Chapter 4
Reflections on the New Science

4.1 Critique of Knowledge

As monumental as it was with respect to man's view of the solar system, his perception of his place in the universe, and his relation to God, the Copernican theory did not structurally differ from Ptolemy's theory. Thus, the Sixteenth Century ended with no significant change in the structure of scientific knowledge or its causal basis, which had been in place for approximately 2000 years. On the other hand, beginning with Kepler's laws, Bacon's experimental method, and Galileo's mathematical epistemology, the Seventeenth Century produced a radical break with the past, its greatest achievement being Newtonian science based on general relational laws that applied to phenomena without requiring reference to strictly physical categories.

Looking back on the Seventeenth Century, Alfred North Whitehead (1861–1947), one the greatest philosophers of the Twentieth Century, commented,

> A brief, and sufficiently accurate, description of the intellectual life of the European races during the succeeding two centuries and a quarter up to our own times is that they have been living upon the accumulated capital of ideas provided for them by the genius of the seventeenth century. The men of this epoch…bequeathed formed systems of thought touching every aspect of human life. [Whitehead, 1990]

It should not be surprising that philosophers in the Eighteenth Century turned their attention to gaining an appreciation of what this "new science" meant, in particular, the relationship of Nature to both man and science, which involves the relationship of science to man—his body, his mind, and his God. The result was a profound critique of knowledge that saw the Eighteenth Century begin with science virtually unchallenged and end with science in a virtual war with feeling.

4.2 John Locke: The Mind as White Paper

John Locke (1632–1704) lived almost his entire life in the Seventeenth Century and published *An Essay Concerning Human Understanding* in 1689. We include him in this chapter for two reasons: first, he published the *Essay* near the end of the Seventeenth Century and after Newton's *Principia* and, second, he is the first of three major empiricists whom we will discuss, Locke followed by George Berkeley and David Hume.

What is empiricism? Typically, it is defined as the theory that all knowledge is derived from sense experience. This definition requires defining knowledge and explaining what it means to be derived. Knowledge can be of many kinds. Here we are working our way towards a modern definition of scientific knowledge. Even more abstruse is what it means to derive knowledge from sense experience. This must somehow characterize the manner in which sensation is processed to arrive at knowledge.

Empiricism may also be defined as the theory that all concepts come from sense experience. This is a bit more general since concepts do not have to represent knowledge. Concepts are called *a posteriori* if they can be applied only on the basis of experience and *a priori* if they can be applied independently of experience. The problem is that these terms are also problematic. Consider the concept triangle. Its definition and properties are all in the mind and so one might argue that the concept triangle is *a priori*; however, an empiricist may claim that the concept triangle has arisen from the experience of physical objects that are essentially triangular so that it is *a posteriori*. We leave these conundrums to philosophers and proceed with a general understanding that an empiricist takes the view that all knowledge is derived from sense experience. This certainly rules out God and immortality.

Regarding his empiricism, in *An Essay Concerning Human Understanding*, Locke writes,

> Let us then suppose the mind to be, as we say, white paper, void of all characters, without any ideas. How comes it to be furnished?... To this I answer, in one word, from experience. In that all our knowledge is founded; and from that it ultimately derives itself. Our observation employed either, about external sensible objects, or about the internal operations of our minds perceived and reflected on by ourselves, is that which supplies our understandings with all the materials of thinking. [Locke, 1689]

To all the subtleties mentioned previously, we can add what is meant by the mind being a "white paper." If the mind is totally void, then how is experience processed? What does the writing on the paper?

Locke breaks the properties we observe into two categories. *Primary qualities* are "utterly inseparable from the body" and are objective. These include solidity, extension, number, and motion. They exist in a substratum ("matter").

Secondary qualities "are nothing in the objects themselves but powers to produce various sensations in us by their primary qualities" and are subjective. These include color, sound, taste, and odor. The separation into primary and secondary properties is an old distinction, essentially adopted by Aquinas, Descartes, Galileo, and Hobbes.

The salient point is that we experience sensations and actually know nothing of the underlying substratum, so that the Aristotelian notion of substance is meaningless. How do we know that matter even exists? Using an empiricist epistemology based strictly on sensation, Locke is driven towards *idealism*, meaning that mind is more fundamental than material and that material objects, insofar as human understanding is concerned, are at least in part products of the mind. If this sounds strange, then think of what Newton has already done: "I frame no hypotheses." He has abandoned the physical substratum in favor of equations relating quantitative observations.

If all knowledge is derived from sensation, then so too must knowledge of the mind. Thus, if Locke is to carry his reasoning to the bitter end, then just as the existence of matter is brought into question, so too must the existence of the mind itself. The following statement from the *Essay* is a bit convoluted but its prescience of the devastating analysis of David Hume yet to come makes reading it well worth the effort:

> It is evident that, having no other idea or notion of matter, but something wherein those many sensible qualities which affect our senses do subsist; by supposing a substance wherein thinking, knowing, doubting, and a power of moving, etc., do subsist, we have as clear a notion of the substance of spirit, as we have of body; the one being supposed to be (without knowing what it is) the substratum to those simple ideas we have from without; and the other supposed (with a like ignorance of what it is) to be the substratum to those operations we experiment in ourselves within. It is plain then, that the idea of corporeal substance in matter is as remote from our conceptions and apprehensions, as that of spiritual substance, or spirit. [Locke, 1689]

In sum, why should an empiricist sensation-based epistemology leave us with any more certainty regarding the existence of mind than regarding the existence of matter?

4.2.1 Innate principles of thought

Gottfried Wilhelm Leibniz (1645–1716) is one of history's greatest geniuses. Not only was he a leading philosopher of his time, independently of Newton he discovered the infinitesimal calculus. In fact, the notation employed today is basically that proposed by Leibniz. Contrary to Locke, and anticipating the view of Kant, Leibniz took the position that mind is not a passive receptacle of experience but rather, via its structure, it transforms the data of sensation: "Nothing is in the mind that has not been in the senses, except the mind itself."

For Leibniz, mind supplies categories of thought and understanding, such as substance, identity, and cause. There are innate principles of thought that develop through experience. Leibniz includes the principle of contradiction and the principle of sufficient reason—"Nothing happens without a reason why it should be so rather than otherwise." For Leibniz, these principles are inherent in the structure of the mind, but only take active form as a person recognizes their operation in his experience. These principles correspond to Kant's notion of *a priori* categories which drive the mind's understanding of Nature. The point is that mind is not completely a clean slate (*tabula rasa*), but that it has an intrinsic operational structure.

4.3 George Berkeley: *Esse Est Percipi*

If all knowledge is derived from the senses, then, comments George Berkeley (1685–1753), there is no reality outside what we have perceived. The primary qualities are as subjective as the secondary qualities. What then is left of matter? Berkeley states, "It is the mind that frames all that variety of bodies which compose the visible world, any one whereof does not exist longer than it is perceived." [Berkeley, 1710] Thus, to be is to be perceived (*esse est percipi*). But what happens if there is no one perceiving? Does the tree crashing in the forest make a sound if there is no one to hear it? But there is a constant perceiver: God. Hence, the external world is not denied, only its materiality. Given Berkeley's arguments, should God not exist, then what?

Like Locke, Berkeley goes on to bring into question the existence of mind. In his *Three Dialogues* (1713), Hylas states,

> You admit nevertheless that there is spiritual substance, although you have no idea of it, while you deny there can be such a thing as material substance, because you have no notion or idea of it…. It seems to me that according to your own way of thinking, and in consequence of your own principles, it should follow that you are only a system of floating ideas, without any substance to support them. Words are not to be used without a meaning. And as there is no more meaning in spiritual substance than in material substance, the one is to be exploded as well as the other. [Berkeley, 1713]

At this point Berkeley demurs and in the *Dialogues* Phylonous rejoins Cartesian-like that he is aware of his own consciousness. Thus, mind is saved, but only momentarily, since Hume will reject the rejoinder.

Are we to take any of this seriously? Yes, if we are concerned about scientific knowledge. In the Twentieth Century, implications of the subtleties introduced by the Seventeenth Century empirical grounding of science, which necessarily include issues regarding human sensation and the existence of objects external to perception, will become clear. In the Introduction to the 1957 Dover Edition of Erwin Schrödinger's *Science Theory and Man*, James Murphy writes,

> The trend of theoretical physics today, in its search for a definite epistemological standpoint, is somewhat in the nature of a pilgrimage to the Cathedral of Cloyne.… The key to much of what Schrödinger writes in the following chapters, about the difficulties of the epistemological problem in quantum mechanics as a whole and especially in wave mechanics, will be found in Berkeley. [Murphy, 1957]

4.4 David Hume: Reason Is Humbled

When Galileo and Newton bracket causality, they not only posit non-causal knowledge, they also permit themselves the luxury of not addressing the meaning of causality. In particular, if we focus on Bacon's perspective, then there is a temporal aspect to causality in that the cause occurs prior to the event and this temporality plays a key role in Bacon's proposed inductive method. David Hume (1711–1776) raises a crucial epistemological question: Are a cause and its effect merely related via temporal priority, with the cause prior to the effect, or is there more than temporal contiguity? To wit, is there something that touches "the deeper boundaries of things," as Bacon would have it? Is there a necessary connection between the cause and the effect? Hume argues that in using the phrase "cause and effect," we mean the latter.

4.4.1 The ghost in the Galilean brackets

In *An Enquiry Concerning Human Understanding* (1751), Hume writes,

> When one particular species of events has always, in all instances, been conjoined with another, we make no longer any scruple of foretelling one upon the appearance of the other, and of employing that reasoning, which alone can assure us of any matter of fact or existence. We then call one object, Cause; and the other, Effect. We suppose that there is some connexion between them; some power in the one, by which it infallibly produces the other, and operates with the greatest certainty and strongest necessity. [Hume, 1751]

Do repeated conjoined observations warrant the supposition of a necessary connection? Is there a ground in reason or an empirical ground for judging there to be a necessary connection? Hume states emphatically that there is no such ground. Belief in causality rests not on reason, but on habit. In one of the key epistemological passages, he writes,

> But there is nothing in a number of instances, different from every single instance, which is supposed to be exactly similar; except only, that after a repetition of similar instances, the mind is carried by habit, upon the appearance of one event, to expect its usual attendant, and to believe that it will exist. This connexion, therefore, which we *feel* in the mind, this customary transition of the imagination from one object to its usual

> attendant, is the sentiment or impression from which we form the idea of power or necessary connexion. Nothing farther is in the case. Contemplate the subject on all sides; you will never find any other origin of that idea. This is the sole difference between one instance, from which we can never receive the idea of connexion, and a number of similar instances, by which it is suggested. The first time a man saw the communication of motion by impulse, as by the shock of two billiard balls, he could not pronounce that the one event was *connected*: but only that it was *conjoined* with the other. After he has observed several instances of this nature, he then pronounces them to be *connected.* What alteration has happened to give rise to this new idea of *connexion?* Nothing but that he now *feels* these events to be *connected* in his imagination, and can readily foretell the existence of one from the appearance of the other. When we say, therefore, that one object is connected with another, we mean only that they have acquired a connexion in our thought. [Hume, 1751]

In *A Treatise of Human Nature* (1738), Hume states,

> [The] supposition that the future resembles the past is not founded on arguments of any kind, but is derived entirely from habit, by which we are determined to expect for the future the same train of objects to which we have been accustomed…. All our reasonings concerning causes and effects are derived from nothing but custom and belief is more properly an act of the sensitive than of the cogitative part of our nature. [Hume, 1738]

The sticking point is necessity. In the *Treatise*, Hume writes, "From the mere repetition of any past impression, even to infinity, there never will arise any new original idea, such as that of a necessary connexion; and the number of impressions has in this case no more effect than if we confined ourselves to one only." [Hume, 1738] Repetition may lead to increased expectation, but not necessity—and certainly not to some deeper relationship. Induction does not depend upon causality; in fact, it is the opposite. Belief in causality is itself an unwarranted leap from repeated observations.

The implications of this conclusion are immense. If, as Aristotle and Bacon believed, scientific knowledge is knowledge of causes, and if causality rests on habit and custom, then the ground of scientific knowledge is brought into question. If, as Hume argues, the concept of a necessary connection between phenomena is subjective, then does not this entail the subjectivity of scientific knowledge?

Hume does not miss this point. Regarding his conclusion that the connection between cause and effect is arrived at by habit and exists only in human thought, in the *Enquiry*, he writes,

> For surely, if there be any relation among objects which it imports to us to know perfectly, it is that of cause and effect. On this are founded all our reasonings concerning matter of fact or existence. By means of it alone we attain any assurance concerning objects which are removed from the present testimony of our memory and senses. The only immediate utility of all sciences, is to teach us, how to control and regulate future events by their causes. Our thoughts and enquiries are, therefore, every moment, employed about this relation: Yet so imperfect are the ideas which we form concerning it, that it is impossible to give any just definition of cause, except what is drawn from something extraneous and foreign to it. Similar objects are always conjoined with similar. Of this we have experience. [Hume, 1751]

In these few words, Hume unsettles the foundations of scientific knowledge. If all reasoning concerning matter of fact or existence is founded on causality and the utility of all sciences is to control nature through the regulation of events via their causes, and if causality is simply a product of habit, then scientific understanding rests on habit, or custom, not on objective physical relations.

All reasoning concerning matter of fact is not founded on causality, and Hume should have been aware of this. While he may have shown there to be nothing of consequence inside the brackets that Galileo and Newton put aside, his skeptical assault does nothing to undercut the mathematical-experimental structure of modern science as conceived by its founders. Their scientific theories do not rest upon causality. Nevertheless, in showing that the brackets contain a ghost—at least insofar as causality represents some intrinsic physical reality—Hume deals a severe blow to the human desire for certainty.

Einstein writes, "Man has an intense desire for assured knowledge. That is why Hume's clear message seems crushing: the sensory raw material, the only source of our knowledge, through habit may lead us to belief and expectation but not to the knowledge and still less to the understanding of lawful relations." [Einstein, 1944b]

4.4.2 Modernity arrives

Hume forever buried the Aristotelian concept of science, and he fundamentally went beyond Galileo and Newton, who recognized that his mathematical theories of science are idealized and can only "estimate" actual behavior. When Hume wrote, "the mind is carried by habit, upon the appearance of one event, to expect its usual attendant," he made the monumental shift from causality to expectation, thereby recognizing that scientific statements are inherently probabilistic; indeed, in the *Enquiry*, the section dealing with the fundamental issues surrounding causality is entitled, "Of the Probability of Causes."

Modernity fully arrives with Hume (and not just in science). He does not bracket causality as a scientific category; he dismisses it as a scientific category altogether by showing that it has no grounding in reason or in Nature, at least insofar as is empirically discernable. Necessary connections are subjective

impressions, not objective relations. Observations lead to expectation, a probabilistic category, not to certainty. Scientific certitude is a fiction, a product of a leap of thought.

Two centuries after Hume's *Treatise*, Erwin Schrödinger wrote, "It can never be decided experimentally whether causality in Nature is 'true' or 'untrue.' The relation of cause and effect, as Hume pointed out long ago, is not something that we find in Nature but is rather a characteristic of the way in which we regard Nature." [Schrödinger, 1957]

Having eliminated causality and weakened scientific knowledge, Hume was not done. Whereas Locke and Berkeley had toyed with the eradication of mind but did not pursue it, Hume was not so hesitant. In the *Treatise* he wrote,

> That which we call a mind is nothing but a heap or collection of different perceptions, united together by different relations, and supposed, though falsely, to be endowed with a perfect simplicity and identity…. The mind is a kind of theatre, where several perceptions successively make their appearance; pass, repass, glide away, and mingle in an infinite variety of postures and situations. There is properly no *simplicity* in it at one time, nor *identity* in different [times], whatever natural propension we may have to imagine that simplicity and identity. The comparison of the theatre must not mislead us. They are the successive perceptions only that constitute the mind. [Hume, 1738]

There is no connecting mind. Experience is a succession of atomistic sense impressions disconnected from each other. The mind is nothing but a bundle of perceptions. Berkeley had eliminated matter; Hume dispenses with mind.

Why did the Age of Reason not lead to clarity and certainty? For Hume the answer was obvious if only we be brutally honest: "Reason is and ought only to be the slave of the passions." The landscape was clear for the Romantic Period, which only awaited the arrival of Jean-Jacques Rousseau, a few years hence.

If reason is a slave to the passions, how can it support religion and morality? Hume does not temporize. Sounding a bit like Augustine, in the *Treatise* he writes, "Belief is more properly an act of the sensitive than of the cognitive part of our natures." Since morality is also thrown back on the passions, like faith, it too is subjective. Hume writes, "We tend to give the name of virtue to any quality in others that gives us pleasure by making for our advantage, and to give the name of vice to any human quality that gives us pain." [Hume, 1738]

Causality, reason, scientific certainty, metaphysics, faith, and morality—all are slain by Hume's dialectical scalpel. Surely such carnage would generate a titanic reaction. And it did—Immanuel Kant.

4.5 Immanuel Kant: Critique of Reason

In his *Prolegomena to Any Future Metaphysics* (1783), Immanuel Kant (1724–1804) tells us whose thinking interrupted his ordered life as a philosopher and astronomer in Königsberg and galvanized him into action: "I freely admit that the

remembrance of *David Hume* was the very thing that many years ago first interrupted my dogmatic slumber and gave a completely different direction to my researches in the field of speculative philosophy." [Kant, 1783] Now awoken, he would counter Hume's skepticism on all fronts and in doing so become the greatest philosopher of modernity. In the process he would write three celebrated critiques: the *Critique of Pure Reason* (1781), the *Critique of Practical Reason* (1788), and the *Critique of Judgment* (1790). Our main interest is with the first critique because of its strong focus on scientific epistemology; however, we will consider the second critique to understand Kant's notion of practical reason and his grounding of morality outside of experience. The *Prolegomena* is to a large extent a shortened and somewhat easier to read version of the first critique.

This section is difficult to read because Kant is difficult and because it will bring many readers into areas of thinking far outside where they have heretofore ventured. For motivation, we begin with a quote by Arthur Schopenhauer (1788–1860) from his classic work, *The World as Will and Representation*:

> Kant's teaching produces a fundamental change in every mind that has grasped it. This change is so great that it may be regarded as an intellectual rebirth. It alone is capable of really removing the inborn realism which arises from the original disposition of the intellect.... The mind undergoes a fundamental undeceiving, and thereafter looks at things in another light.... On the other hand, the man who has not mastered the Kantian philosophy, whatever else he may have studied, is, so to speak, in a state of innocence; in other words, he has remained in the grasp of that natural and childlike realism in which we are all born. [Schopenhauer, 1818]

As brought home by quantum mechanics in the first half of the Twentieth Century, natural realism is a powerful impediment to the progress of science.

4.5.1 Categories of the understanding

The linchpin of Hume's analysis is his elimination of causality. Kant would have to re-establish causality in a way that would not be susceptible to Hume's arguments. Recall that for an empiricist all knowledge is *a posteriori*, meaning that it is derived from sense experience. Kant concurs with this empiricist view up to a point. He accepts that knowledge begins with sensations (stimulations of the senses) but insists that these are at once transformed by the mind to form perceptions (mental objects) that are conceptually organized by the mind's *categories of the understanding*, which are part of its structure (recall Leibniz). The categories are *a priori* because they are intrinsic to the structure of the mind and therefore exist prior to experience.

In this way, Kant defines pure reason: "The faculty of knowledge from *a priori* principles may be called pure reason, and the general investigation of its possibility and bounds the critique of pure reason." [Kant, 1790] Pure reason concerns *a priori* knowledge, and the examination of the possibility and limits of

pure reason constitute its critique. *Pure theoretical (speculative) reason*, the subject of the first critique, employs the categories of the understanding, and its application is limited to experience.

Kant agrees with Hume that the principle of causality is not a product of reason. In the *Prolegomena*, he writes, "[Hume] justly maintains that we cannot comprehend by reason the possibility of causality, that is, of the reference of the existence of one thing to the existence of another, which is necessitated by the former." [Kant, 1783] However, whereas for Hume habit underlies causality, for Kant, causality is a category of the understanding. It is a form imposed on phenomena by the nature of the human mind. The mind imposes forms on the data of sensation, and scientific knowledge is limited by these forms. The way things appear, such as being spatially coordinated and connected by causality, are due to subjective *a priori* conditions for knowledge. One cannot know things apart from the manner in which they conform to these *a priori* mental forms.

Of the categories of the understanding, including causality, in the *Critique of Pure Reason*, Kant writes,

> Conceptions of objects in general must lie as *a priori* conditions at the foundation of all empirical cognition; and consequently, the objective validity of the categories, as *a priori* conceptions, will rest upon this, that experience (as far as regards the form of thought) is possible only by their means. For in that case they apply necessarily and *a priori* to objects of experience, because only through them can an object of experience be thought. [Kant, 1781]

The last line is the crux: only through the categories can an object of experience be thought.

The mind, in its very structure, imposes causality on our experiences as a prior condition for thinking about the experiences. In the *Prolegomena*, Kant writes, "We ourselves introduce that order and regularity in the appearance which we entitle 'Nature.' We could never find them in appearances had we not ourselves, by the nature of our own mind, originally set them there." [Kant, 1783]

Kant's argument imposes causality upon the phenomena we experience but not on the *things-in-themselves* that underlie the phenomena, the *noumena*, as he calls them, or what we might refer to as reality. We cannot experience the things-in-themselves because they lie outside our sense experience. Kant asserts the existence of things-in-themselves, which for a strict empiricist like Hume cannot be asserted. Kant does not ascribe causality to the things-in-themselves, only to the phenomena. The mind imposes causality on the phenomena as a condition of thinking about them, but the categories of the understanding apply only to phenomena, not to noumena (reality beyond experience). For Aristotle causality is in Nature; Kant moves it to the mind.

Reasoning in terms of the categories can yield certain conclusions because they cannot be contradicted by experience since they are prior to experience;

however, pure theoretical reason is limited by the categories and the categories are applicable only to the phenomena. Proofs of the existence of God are out—a conclusion regarding a first cause would have to apply the category of causality outside the phenomena and therefore would be fallacious, but proofs about God's nonexistence are also out. Hume's attack on causality is circumvented because science is not about the noumena; it is about the phenomena, and there causality is imposed by the understanding. Metaphysics is possible because its subject matter consists of the categories themselves. Mind can study mind, insofar as the categories are concerned.

Among Kant's categories, causality is a category of relation, between cause and effect. Surely the mind relates events. But if there is contiguity between a prior event *A* and a posterior event *B*, then why insist that the mind imposes the category of causality as the relation between them? If causality is more than mere temporal contiguity, then the category seems to say that the mind imposes the belief that there is some occult connection, precisely the notion that Newton brackets and Hume rejects as having no logical or empirical foundation. Hume has already seen that the functional category of understanding is expectation. Observation of event *A* leads one to expect event *B*. Hume sees correctly that expectation is a probabilistic concept. There is simply no empirical or logical reason to raise the idea of causality. If experience shows that event *A* tends to precede event *B*, or even if in our experience event *A* has always preceded event *B*, then why go beyond saying that upon observation of event *A* we expect to observe event *B*? Hume recognizes that there is no empirical or logical reason for introducing a category beyond expectation. What he fails to see, and what would await the Twentieth Century, is the manner in which expectation would be incorporated into a rigorous mathematical theory of probability and how scientific knowledge would be constituted in a probabilistic framework.

Kant's basic position is that mind imposes categories on the way in which Nature is humanly understood. He agrees with Hume that causality cannot be grounded in Nature, but argues that it is more than habit because, in conjunction with other categories of the understanding, it is imposed upon experience. One need not agree with Kant that the categories lie in the domain of metaphysics, in the sense that they "determine the whole range of the pure reason, in its limits as well as in its content, completely according to universal principles." Yet, the point remains that human experience does not arrive qua experience; rather, as human experience it arrives via the senses and the mind. The mind imposes connectivity upon events. For Hume, there is no mind to organize successive perceptions into a coherent whole because the perceptions, themselves, "constitute the mind." Kant puts mind, as an organizing and connecting entity, prior to experience.

As for causality, although it is not a scientific category, humans do tend to apply it to events in their ordinary understanding. While Kant disagrees with Newton when he imposes a subjective form of causality on scientific thinking to replace the objective form discredited by Hume, at minimum, his insistence on causality being intrinsic to human understanding possesses considerable merit.

In arguing that the application of causality lies at the level of the phenomena, Kant is making a second, fundamental point: whatever ultimately lies behind the phenomena is outside the domain of science. A strict empiricist like Hume dogmatically asserts that one cannot speak of anything lying behind the phenomena. Kant argues otherwise and, in doing so, is more in line with Newton, who believes that gravity exists, although he can say nothing about it except what is revealed by the mathematical formulae expressing phenomenal relations. Insofar as science is concerned, Galileo, Newton, and Kant bracket physical substance, but among the three, Kant does not bracket causality. He places it in a different place—in the mind, but not as Hume would have it, as habit, but as a prior condition for experience.

The differing views of Hume and Kant on causality lead to two fundamentally different perspectives on the structure of scientific propositions. For Hume, science is intrinsically probabilistic, so that scientific statements are framed in terms of probabilities; for Kant, causality leads to determinism. Given the accuracy of predictions resulting from Newtonian mechanics, whose equations are deterministic, it is easy to see that, even if one were to disagree with Kantian epistemology, he might still reject Hume's probabilistic interpretation and remain a determinist, agreeing with Laplace that observed variation is due to measurement error or ignorance of deeper laws, which when discovered would eliminate uncertainties.

4.5.2 The transformation of human reason

We started out this section with a quote from Arthur Schopenhauer to the effect that Kant ended the human period of naïve realism. Let us say that Kant, reflecting on the scientific events from Bacon and Galileo through Newton and on into the Eighteenth Century recognized the massive role of mind in the new science. He was not primarily about building an idealistic epistemology in which objects are a product of the mind; rather, his idealism resulted from his assessment of his empiricist predecessors, especially Hume.

In *The Illusion of Technique*, William Barrett writes,

> Kant…has more than a century of the new science to reflect upon, and he is the first philosopher to understand what has happened. The whole of his *Critique of Pure Reason* is not primarily an attempt to set up a system of idealistic philosophy; it is the effort, stubborn and profound, to grasp the meaning of the new science and its consequences for human understanding generally…. What has happened is nothing less than the transformation of human reason itself. [Barrett, 1979]

Barrett argues that the key to the scientific revolution is that the scientist no longer tries to conform his understanding to haphazard data; rather, his reason becomes "legislative of experience," to the extent that concepts are no longer expected to be realized in Nature but instead are to dictate how the facts are to be

measured. Kant, he claims, is the first person to recognize the significance of this change. Barrett writes,

> What does Galileo do? He does not turn to the 'irreducible and stubborn' facts; rather, he sets up a concept [inertia] that can never be realized in actual fact…. Rationalism does not surrender here to the brute facts. Rather, it sets itself over the facts in their haphazard sequence; it takes the audacious step of positing conditions contrary to fact, and it proceeds to measure the facts in the light of these contrafactual conditions. Reason becomes 'legislative of experience'—this was the decisive point that Kant's genius perceived as the real revolution of the new science. [Barrett, 1979]

Recall Kant's words: "Reason must approach nature…in the character…of a judge, who compels the witnesses to reply to those questions which he himself thinks fit to propose."

4.5.3 The moral philosopher

Kant's second goal is to rescue the moral law from Hume's skepticism, which had left morality as nothing more than subjective desire. Our interest being science, for most philosophers their moral philosophy would be irrelevant, but with Kant this would leave a very wrong impression of this thinking, especially because his moral theory depends on the limitations he has imposed upon the domain of application for theoretical reason. In the preface to the second edition of the *Critique of Pure Reason*, Kant writes, "I have found it necessary to deny knowledge [of things-in-themselves] in order to make room for faith." In addition, Kant's role in the transformation of the Age of Reason to the Romantic Period would be completely missed, a transformation that continues to have major impact today, including a significant detrimental influence on science.

To recover the moral order requires that Kant establish human freedom in the moral sphere conditioned on causality being a category of the understanding, which has as a consequence a deterministic understanding of phenomena. His solution is a duality. As phenomena, human actions are viewed in the light of cause and effect, so that the necessary condition for moral action, freedom, does not exist; however, causality and its consequent elimination of moral action only apply to the phenomenal world because that is the world experienced through the categories of the understanding. Causality does not apply to the noumenal world, and freedom resides therein.

Essentially, Kant wants to show that the moral law is *a priori*, that it is universal and does not depend upon experience. Whereas pure theoretical reason applies to phenomena, *pure practical reason* applies to action, which in all cases (at least for Kant) has a moral dimension. As Kant had flipped causality from being a part of Nature to being a condition of experiencing Nature, he now flips morality as emanating from God to emanating from the nature of man. In the *Critique of Practical Reason*, he famously writes,

> Two things fill the mind with ever new and increasing admiration and awe, the oftener and the more steadily we reflect on them: the starry heavens above and the moral law within. I have not to search for them and conjecture them as though they were veiled in darkness or were in the transcendent region beyond my horizon; I see them before me and connect them directly with the consciousness of my existence. [Kant, 1788]

The moral law is immediate, not a matter of reflection. Kant feels it as directly part of his existence.

The moral law does not derive from experience: it is *a priori*. It is not a collection of prudent rules to facilitate social cohesion. It is universal and, like the categories, inherent in our being. It is absolute and unconditional, that is, categorical. Kant has the problem of providing a *categorical imperative* to serve as the fundamental law of the practical reason. He gives two forms of his categorical imperative: (1) "Act so that the maxim of thy will can always hold good as a principle of universal legislation;" and (2) "So act as to treat humanity, whether in thine own person or in that of any other, in every case as an end, never only as a means."

The categorical imperative is supposed to provide a way of rationally judging maxims. For instance, under the categorical imperative, if I hold the maxim that it is acceptable to lie, then I must be able to will lying as a universal principle. This means that I accept being lied to. As a second example, if I hold the maxim that it is acceptable to kill those who are inconvenient, then I must be able to will such killing as a universal principle, even if I am the one who is judged inconvenient by those holding the power to do so.

While the two formulations of the categorical imperative might at first sound appealing, they are fraught with difficulties. For instance, if my child is about to be killed and I have a gun, should I shoot the assailant? Kant seems to saying that if I shoot, then I am acting so as to make shooting another human being a principle of universal legislation; however, if I do not shoot, then I am acting so as to make not defending my child a principle of universal legislation. Surely such a simplistic seemingly rational imperative cannot serve as a fundamental law of the moral order.

Given the existence of the moral law, Kant argues that, since freedom, immortality, and God cannot be theoretically established or rejected based on the theoretical reason, and since our belief in them provides vital practical support to the moral law, he will postulate their existence, believe in them, and act according to this belief.

Being more specific, having arrived at the moral law from feeling, Kant proceeds to arrive at God via the will:

> Admitting that the pure moral law inexorably binds every man as a command (not as a rule of prudence), the righteous man may say: 'I will that there be a God, that my existence in this world be also an existence

> outside the chain of physical causes, and in a pure world of the understanding, and lastly, that my duration be endless; I firmly abide by this, and will not let this faith be taken from me; for in this instance alone my interest, because I must not relax anything of it, inevitably determines my judgment.' [Kant, 1788]

In the first critique Kant moves science from the study of Nature to the study of the product of man's categories of the understanding applied to Nature; then, in the second critique, he moves religion from being grounded in scripture or reason to being grounded in feeling and will.

To get a better sense of Kant's thinking in the *Critique of Practical Reason*, consider the following comment on the argument from design:

> I see before me order and design in Nature, and need not resort to speculation to assure myself of their reality, but to explain them I have to presuppose a Deity as their cause; and then since the inference from an effect to a definite cause is always uncertain and doubtful, especially to a cause so precise and so perfectly defined as we have to conceive in God, hence the highest degree of certainty to which this presupposition can be brought is that it is the most rational opinion for us men. [Kant, 1788]

Kant cannot apply pure theoretical reason to assure himself of the reality of order and design, so they are not part of science. To explain them he would need to infer God as a cause but he cannot because causality only applies to the phenomena. Thus, the "most rational opinion" is to suppose the existence of a deity behind the order and design.

In the second critique Kant takes the very practical position that one cannot live within the domain of pure theoretical reason. Human beings possess feelings and desires, and these must be considered by a philosopher if he is to take his subject, man, as a whole. With respect to the movement from the *Critique of Pure Reason* to the *Critique of Practical Reason*, the Spanish philosopher Miguel de Unamuno says, "He [Kant] reconstructs in the latter what he destroyed in the former…. Kant reconstructed with the heart that which with the head he had overthrown." [Unamuno, 1954]

Partly because he embraces both theoretical and practical reason, and partly because he wishes to save both science and faith from Hume's criticism, Kant's thinking is rife with paradox. What else could be expected from one whose purview is so vast? Barrett calls Kant "the pivot." There is philosophy anterior to Kant and philosophy posterior to Kant. Barrett has a figure entitled, "A Map of the Modern World." It shows two arrows leading into Kant, one from empiricism and another from rationalism. It shows four arrows emanating from Kant: idealism, pragmatism, existentialism, and positivism. Each of these and their variants begins with an aspect of Kant but under the desire for consistency narrows its scope and resorts to marginal thinking. On the other hand, Kant takes the whole man as his subject matter—a much more difficult endeavor.

4.6 Jean-Jacques Rousseau: No to Science

Kant's appeal to the heart has roots in the thinking of Jean-Jacques Rousseau (1712–1778), whose picture hung on the wall of Kant's study. Rousseau comes chronologically before Kant but since Hume awoke Kant from his dogmatic slumber and the *Critique of Pure Reason* was a response to Hume regarding reason and science, we wanted to discuss them in sequence. Rousseau is a major intellectual figure of the Eighteenth Century. He almost single handedly brought an end to the Age of Reason and that is why we have dated its end with the publication of his first discourse. Rousseau shunned the salons of Paris where wealthy aristocratic intellectuals held sway. He was not from their class and the air of the salons was not conducive to his sensitivity.

Prior to Rousseau's emergence, reason had ruled the French Enlightenment. Voltaire was the great champion of reason and a bitter foe of the Catholic Church, although he remained religious and in old age attended Mass regularly. The first volume of the great *Encyclopédie*, edited by Denis Diderot and Jean le Rond d'Alembert, which was to be a paean to The Age of Reason, was published in 1751, but Rousseau's *Discourse on the Arts and Sciences* had already appeared in 1750 and his *Discourse on the Origin and Basis of Inequality Among Mankind* would appear in 1754. An age of sensibility had already begun.

Rousseau saw civilization as the bane of mankind and saw primitive man as free from civilization's discontents and a natural repository of pity, an emotion that he claimed had waned when men began to parcel out property and ceased to take sexual partners as one would pick apples from a tree. He opposed reason on behalf of feeling and openly rejected logic and the need for facts.

In the *Discourse on Inequality*, Rousseau wastes no time in rejecting science: "Let us begin therefore, by laying aside facts, for they do not affect the question…. You shall hear your history such as I think I have read it, not in books composed by those like you, for they are liars, but in the book of Nature which never lies." [Rousseau, 1754] Rousseau's anthropology of primitive man will not be affected by facts, nor will it be related to Nature via observation. Absent data, he will read the book of Nature. Rousseau's arguments cannot be invalidated with data because these are not relevant. Like Descartes, Rousseau exemplifies Bacon's spiders spinning their webs—with the exception that Descartes has the excuse that he was meditating a half century before Newton's *Principia*, whereas Rousseau was meditating more than a half century after.

Further on in the *Discourse on Inequality*, Rousseau tells us that although his explanations are conjectural, because his conclusions are certain, any set of conjectures acceptable to him would lead to the same conclusions:

> I must own that, as the events I am about to describe might have happened many different ways, my choice of these I shall assign can be grounded on nothing but mere conjecture; but besides these conjectures becoming reasons, when they are not only the most probable that can be drawn from the nature of things, but the only means we can have of

> discovering truth, the consequences I mean to deduce from mine will not be merely conjectural, since, on the principles I have just established, it is impossible to form any other system, that would not supply me with the same results, and from which I might not draw the same conclusions. [Rousseau, 1754]

Rousseau's "conclusions" regarding anthropological phenomena are true *a priori*!

Having eliminated observation in the *Discourse on Inequality*, in his immensely influential work, *The Social Contract* (1762), Rousseau goes on to reject logic when he states the fundamental problem to be solved by *The Social Contract*: "The problem is to find a form of association which will defend and protect with the whole common force the person and goods of each associate, and in which each, while uniting himself with all, may still obey himself alone, and remain as free as before." [Rousseau, 1762] Consider the logic. Statement *X* is that a person will always be as free as before, meaning in the state of Nature where he is free to do anything he desires. Statement not-*X* is that he will not always have such freedom, in particular, when the state says that he cannot do something he desires. Rousseau proposes to provide an instance where the statement "*X* and not-*X*" is true, thereby denying the law of contradiction.

To get around it, Rousseau creates a fiction called the *general will*, which is more than the sum of the individual wills of the body politic. He spuriously solves the problem by defining freedom to be conformity with the general will. He appears to believe that redefining a term as its negation can escape a contradiction. It reminds one of George Orwell's "Freedom is Slavery." Lest his thinking not be clear, Rousseau explains, "Whoever refuses to obey the general will shall be compelled to do so by the whole body. This means nothing less than that he will be forced to be free." [Rousseau, 1762]

The general will is a prominent example of an idol of the marketplace, the kind that Bacon describes as "names of things which do not exist (for as there are things left unnamed through lack of observation, so likewise are there names which result from fantastic suppositions and to which nothing in reality corresponds)." These include "Fortune, the Prime Mover, Planetary Orbits, Element of Fire, and like fictions which owe their origin to false and idle theories." Had Bacon lived long enough he could have added the general will to his list.

While scientists tend to have negligible interest in Rousseau, his opposition to science, his elevation of sentiment over reason, and his political philosophy are ubiquitous. Whereas Descartes' legacy is a tendency to subordinate the empirical to the rational, Rousseau's thinking is manifested in a rejection of both the empirical and the rational in favor of desire and will. Those who believe that modernity and science are concomitant, and that science is unassailable, need to reflect on Rousseau's continuing influence.

At this point, when discussing perhaps the greatest modern foe of science, it might be enlightening to reflect on the following words of Ortega y Gasset:

> Experimental science is one of the most unlikely products of history. Seers, priests, warriors and shepherds have abounded in all times and places. But this fauna of experimental man apparently requires for its production a combination of circumstances more exceptional than those that engender the unicorn. Such a bare, sober fact should make us reflect on the supervolatile, evaporative character of scientific inspiration." [Ortega y Gasset, 1994]

This thought should arouse our vigilance as the Twenty-first Century human longing for knowledge of complex systems and the benefits that would accrue from such knowledge pushes against the limitations of scientific epistemology.

4.6.1 Kant and Rousseau

How deep was the impact of Rousseau on Kant? Clearly there was negligible impact on the *Critique of Pure Reason*, but what about Kant's moral theory in the *Critique of Practical Reason*? Political philosopher Stephen Smith thinks that Rousseau's influence on Kant was considerable. He states, "Kant's entire moral philosophy is a kind of deepened and radicalized Rousseauianism where what Rousseau called the general will is transmuted into what Kant calls the rational will and the categorical imperative." [Smith, 2008]

One can certainly debate the relationship between the categorical imperative and the general will; nevertheless, Kant makes it clear that for him the moral law arises from feeling and belief in the existence of God is a product of will. Recall his words on willing God. Then consider the closing words of Rousseau in a letter to Voltaire (1756):

> I have suffered too much in this life not to look forward to another. All these metaphysical subtleties may embitter my pains, but none can cause me to doubt a time of immortality for the soul and a beneficent providence. I sense it, I believe it, I wish it, I hope for it, I will uphold it until my last gasp—and of all the cases I will have supported, it will be the only where my own interest will not be forgotten. [Rousseau, 1756]

The similarity is striking.

Now consider Kant's own thoughts on Rousseau: "There was a time when I thought that this [knowledge] alone could constitute the honor of mankind, and I despised the people, who know nothing. Rousseau brought me to rights. This blind prejudice vanished. I learned to honor human beings." [Kant, 1997] Whereas Hume awoke Kant from his dogmatic slumber on metaphysics, it seems that Rousseau awoke him from his indifference to human dignity.

If Rousseau awakened the heart of Kant, then this is to the good, but with respect to reason the salient point is that Rousseau appears to have widened Kant's thinking beyond logic and the categories of the understanding. Kant, having to his satisfaction demonstrated that pure theoretical reason is limited to phenomena and that it frames human experience relative to those phenomena, had severely limited its domain of application. Proofs of God's existence and His

nonexistence were out, as well as any possible theoretical grounding for the moral law. So Kant, emulating Rousseau, based the moral law and God on his inner feelings.

Yet there is a huge difference between Kant and Rousseau. Rousseau makes no critique of reason; rather, he simply makes a shambles of it. Kant absorbs what has come before and proceeds to analyze the transformation in reason and perception that was underway thanks to the scientific revolution of Bacon, Galileo, and Newton. Mathematical and scientific developments would make many of his particulars wrong, especially developments in the Twentieth Century, but in recognizing the role of the understanding in framing experience, he found a nugget. Rousseau on the other hand seems ignorant of the scientific revolution that had preceded him and would change man's perspectives on Nature and himself. Perhaps Hume, who personally knew Rousseau, stated it best when he said of Rousseau, "He has not, indeed, much knowledge. He has only felt, during the whole course of his life."

4.7 Mill: Metaphysics through the Back Door

John Stuart Mill (1806–1873) wished to empirically ground science in induction, which, following Bacon, means that he had to resuscitate causality. In *A System of Logic, Ratiocinative and Inductive* (1843) he wrote, "At the root of the whole theory of induction is the notion of physical cause. To certain phenomena, certain phenomena always do, and, as we believe, always will, succeed. The invariable antecedent is termed the 'cause,' the invariable consequent, the 'effect.'" [Mill, 1843] Mill proceeded to the following definition: "The Law of Causation, the recognition of which is the main pillar of inductive science, is but the familiar truth that invariability of succession is found by observation to obtain between every fact in nature and some other fact which has preceded it." [Mill, 1843]

There are four salient points to Mill's view: (1) no necessary connection is implied by causality; (2) the effect must be the "invariably and unconditionally consequent" of the cause; (3) causality makes no reference to what is behind the phenomena; and (4) causality is "coextensive with human experience." In one sense, Mill escapes Hume's criticism by abandoning any notion of necessary connection and making induction purely sequential, but he misses Hume's critical scientific point regarding the impossibility of arriving at the unconditional invariability of succession by any finite number of observations.

Mill recognizes that causality cannot be as simple as a single event being the sole cause of an effect. Regarding the complexity of causation, he states, "But the real cause is the whole of the antecedents, the whole of the contingencies of every description, which being realized, the consequent invariably follows. Yet even invariable sequence is not synonymous with causation. The sequence, besides being invariable, must be unconditional." [Mill, 1843] Clearly, "the whole of the antecedents, the whole of the contingencies of every description" has no bounds and may very well be the entire universe, which would reduce the entire notion of cause and effect to a statement about universal determinism. This would be a restatement of Laplacian determinism absent any individual causal

relations within the universe. It is therefore not surprising that Mill adopts a Laplace-like position, except that unlike Laplace, who appeals to a "sufficiently vast" intelligence, Mill remains within the realm of human experience. He writes,

> The state of the whole universe at any instant, we believe to be the consequence of its state at the previous instant; insomuch that one who knew all the agents which exist as the present moment, their locations in space, and all of their properties, in other words, the laws of their agency, could predict the whole subsequent history of the universe, at least unless some new volition of a power capable of controlling the universe should supervene. [Mill, 1843]

If causality depends on knowing all the antecedents composing a cause, then surely it is not coextensive with human experience. On the other hand, expectation is very much coextensive with human experience.

Mill follows Bacon in recognizing that haphazard observation is insufficient for the discovery of causal relations. He writes,

> We must either find an instance in nature suited to our purposes, or by an artificial arrangement of circumstances make one. When we make an artificial arrangement, we are said to experiment; and experimentation has great advantages over observation in that it often enables us to obtain innumerable combinations of circumstances which are not to be found in nature. [Mill, 1843]

But instead of the Newtonian recognition that experimental constraint leads to relations that "estimate" relations among naturally occurring phenomena, Mill wants to use experiment to obtain "innumerable combinations of circumstances," a goal that on its face is impossible.

In trying to circumvent Hume's attack on causality on strictly empiricist grounds, Mill returns to a pre-Galilean world in the sense that, although necessary connection is abandoned, causality remains a requirement for knowledge. Hume's analysis regarding uncertainty and the impossibility of concluding a necessary connection, one that is unconditional and invariable, is impenetrable because the certainty of formal logic does not apply to human interaction with Nature. Expectation, not causality, is coextensive with human experience. Mill's problem is that he wants to bring metaphysics in through the back door. Aristotle was correct in placing the four forms of causality in the *Metaphysics*, but not correct in placing them in the *Physics*. Mill's hope of grounding causality in invariable and unconditional empirical sequences had already been doomed by Hume. Kant had recognized this but Mill did not.

4.8 Bertrand Russell: Causality, a Relic of a Bygone Age

In his 1913 essay, *On the Notion of Cause*, Bertrand Russell (1872−1970) stresses the impossibility of giving precise meaning to several different attempts to define "cause." For the sake of argument, he settles on the previously cited definition of Mill as perhaps the best attempt at a viable definition of causality. He shows that this attempt fails owing to the impossibility of supplying it with a suitable notion of event and the "insuperable difficulties," which Russell carefully articulates, of trying to define the timing between a cause and an effect.

Russell recognizes that Mill's reasoning regarding induction and causality are based on the appearance of uniformities in Nature and addresses the issue:

> It must, of course, be admitted that many fairly dependable regularities of sequence occur in daily life. It is these regularities that have suggested the supposed law of causality; where they are found to fail, it is thought that a better formulation could have been found which would have never failed. I am far from denying that there may be such sequences which in fact never do fail. It may be that there will never be an exception to the rule that when a stone of more than a certain mass, moving with more than a certain velocity, comes in contact with a pane of glass of less than a certain thickness, the glass breaks…. What I deny is that science assumes the existence of invariable uniformities of sequence of this kind, or that it aims at discovering them. All such uniformities, as we saw, depend upon a certain vagueness in the definition of the 'events.' That bodies fall is a vague qualitative statement; science wishes to know how fast they fall. This depends upon the shape of the bodies and the density of the air. It is true that there is more nearly uniformity when they fall in a vacuum; so far as Galileo could observe, the uniformity is then complete. But later it appeared that even there the latitude made a difference, and the altitude. Theoretically, the position of the sun and moon must make a difference. In short, every advance in a science takes us farther away from the crude uniformities which are first observed, into greater differentiation of antecedent and consequent, and into a continually wider circle of antecedents recognized as relevant. The principle 'same cause, same effect,' which philosophers imagine to be vital to science, is therefore utterly otiose. As soon as the antecedents have been given sufficiently fully to enable the consequent to be calculated with some exactitude, the antecedents have become so complicated that it is very unlikely they will ever recur. Hence, if this were the principle involved, science would remain utterly sterile. [Russell, 1913]

Russell makes it clear that the Laplace-Mill effort to frame causality in terms of "the state of the whole universe at any instant" is vacuous.

Russell neatly sums up his view of causality: "The law of causality, I believe, like much that passes muster among philosophers, is a relic of a bygone age, surviving, like the monarchy, only because it is erroneously supposed to do no harm." [Russell, 1913]

To the extent that science must be grounded on certainty, or on unconditional and invariable sequences, Hume's analysis is devastating. In the *Rise of Scientific Philosophy*, Hans Reichenbach (1891–1953) writes, "Empiricism broke down under Hume's criticism of induction, because it had not freed itself from a fundamental rationalist postulate, the postulate that all knowledge must be demonstrable as true. For this conception the inductive method is unjustifiable, since there is no proof that it will lead to true conclusions." [Reichenbach, 1971] Science does not depend on unconditional sequences, does not base its formulations on a notion of "logical" induction, and does not have a notion of certainty. This does not mean that science is ungrounded, only that its theoretical home is in probability theory and statistical inference, not in deterministic logic and induction.

4.9 James Clerk Maxwell: Hoping for an Intelligible Theory

The electromagnetic field theory, which is responsible for much of today's technology, is based on equations proposed by James Clerk Maxwell (1831–1879). Its applications depend on the behavior of detectors as predicted by the theory. As to the nature of the physical processes behind the equations, Maxwell does not know. In his theorizing he finds himself on the horns of a dilemma. He is unhappy with a purely mathematical theory because he desires a physical understanding of the phenomena and yet he fears physical hypotheses because these can filter the facts according to preconceptions.

In his 1861 paper *On Faraday's Lines of Force*, Maxwell writes,

> The first process therefore in the effectual study of the science, must be one of simplification and reduction of the results of previous investigation to a form in which the mind can grasp them. The results of this simplification may take the form of a purely mathematical formula or of a physical hypothesis. In the first case we entirely lose sight of the phenomena to be explained and though we may trace out the consequences of given laws, we can never obtain more extended views of the connexions of the subject. If, on the other hand, we adopt a physical hypothesis, we see the phenomena only through a medium, and are liable to that blindness to facts and rashness in assumption which a partial explanation encourages. We must therefore discover some method of investigation which allows the mind at every step to lay hold of a clear physical conception, without being committed to any theory founded on the physical science from which that conception is borrowed, so that it is neither drawn aside from the subject in pursuit of analytical subtleties, nor carried beyond the truth by a favorite hypothesis. [Maxwell, 1855]

In fearing that a mathematical approach "may lose sight of the phenomena to be explained," Maxwell still has one foot in the Aristotelian epistemology; in his concern that adopting a "physical hypothesis" that may lead to "blindness to facts and rashness," he reminds us of Newton's *Hypotheses non fingo*. Hypothetical assumptions based on human understanding cannot be trusted. They can lead to distorted interpretations of the observations to fit a "favorite hypothesis." Maxwell instead desires a "physical conception" to guide his thinking while at the same time not being committed to the science behind the conception—an analogy to guide his thinking but not bias it towards a preconceived notion. The question one might ask is why analogical thinking would be free from distortion, except perhaps that one knows it to be analogical and is therefore less likely to overly rely upon it.

Following an explanation of how analogies with physically based models are often useful for arriving at satisfactory theories, even when a model may relate to a different physical setting than the one being considered, Maxwell comments that he will analogize lines of force as "fine tubes of variable section carrying an incompressible fluid." After discussing the aim and methodology of the fluid analogy, he writes,

> I propose, then, first to describe a method by which the motion of such a fluid can be clearly conceived; secondly to trace the consequences of assuming certain conditions of motion, and to point out the application of the method to some of the less complicated phenomena of electricity, magnetism, and galvanism; and lastly to shew how by an extension of these methods, and the introduction of another idea due to Faraday, the laws of the attractions and inductive actions of magnets and currents may be clearly conceived, without making any assumptions as to the physical nature of electricity, or adding anything to that which has been already proved by experiment. By referring everything to the purely geometrical idea of the motion of an imaginary fluid, I hope to attain generality and precision, and to avoid the dangers arising from a premature theory professing to explain the cause of the phenomena. If the results of mere speculation which I have collected are found to be of any use to experimental philosophers, in arranging and interpreting their results, they will have served their purpose, and a mature theory, in which physical facts will be physically explained, will be formed by those who by interrogating Nature herself can obtain the only true solution of the questions which the mathematical theory suggests. [Maxwell, 1855]

Maxwell proceeds "without making any assumptions as to the physical nature of electricity." In this way he avoids being constrained by "a premature theory professing to explain the cause of the phenomena," that is, by a misleading application of the categories of the understanding. Nevertheless, he remains hesitant, adding that the mathematical theory is only suggestive of the

"true solution." He hopes for an intelligible "mature theory, in which physical facts will be physically explained."

Maxwell is not alone in this dissatisfaction. Historian Morris Kline writes,

> Despite the Herculean efforts to determine physically what an electric field and a magnetic field are, scientists are unsuccessful…. We do not have any physical account of the knowledge of the electromagnetic waves as waves. Only when we introduce conductors such as radio antennae in electromagnetic fields do we obtain any evidence that those fields exist. Yet we send radio waves bearing complex messages thousands of miles. Just what substance travels through space we do not know. [Kline, 1985]

As Newton brackets causality and the physical nature of gravity in favor of mathematical relations, Maxwell brackets the physical waves behind the field theory. The upshot of all this bracketing is that the subject of physics (as science) is embedded within mathematics. Science does not try to force Nature into the straight jacket of human intelligibility. Thus, it is free to develop mathematical systems that allow us to build devices that respond according to the equations and thereby produce pragmatic effects in the physical world. The full meaning of putting aside the categories of the understanding in favor of mathematics will become clear in the Twentieth Century.