THE INTELLIGIBILITY OF NATURE

How Science Makes Sense of the World

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Science as Natural Philosophy, Science as Instrumentality

I. Two Faces of Science

What do you do when you want to know about some aspect of the natural world? Most people, certainly most people in the industrialized world, would find out what the scientists have to say. If you want to know about the stars, you ask an astronomer or an astrophysicist; if you want to know about biological inheritance, you ask a geneticist; if you want to know about the history of the earth, you ask a geologist or a geophysicist.

"Science," taken as a general category, is a very prestigious label that we apply to those bodies of knowledge reckoned to be most solidly grounded in evidence, critical experimentation and observation, and rigorous reasoning. Science is practiced, as a matter of circular definition, by scientists. Despite the diversity of specialized scientific disciplines, you may be sure that, even if the first professional scientist of whom you ask your question is of the wrong specialty, that person will guide you to another scientist (or something written by one) who actually is an expert in the relevant field—scientists are recognizable as a group by their tendency, in such circumstances, to stick together. And from these people you will receive an account of how things work, or how things are, in the natural world around us—an account of what kind of universe it is that we are a part of.

In giving their accounts, the scientists will be telling you about what used to be, but is no longer, called "natural philosophy." That term largely fell into disuse during the nineteenth century, but in the first half of that century and earlier it was the standard way of referring to an intellectual endeavor aimed at understanding nature. By the end of the nineteenth century, natural philosophy had become absorbed into "science" in the sense in which we know it today. But the term "natural philosophy" is perhaps one worth reviving, precisely because it emphasizes that aspect of science which is concerned with explaining and understanding the world—what is often called the "scientific worldview." When journalists and popularizers treat such figures as Albert Einstein, or Stephen Hawking, or Stephen Jay Gould as people with profound insight into the true nature of the universe, or when they tell us what scientists have to say about the fundamental structure of matter, or about distant galaxies, or life on Mars, this is the face of science that they present: science as natural philosophy, which strives to give an account of nature—to make sense of it. But, of course, this is not the only face of science.

Science is also about power over matter, and, indirectly, power over people. Scientists are not only fonts of wisdom about the world, our "priests of nature," typically inhabiting universities; they are also people who work for business corporations and for military concerns (interests frequently shared, indeed, by the universities themselves, with their business and government contracts). Scientists and their science, in other words, do practical things that others want. The popular image of a scientist is of someone in a white coat who invents something—a vaccine, a satellite, or a bomb. Indeed, the main reason for the great prestige of science seems to be that the word is frequently associated with technological achievement. Alongside science as natural philosophy, therefore, we have science as an operational, or instrumental, set of techniques used to do things: in short, science as a form of engineering, whether that engineering be mechanical, genetic, computational, or any other sort of practical intervention in the world.

Indeed, when scientists are invited to testify before congressional committees in the United States, or otherwise to provide advice to those in political power, their status as authorities, as experts, resides above all in their presumed ability to pronounce on matters of pressing practical importance. Whether these matters concern the assessment of environmental risks associated with industrial pollution or the health risks associated with dietary or drug regulations, people with doctorates in relevant scientific fields are regarded as the ones most fit to provide guidance, because scientists, on this standard view, *know how nature works.*

However, a number of recent scholars argue that an easy and direct association between scientific truth-claims and technical achievements is much less obvious than is usually supposed. Cases of the direct "application" of so-called "basic" or "pure" science, when examined closely, show that the practical and theoretical effort that scientists have to exert in order to get things to work properly is much greater than the usual distinction between "pure" and "applied" science would suggest. In fact, as the history of science shows time and again, it is sometimes unclear that the world even contains the natural objects referred to by the theory supposedly being "applied."

II. Instrumentality and the History of Science

If we thought that successful application demonstrates the truth of relevant theories, we would have to believe that all of space is filled with a material, mechanically structured substance called "aether," which occupies even those regions that we normally think of as being completely empty. This aether would be composed of particles that move in particular ways so as to produce the forces found in the phenomena of electricity and magnetism. It was, after all, on the basis of such a picture that James Clerk Maxwell, in the 1850s and '60s, first developed the theory that predicted the existence and the means of producing radio waves. But despite the fact that radio waves were originally predicted on the basis of Maxwell's theory (by the German physicist Heinrich Hertz in the 1880s), few people would nowadays want to say that the technical ability to produce and detect them means that there is truly a mechanical aether filling the universe.

When we look back over the history of science, we do not see the clear, progressive development of a single picture of what the world is like, of what kinds of things it contains and the ways by which they interact. Instead, we see a picture that changes constantly in many of its most prominent features. To take a particularly striking example: before the acceptance of Einstein's special theory of relativity in the early twentieth century, many physicists believed, like Maxwell, in a material aether as the medium that carried the forces of light, electromagnetism, and even gravity. After the acceptance of Einstein's theory, however, the aether had simply vanished; it was no longer needed. Far from being gradual and cumulative, the shift amounted to a radical alteration in views of what the world is like.

There are many other examples of this sort, such as ideas about the true nature of heat. In seventeenth-century Europe, during the so-called Scientific Revolution, heat came to be regarded as an effect of particles of matter in rapid agitation. In the eighteenth century, that idea was generally replaced with the view that heat is a kind of fluid, called caloric, that pervades bodies like water in a sponge. That theory fitted in well with new eighteenth-century ideas concerning specific and latent heats, and with chemical theories of matter. It proved so useful that it was not abandoned until the middle of the nineteenth century, after which the idea of heat as a rapid motion of particles returned to favor—the kinetic theory of heat. The history of science is full of flips back-and-forth on fundamental questions about the underlying nature of physical phenomena.

This fact does not imply that nothing really changes in scientific (natural-philosophical) understanding. Obviously it does; the kinetic theory of heat that was developed in the nineteenth century was useful in accounting for a lot that the much vaguer seventeenth-century concepts about heat as motion could not. But ideas about what kind of thing in the world corresponded to the multifarious phenomena of heat (as with electromagnetism after Maxwell) clearly did not proceed in any clear, cumulative line of development. If there was "progress," that progress certainly did not take the form of an ever-closer approximation to a true picture of what heat really is.

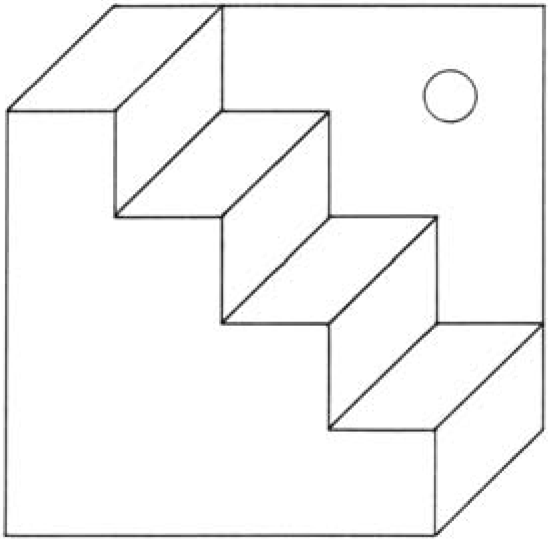
Why, then, should any particular view of the nature of heat (or, for that matter, radio waves) be preferred over any other? A standard answer to such questions is that scientific theories are believed to be true because they work; philosophers sometimes speak of the practical success of science as something to be explained by the truth of its theories: in effect, practical efficacy is used as evidence for the truth of the natural philosophy which, it's assumed, underlies and explains it. But the "efficacy" of Maxwell's original theory of the electromagnetic aether is no longer taken as evidence for the real existence of the aether; instead, different theories of electromagnetism, which posit different constituents of the universe, are now attributed the efficacy that Maxwell's theory was once supposed to possess. At the same time, many theories are still employed for the purposes of practical engineering that are no longer believed to be literally true in their natural-philosophical content—a simple example being the use of earth-centered astronomy for purposes of navigation. Either way, the practical efficacy of scientific theories, what can be called their "instrumentality," is a component of science distinguishable from its natural philosophy.

Just as this instrumentality is routinely assumed to provide support for natural-philosophical assertions, so arguments of a natural-philosophical kind are often used to explain the instrumental success of particular techniques. The wave properties of electrons, a part of the natural philosophy presented by quantum mechanics, are used to explain how and why electron microscopes work; DNA profiling is an effective technique because people believe that the natural philosophy of modern genetics and molecular biology explains and justifies it. If the natural philosophy were not believed, the technique would not be seen as effective.

That certain techniques really are effective is clearly the case, and is one of the defining features of modern industrial and postindustrial societies. But to imagine that the efficacy attributable to modern science flows directly from the truth of its representations of the world, that is, from its natural-philosophical content, is unrealistic. It would do a grave injustice to the work and intellectual content of technical and engineering practices. Such accomplishments, frequently and routinely attributed to something called "science," in fact result from complex endeavors involving a huge array of mutually dependent theoretical and empirical techniques and competences. There is usually only a tenuous path back to a natural-philosophy component located amidst the tangle. The "D" in "R&D" (research and development) is not, as any practitioner will tell you, a trivial exercise in "application" of theory; there will always be jobs for test pilots.

Nonetheless, the widespread and longstanding assumption that science's instrumentality is nothing more than a matter of "applying" the knowledge provided by its natural philosophy has had an enormous cultural impact. The authority of science in the modern world rests to a considerable extent upon the idea that science is powerful; that science can do things. Television sets, or nuclear explosions, can act as icons of science because it is taken for granted that they somehow legitimately represent what science really is—the instrumentality of science, that is, often stands for the whole of science. At the same time, when science is appealed to as the authority for an account of how something really is in nature—that is, when science is seen in the guise of natural philosophy—its accepted instrumental efficacy seems to justify that image of truthfulness.

Science in its broad "umbrella" sense is an amalgam of natural philosophy and instrumentality, even though each is not always clearly present with the other in every field: astrophysicists or cosmologists do not yet offer the prospect of manipulating black holes, for example. But the overall totalizing effect of the amalgam is hugely powerful. Why are science's instrumental techniques effective? The usual answer is: by virtue of science's (true) natural philosophy. How is science's natural philosophy shown to be true, or at least likely? The answer: by virtue of science's (effective) instrumental capabilities. Such is the belief, amounting to an ideology, by which science is understood in modern culture. It is circular, but invisibly so.



0.1. An optical puzzle: is the wall marked with a circle behind a staircase, or in front of a terraced ceiling?

The way in which these two faces of science are related is not, then, a straightforward matter of two different definitions sitting side by side, always sharply distinguished from each other. In fact, each of those two categories is what is known as an "ideal type": a coherent system of representing some kind of thing in the world. One might, for example, want to describe a society as fundamentally communist, or free-market capitalist, or fascist, even though any real example will always have idiosyncrasies that make it depart to a greater or lesser extent from the ideal type that best describes it. The complication in the case of science is that it best corresponds not to one, but to *two* ideal types simultaneously. A useful analogy is the well-known kind of visual illusion that can be seen in either of two ways: does the staircase in the picture (fig. 0.1) go upwards from right to left, so that the wall with a circle on it is at the back, or does this show a terraced ceiling, the circle being on the nearest wall? Most people can switch between seeing the picture in one of those ways and in the other—but not both at once. And yet the picture itself is always unchanged; it is not the case that it switches back and forth. Similarly, "science" can be represented in modern culture in its guise as natural philosophy or in its guise as instrumentality, but not both at the same time. When a scientific statement is regarded as a piece of natural philosophy, it has the status of a description of the natural world. Something might perhaps be done with it, but as it stands, it is simply about how the world is. Conversely, when a scientific statement is regarded as an expression of instrumentality, it is an account of how to do something, an account that may also be said to have implications about how the world is. Scientific statements are inherently ambiguous as to which sort they claim to be, natural-philosophical or instrumental. But although the ambiguity is seen in terms of just one way or the other, *both* perceptions must always be at least conceivable—even if astrophysicists might have difficulties in actually manipulating a galaxy.

This ambiguity suggests that the widespread modern view of science is in important ways fallacious; that it attributes to science a character that it does not in fact possess. If that is so, how could things have come to be that way? What sustains the illusion? An answer will require an excursus into the history of science, and in particular into the history of one half of the twin components of modern science, natural philosophy.

III. Natural Philosophy and Intelligibility

Natural philosophy is a much older enterprise than modern science. Within broadly European intellectual traditions, from antiquity to the seventeenth century, the term itself denoted an enterprise that was later associated with that of "science," as that category took full shape in the nineteenth century. But in medieval and early-modern Europe, natural philosophy was understood in literate culture as an enterprise that was entirely separate from practical knowledge, or know-how. The distinction was rooted in the works of the Greek philosopher Aristotle (fourth century BC), which formed the backbone of university education throughout the entire period: Aristotle's Greek terms were *epistēmē* and *technē,* translated into Latin in the Middle Ages as *scientia* (science) and *ars* (art). The first item in the pair designated logically and empirically demonstrable knowledge of truth, while the latter referred to the skilled practice of manipulating material things (*technē* is a root of the word "technology," just as *ars* is of the word "artificial"). The reason for Aristotle's making such a sharp distinction between the two is generally reckoned to reflect ancient Greek social arrangements: only free men, such as the citizens of the city-state, had the leisure to devote their time to philosophizing, while practical abilities were the province of servants and slaves. Not surprisingly, therefore, a free man like Aristotle regarded *epistēmē* as being a much worthier and more noble object than the skills of the manual laborer, and of a quite different character. The clerical, contemplative world of the medieval and early-modern university evidently agreed; it adopted Aristotle's categorization wholeheartedly. And the particular *scientia* concerned with understanding and explaining the natural world was "natural philosophy," often called "physics" (from the Greek *physis,* a word that stands for "nature").

A good example of what this sense of natural philosophy meant is the distinction that was made throughout this period between the natural philosophy of the heavens, on the one hand, and astronomy, on the other. Natural philosophy as it concerned the heavens was all about such questions as what the heavens are made of, what moves the sun, moon, and planets, whether the universe is finite or infinite; questions to do with understanding the *nature* of the heavens. Astronomy was something entirely different: for one thing, it was not part of natural philosophy. It counted instead as a part of mathematics, an applied branch that had to do with the positions and motions of celestial bodies—tracking lights in the sky and applying geometry to their behaviors. All that astronomy aspired to do was to provide formalized descriptions and predictions of heavenly motions, for practical uses—casting horoscopes, constructing calendars, or navigating by the stars, for example. Astronomy declined to ask what the moving bodies actually were, or why they moved, because trying to understand the heavens was not its concern; it just charted them. Understanding was the job of natural philosophy, which in turn had no interest in crunching numbers for utilitarian ends.

This widespread view of natural philosophy began to change during the seventeenth and eighteenth centuries. During that time there emerged a new view of natural philosophy whereby it would have, as one of its primary goals, practical uses. This new conception was especially associated in the seventeenth century with the ideas of Francis Bacon (1561–1626) and in the early eighteenth century with the work and propaganda of Isaac Newton's English followers and publicizers. Bacon had actively opposed the established Aristotelian conception of natural philosophy, and asserted that a true natural philosophy should be concerned with active intervention in nature for the benefit of mankind. Bacon presented this project as one of Christian charity, to alleviate suffering. Because he was a lawyer and statesman, Bacon viewed these matters as a proper concern of the state itself, the most obvious, and powerful, agent for the amelioration of the human condition. Despite his political failure to get his ideas enacted as English government policy, Bacon's writings on the subject struck a chord that resonated throughout Europe, and they represent a widespread ambition in this period among the educated. By the eighteenth century, following the work of Newton (1642–1727), such views had become almost commonplace. Newton's followers in England, as well as others elsewhere in Europe, promoted a view of nature that underpinned and legitimated a much greater concern with practical matters on the part of the upper echelons of society. These were especially people who sought to make money from improvements in agriculture, mining, and, increasingly, manufactures. A natural-philosophical universe like Newton's, which consisted of lifeless matter bouncing around according to mechanical laws, was clearly exploitable for human ends: it lent itself to instrumentality. Tinkering with the world-engine could now be justified as natural philosophy, not artisanal labor, although some still complained that the distinction between the two was being ignored, and that Newton's work was in fact *not* real natural philosophy at all.

Doing things and understanding things thus became increasingly folded into one another. Eventually, the label "natural philosophy" itself faded away, absorbed by "science": Michael Faraday (1791–1867), in the mid-nineteenth century, was resisting a trend when he insisted on being known, still, as a "natural philosopher," and yet he involved himself in a good many practical scientific enterprises, from chemistry to telegraphy.

When we restrict the label "natural philosophy" to its original sense, that of intellectual understanding of the natural world, we can see clearly that the cultural activity called "science" as it developed during the nineteenth and twentieth centuries has not been the same as the old natural philosophy. The changes that the latter label had undergone during the seventeenth and eighteenth centuries resulted in the establishment of a new enterprise that took the old "natural philosophy" and articulated it in the quite alien terms of instrumentality—science was born a hybrid of two formerly distinct endeavors.

The natural-philosophical component of science is the one that has, perhaps, the most profound role in shaping our views of ourselves. The universe in which we live, the bodies that we experience as part of ourselves, and the sense we have of our immediate environments are all shaped by our acceptance of the images of reality that we owe to science in its guise as natural philosophy. But what is it that gives scientific knowledge-claims their powerful authority over our imaginations? One answer is, of course, their association with instrumentalities of various sorts, which is why it is now fashionable in some academic quarters to refer to contemporary science and technology as "technoscience," representing the two as a single enterprise. That association appears endlessly in popular science fiction. At a more fundamental level, however, there is the powerful social authority of science, which serves to render most people unable to refuse a knowledge-claim presented as a "scientific fact," even though they are incapable of judging its truth for themselves. The academic credentials of scientists and the institutions at which they work are important parts of the general credibility of science.

There is more to the natural philosophy inside science than just facts about what is in the world, and how it behaves, and where it came from. Besides facts, there are explanations and stories that pull the facts together into accounts that make sense. Making sense, in turn, means more than just conforming to the rules of logical inference. Examples that are considered in later chapters of this book include such epoch-making work as that of Isaac Newton on gravity. When Newton first published his great work, the *Principia,* in 1687, with its assertions and demonstrations concerning the mutual gravitational attraction of matter and the inverse-square law governing the relation between the force of that attraction and the distance between the gravitating bodies, many critics objected that, for all the impressive mathematics in the book, what Newton had done was not natural philosophy. For those critics, a true natural-philosophical, or physical, explanation of gravity would require an account of what gravity "really was," rather than just a description of how it behaves. They also knew what kind of account would do. For them, a physical explanation of gravitational attraction would be a strictly mechanical one, by which they meant the effect of direct contact-action of matter pushing on matter. And Newton had been quite explicit about not providing one—because, try as he might, he was unable to come up with a mechanical explanation that would fit his mathematical description of gravity, a description that accorded so well with empirical measurements.

The reason for this general demand for a "mechanical" explanation of gravitational attraction is that a good number of prominent natural philosophers had, during the course of the seventeenth century, become convinced that only explanations for natural phenomena that were couched in the terms of lumps of dead, inert matter pushing against other lumps of inert matter, and thereby pushing them, were truly *intelligible.* Newton appeared to many people to be suggesting that gravity operated by strict action at a distance: a material body simply exerted a force on another body that was separated from it by empty space, with nothing passing between them. But Newton's critics thought that this just made no sense. And since Newton had not explained gravitational attraction in a way that made sense, he had failed as a natural philosopher—although not as a mathematician.

During the course of the eighteenth century, however, many people became accustomed to the idea of action at a distance. As they became used to working with it, and applying Newton's principles to the solution of specific, mathematically structured problems, philosophers ceased to worry about the foundational objections that had earlier been leveled against it. The result was that action at a distance eventually came to be seen, almost by default, as an explanatory approach that was satisfying to the understanding. In the nineteenth century, the situation again shifted. James Clerk Maxwell (1831–79) and other British physicists in the second half of the century argued that a satisfactory explanation of gravity (as well as of other phenomena) could be couched only in terms of contact-action using, as we saw earlier, a mechanical aether. Ironically, both Maxwell and Michael Faraday cited Newton as a supporter of their view that anything else would be implausible at best (see chapter 6).

Another striking example of intelligibility, again from the nineteenth century, concerns one of the most profound shifts of recent centuries in sensibilities about how nature should be understood. Charles Darwin (1809–82) found the idea of natural selection a satisfactory way of explaining how the organic world comes to display so much apparent designfulness and purpose—how animals and plants seem to be so well fitted to the kinds of lives they lead. Rather than infer, as most of his predecessors had done, that the functional *designfulness* of living things implied a benevolent Creator God who had deliberately made them that way, Darwin suggested that, had they not been as they are, they would not have been able to survive: the living beings that we see around us are the ones that happened to have what it took to survive—they had, as it were, won life's lottery. But for some of his contemporaries, this "natural selection" was inadequate to its explanatory task; for them, it just wasn't the right *sort* of explanation. The doyen of mid-Victorian philosophy of science, John Herschel (1792–1871), famously described natural selection as "the law of higgledy-pigglety." He said this not to pour scorn on it—he was certainly able to follow the argument—but because random, statistical processes seemed by definition unable to account meaningfully for order in the universe; apparent design surely required real intelligence (see chapter 4). His response parallels Albert Einstein's (1879–1955) celebrated condemnation of the probabilistic, rather than strictly causal, explanations of quantum mechanics: "God doesn't play dice with the universe." Evidently, then, there are no timeless, ahistorical criteria for determining what will count as satisfactory to the understanding. Assertions of intelligibility can be understood only in the particular cultural settings that produce them.

"Intelligibility" is ultimately an irreducible category—by definition, you cannot analyze fundamental, bedrock principles down to anything more basic than themselves. An account makes sense just because it does, not because of some prior condition or criterion: the intelligible is the self-evident; the unintelligible is simply the unspeakable. In the historical development of science, the awkward and unresolved tension between instrumentality and natural philosophy has yielded views of the universe that are dependent on particular human conceptions of what makes sense. Presumed intelligibility is an essential ingredient of natural philosophy, and in that sense natural philosophy is, and always has been, about feeling at home in the world. Perhaps the difficulties that some people find in feeling at home in the modern world are at least in part due to the way that science's instrumentality has increasingly displaced part of that natural-philosophical intelligibility.