the century demur, one on behalf of reason over observation and the other on behalf of faith over reason. These are two very different messages. Descartes’s extreme rationalism is destructive of science, whereas Pascal is simply warning of the limitations of science

In the *Critique of Pure Reason*, Immanuel Kant sounds a similar warning:

[Reason] begins with principles, which cannot be dispensed with in the field of experience, and the truth and sufficiency of which are, at the same time, insured by experience. With these principles it rises, in obedience to the laws of its own nature, to ever higher and more remote conditions. But it quickly discovers that, in this way, its labors must remain ever incomplete, because new questions never cease to present themselves; and thus it finds itself compelled to have recourse to principles which transcend the region of experience, while they are regarded by common sense without distrust. It thus falls into confusion and contradictions. [Kant, 1781]

One may wish that science could uncover “the highest principles for explaining the universe,” but it cannot.