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The Causalist Quest in Physical Science

ONE OF THE PREPARATORY TASKS is to beckon contemporary philosophy and scientific thinking back toward a healthy concern and involvement with natural science in a certain domain, after a period of deepening alienation. By "natural science" I mean a general and unfolding understanding of the natural world attained through a history of inquiry whose legacy is broadly accessible to educated people, not a collection of specialized disciplines and departments. My urging is that natural science needs to assert itself *philosophically* in questions related to physics, and, as if that were not enough, that it needs to proceed down an uncharted path. Its eventual course has to be one of *ontological* research, capable of resurrecting questions directed toward a first and most basic understanding of a profound matter: the nature of the causal activity that comprises physical space whether empty or occupied by objects. As such it has to move directly against the major current of our time regarding such questions and regarding conceptions of physical science in general, because this current is dominated by the influence of *a characteristic unique to physics in its present era*, namely, a hegemony of what I have designated aspect (2) (see Introduction), whereas physical ontology is primarily a concern with aspect (1) on its own. The current aspect-hegemony is reflected in and reinforced by the fundamental positions of influential philosophers of science.

The purpose of the brief revisionist history of physical science presented here is to orient the revived natural philosophy historically and scientifically, or in other words, to recover a sense for the questions whose consignment to oblivion I have termed scientific nihilism. This preparatory process requires complete autonomy from the recent nihilist consensus, which arose from conceiving theoretical science in general on the model of contemporary theories of physics. This autonomous point of view is achieved by emphasizing the history of aspect (1), its erstwhile vitality and its current entombment. Specifically, the argument aims to show that the new project of explanation, correctly oriented, will neither employ nor emulate the theoretical and technical/mathematical procedures and methodologies of today's physics, because this science as we know it has effectively confined the whole of constructive theorizing to mathematical formulas (often viewed, mistakenly I believe, as encoded or symbolic explanatory descriptions of which one might venture an unofficial narrative and inherently speculative interpretation) and convenient modeling language. Theory thus confined has its own rationale and an open-ended applicability but cannot itself lead to causal explanation, let alone furnish an ontology. Fortunately, as I will try to show, intuitions about the meaning of "physical explanation" that can be emulated by the natural philosopher in a time of scientific nihilism are on display in some powerful figures from the history of physics. The chapter traces this history with the spotlight on these intuitions, but it begins with a singular giant of science who stands at the opposite pole from these causalist physicists.

Early Philosophical Turbulence

The story begins with Galileo Galilei (1564–1642), the great forefather of modern acausalist and mathematical physics. One of the forces that shaped his thought was a love of mathematics, and another was a reaction against the Scholastic physicists in the late Aristotelian tradition of his time. The Scholastics, and even Galileo himself at first, sought to understand, for example, the acceleration of a falling body by an ad hoc conjecture about its immediate cause. The trajectory of a thrown object was thought to be explained as the result of a continually impressed force that for some reason diminishes over time.[1] But Galileo developed a radically different scientific approach. Concerning free fall, his new procedure was to attend closely to the phenomenon itself, assume the simplest proportions among its measures, and produce a mathematical analysis or "definition" of acceleration. By this means, and by applying a mathematical theory of proportions, he predicted with dazzling accuracy a truth that is striking to a naive expectation: that the rate of acceleration in free-fall (in a vacuum) is unaffected by weight. The upshot was that he provided science with the modern concept of *inertia*. It is widely thought that "Galilean science" is a synonym for "modern science," that is, Western science roughly since Galileo's time, but this chapter should help to show that this is a mistaken notion stemming from twentieth-century prejudices.

The kind of success in the furtherance of science achieved by Galileo's revolutionary methods can produce the strong suggestion that to conjecture about the hidden causes for physical phenomena in general is simply the wrong way for science to proceed. Indeed, Galileo was led by the fruitfulness of his mathematical approach, which no doubt bolstered his reaction against the Scholastic-Aristotelian approach, to think that in general it was vain to seek for the "true and internal essences of natural substances" and that science should "content [itself] with a knowledge of some of their properties."[2] Given this attitude, it is not surprising that Galileo was not inclined to speculate about occurrences in the surroundings of objects that would account, for example, for electric and magnetic forces.

Pierre Gassendi (1592–1655) was a follower of Galileo, and understood well the objections to speculations beyond the sphere of what can be confirmed by observation. But after duly expressing qualms and asking the reader to indulge him some "uncertain conjectures" and "murky babblings," he felt justified in pursuing serious reflections on questions about the possible causes of magnetism, static electricity, gravity, and light propagation, sketching "a theory that seems closer to the truth than the others."[3] One of his written works echoes Galileo by attacking the possibility of "Aristotelian science," and this work has given Gassendi a reputation as a strict empiricist, even though this is contradicted by his serious aspect (1) conjectures. "Aristotelian science" meant science guided by the expectation that the "necessary" causes of things could be determined by logical demonstration, so that his criticism does not speak against the possibility of causal conjectures that are not demonstratively certain, but may have some degree of plausibility and some claim to truth. Also, there is in this same work a passage that, whether intentionally or not, movingly defends the calling of a speculative natural philosophy:

> Therefore, I conclude that whatever certainty there is in mathematics is related to appearances, and in no way related to genuine causes or the inner natures of things. However, I must add that with the help of mathematics I can become certain that, for instance, the earth is round; this can be made manifest through the eclipses of the moon and the varying height of the poles. But why is the earth round? what is its true nature? is it animate or not? and if it has a soul, what kind does it have? what functions does it perform? what properties is it alloted? why does it lie motionless at the center, or if it moves, what impels it? The same questions are to be asked about the sun and the other stars, and likewise about sound, which is the subject of music, and light, the subject of optics, and so forth. Truly, the moment you pass beyond things that are apparent, or fall under the province of the senses and experience, in order to inquire about deeper matters, both mathematics and all other branches of knowledge become completely shrouded in darkness.[4]

Regarding one of the matters that fall under the province of speculation, that of the ultimate nature of the matter-space relation, Gassendi did have a disputant in his contemporary René Descartes (1596–1650). Gassendi though that the ultimate structure of things had to consist of atoms moving around in a void, whereas Descartes considered the void an impossibility, and thought that substance must be present everywhere, a "plenum." Today a physicist views these theories of fundamental physical structure founded on the contrast between empty and occupied space as too simple and naive for advanced knowledge; in modern "field" physics there is an implicit, background recognition of the existence of *empty space events*. However, there is no basic physical account or narrative description of such events, despite the thorough utility of a merely convenient technical terminology.

To try to determine where Descartes stood on the question whether Galileo had formed the correct conception of physics will end in confusion. He sought to build up all knowledge from self-evident certainties and rules of inference, forging a mathematical/deductive approach into methodological precepts for developing a system of the world, a system free from the unfounded hypotheses he thought were characteristic of philosophies of the past. This is a stance fully ambivalent between a Galilean anticonjectural method and an Aristotelian quest for encompassing knowledge. Against Galileo and Gassendi, Descartes was opposed to the overriding emphasis upon what "appears to the senses," and proposed elaborate mechanistic explanations of magnetism and light in terms of invisible particles and processes of the plenum; however, he capitulated in a way to the empiricist proscription on knowledge in a remark displaying vacillation as to whether these explanations were to be taken seriously as candidates for the truth.[5] Gassendi was more thoughtful on this point, and merely disclaimed any undue expectation of certainty or adequacy for his conjectures.

The explicit historical discussion on the proper aims and expectations of physics that had been sparked by Galileo's work died out in this confused condition. Meanwhile, in early research into magnetism and electricity, explanatory conjectures were developed and refined along with experimental progress as if the quest for a causal understanding of the phenomena unquestionably belonged to the basic mission of science.

Next our interest comes to rest on Isaac Newton (1642–1727). Due to the dominant prejudices of today, Newton is often treated as if he were a pillar of acausalist physics, the man who formulated complete laws of motion and gravitation and, when it came to the question of the cause of gravity, said "*hypotheses non fingo*." This Latin phrase, whose suggestion depends quite a bit on the chosen translation, is understood on this view to encapsulate the thought that it is illegitimate for science to engage in speculations about the causes of forces, or about "unobservable" causes in general. But this is a misrepresentation of Newton's views. We know from his letters to Boyle and Bentley and from other writings that he had no doubt there was something, whether "material or immaterial," *mediating across the space between objects* that would explain forces, and that he tried to account for the force of gravity by the action of a pervasive material medium but was never satisfied with the results. There occurs in the third letter to Bentley a passage whose forceful causalism brought it fame even in our era:

> That gravity should be innate, inherent and essential to matter, so that one body may act upon another at a distance through a vacuum, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it.[6]

As discussed further below (page 29), biographical material indicates that the reason Newton did not publish his causal conjectures about gravity was that he could not conceive a satisfactory mechanism, not that he did not condone such conjectures philosophically, that is, from the standpoint of a doctrine or theory of the true scientific method. Also, Newton devised the corpuscular theory of light, which dominated optics for the subsequent century and a half. Though on the surface narrative theories of light are more tractable than speculations about gravity, especially for this innocent era, both are conjectures beyond the conceivable province of direct observation.

In a wide-ranging debate by correspondence with Leibniz, the Newtonian metaphysician Samuel Clarke (1675–1729) said the following:

> That one body should attract another without any intermediate means, is indeed not a miracle, but a contradiction: for 'tis supposing something to act where it is not. But the means by which two bodies attract each other, may be invisible and intangible, and of a different nature from mechanism; and yet, acting regularly and constantly, may well be called natural; being much less wonderful than animal-motion, which is yet never called a miracle.
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> If the word *natural forces*, means here mechanical; then all animals, and even men, are as mere machines as a clock. But if the word does not mean, mechanical forces; then gravitation may be effected by regular and natural powers, though they be not mechanical.[7]

Note that Clarke is not suggesting a teleological explanation, as if to say that that gravitation might be effected by something having the purposefulness of animal and human behavior; indeed if it were anything of this sort, then for the theistic worldview it might have to result somehow from God's volition, which would make it miraculous, that is, outside the scope of natural science, and would also seem to require that it be to some degree unpredictable and changeable, rather than ever-present and constant. Clarke merely urges an openness to the possibility that the "intermediate means" may be neither teleological nor mechanical (meaning roughly: involving matter in motion). This remarkably open suggestion, which stops short of any positive conception of the "intermediate means," anticipates the course that narrative causal explanation is finally challenged by the evidence to follow (assuming its aims remain valid) in the twentieth century.

To summarize: Galileo began an early historical reflection concerning the basic goals and prospects of physical science by throwing his weight behind mathematical analysis of the empirical properties of things (at least for nonastronomical matters) in reaction against Scholastic physics. But despite the influence of Galileo's breakthrough, the procedure of speculating beyond the observations for the specific causes of what is observed was far from vanquished; there was even the phenomenon of Gassendi, who generally promoted the Galilean reaction, but was a natural philosopher nonetheless. After this discussion on the aims of physical science died out, Newton, most famous for having applied the mathematical approach to produce the laws of motion and gravitation, actually followed a balanced approach; despite "*hypotheses non fingo*" there is really no reason to think he did not remain solidly behind aspect (1) questions in principle.

Advanced Causalist Physics

During the eighteenth and early nineteenth centuries the sciences of electricity and magnetism saw development in both aspect (1) and aspect (2) research. A variety of theories of electric and magnetic fluids, flowing through objects and through the space surrounding them, were put forth to account for the accumulating results of experiment, with some limited success. Leading intellectuals who were not experimental investigators or scientific specialists also contemplated the forces. As for aspect (2), inverse square laws corresponding to Newton's law of gravitation were established for electric and magnetic forces. Along with these successes came the practice of talking about action at a distance rather than about the adventures of the electric and magnetic fluids in the interspace of objects. Despite Newton's real views about this as expressed in the letter to Bentley, the era during which the idea of forces acting at a distance dominated physics is often referred to as the Newtonian era.

That in this "Newtonian" period there was a certain dominance of aspect (2) is evident in the suppression of the causalist conviction that mediating factors of some kind must exist. The extent to which aspect (2) dominated the thinking of these later researchers need not concern us here. But aspect (1) continued to have a role during this period, since the electric and magnetic fluids merely came to be thought of as confined within the objects, and even theories of fluids acting externally to the objects were not entirely abandoned—and in any case, the quasi-material medium of light transmission was alive and well.

Also noteworthy in this period were the experimental discoveries of interactions between electric and magnetic phenomena, which suggested that at least these, and perhaps all forces of attraction and repulsion, have a common basis in nature.

This brings us to Michael Faraday and James Clerk Maxwell. I discuss these scientists together not only because they are closely associated historically, but also because they shared important intuitions regarding the goals of science, though their individual contributions were very different.

Faraday (1791–1867) epitomizes the aspect (1) researcher whose life-project is summarized in the statement that "it is the cause of the forces that one wants to lay hold of."[8] Untrained in mathematics, he was a highly productive experimenter who developed rudimentary physical conceptions of the routes of transmission of electric and magnetic effects, involving structures in the space surrounding objects: the *lines of force* (manifested, for instance, in the patterns observed when iron filings are distributed on a sheet of paper and a magnet is placed underneath). Faraday thought of the transmission along the line of force (through empty space) as if it were something analogous to a state of tension in a piece of string, but he did not arrive at a more adequate physical specification. He came to regard the lines of force as more than a useful construct or model assisting experimental intuitions; he was devoted to the quest for a genuine understanding of how forces in general are brought about, and saw the lines of force as an answer or partial answer. That is, he clearly thought these structures were physical realities, whatever the limitations of his attempts to describe them. His basic scientific hope and expectation was that the common basis in nature for all the forces would someday be discovered and described.

What is especially significant about Faraday's work from the standpoint of the present inquiry is that he came to reject the other three modes of explanation that prevailed in his time: electric and magnetic fluids, action at a distance, and the mysterious ether filling all of space. In other words, he developed the idea that the transmission of forces must occur in and through *space devoid of matter.* This is the pioneering intuition of "field" physics, whatever one wants to make of the notion of "field"—and the usual account from our standpoint today would hasten to add that Faraday was nevertheless naive in thinking that the field could be given a "nonmathematical description." But from my own point of view, he leapt far beyond his time by envisioning potentially describable causal structure integral to space itself, and hence of the true direction for achieving fundamental narrative explanations. He *correctly* rejected material substrata, but at the same time he did not positively surpass the concept of localized entities or local "tensions" and "strains,"[9] though his thought did develop in the direction of such an overcoming (the significance of this particular limitation will become clearer in due course). Chapter 8 touches on Faraday's more speculative thinking.

Faraday's explanatory ideas might easily be dismissed today as those of an experimenter who was naive about theory; but no mathematical innocence can be attributed to Maxwell (1831–79), who was an avid promoter of Faraday's research and ideas. He claimed that Faraday's "lack" of mathematical training was not a hindrance to his having produced, with the lines of force and their variables of density per unit of space and individual intensity, a mathematical theory in its own original sense—a "new mathesis," as he put it. Maxwell himself followed a path decidedly balanced between aspects (1) and (2). The best evidence for this is not the fact that he constructed physical models of activity in apparently empty space as never before, for example, imagining a compact system of spinning vortices in the ether separated by smaller "idle wheels" rolling between them. He fully recognized the artificiality of these models, constructed as they were ad hoc in response to particular features or groups of features within a broad class of interrelated phenomena; he knew they could not finally be retained as the "true interpretation"[10] (the hope for which he did not at all view as chimerical), and claimed of them only that they helped suggest a formulation of the mathematical relations. By such means he was in fact able to produce the complete quantitative laws for the electromagnetic field, incorporating electricity, magnetism, and light in a single, integrated, aspect (2) theory (the only surviving vestige of aspect [1] or narrative explanation in Maxwell's electromagnetic theory is the simple schematic relation among the vectors of electric and magnetic forces and light propagation, though this schema originally had a physical dimension provided by the background idea of an ethereal medium). I will argue here that Maxwell's true commitment to aspect (1) was shown not so much by the use of physical models, but more by his defense and promotion of Faraday's explanatory ideas and his expectation that these rudimentary ideas would develop into a more adequate understanding in the future, one that he thought would amount to a science yet unnamed.

As in the case of Newton, twentieth-century commentators on Maxwell tend to emphasize the illustrious success of the unified field laws for electromagnetism, and to discount, overlook, or ignore what I would call Maxwell's unwaning commitment to aspect (1). Commentators often point to his sophistication in not believing his ether-based models to be finally correct explanations; but this is no argument that he thought that genuine physical explanations, for instance along the lines of those sought by Faraday, were not a proper business of physical science. There is an appearance of disagreement with Faraday in that Maxwell believed in some kind of an ether, but if this shows anything it is only that he retained a stronger element of materialism; more basically, the fundamental importance of both narrative and quantitative approaches in his views about physical theory can be seen in his writings, especially in his attitude toward Faraday. The quoted passages to follow do not lay out a *theory* of what "physical explanation" ultimately means, but show some intuitions and attitudes that identify strongly with the causalism of Newton and Faraday.

Maxwell explained his purposes in elaborating Faraday's lines of force into tubes filled with moving fluid as follows:

> 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.[11]

Clearly he did not think the mature stage of theory in which real physical explanations first appear is attained with successful mathematical theory, which only "suggests" such physical explanations. What then is one to take as a model for understanding the *basic character* of the explanations that would eventually be produced by "interrogating Nature herself"? The penultimate paragraph of this same article lists some options for a physical explanation of electric and magnetic phenomena, and they are the three kinds of causal hypothesis existing at the time: motions in the ether, flowing "imponderable" fluids, and action at a distance. This confirms what is stated clearly enough in this passage, that he envisioned the future explanations at least as some kind of aspect (1) or causal narrative explanations. But Maxwell clearly does not here commit himself to any of these traditional options, and is in fact expressing doubts about them as a group. Therefore this article is of little help to us in understanding how Maxwell conceived the *positive* character of the future explanations.

But his writings do offer important guidelines about this. I think the soundest way to describe his views on the nature of physical explanation in the area of forces and radiation is as follows: He believed that genuine explanations of electromagnetic phenomena did not yet exist and that the future explanations would be the result of *an extension of Faraday's approach under some kind of transformation*. To show that this was the direction of Maxwell's thought, I bring together several separate pieces of text. First, let us note that he defended Faraday against the arrogance of the mathematicians who regarded their methods as superior to—more scientific than—Faraday's conceptions:

> Up to the present time the mathematicians who have rejected Faraday's method of stating his law as unworthy of the precision of their science have never succeeded in devising any essentially different formula which shall fully express the phenomena without introducing hypotheses about the mutual action of things which have no physical existence, such as elements of currents which flow out of nothing, then along a wire, and finally sink into nothing again.[12]

Here Maxwell is supporting the idea of lines of force by pointing out that a limitation of physical reality to visible objects and *space as a void* will not yield explanations. He uses the word "law" in a sense that extends beyond quantitative analysis and overlaps with efforts at physical explanation.

In another paper he wrote about the special exertion of the mind that is really required of a successful explanatory endeavor, and also about the basic difference between the mathematical and experimental approaches to physical science and how each of these has its own built-in pitfall:

> Each of these types of men of science is of service in the great work of subduing the earth to our use, but neither of them can fully accomplish the still greater work of strengthening their reason and developing new powers of thought. The pure mathematician endeavors to transfer the actual effort of thought from the natural phenomena to the symbols of his equations, and the pure experimentalist is apt to spend so much of his mental energy on matters of detail and calculation, that he has hardly any left for the higher forms of thought. Both of them are allowing themselves to acquire an unfruitful familiarity with the facts of nature, without taking advantage of the opportunity of awakening those powers of thought which each fresh revelation of nature is fitted to call forth.
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> There is, however, a third method of cultivating physical science, in which each department in turn is regarded, not merely as a collection of facts to be co-ordinated by means of the formulae laid up in store by the pure mathematicians but as itself a new mathesis by which new ideas may be developed.
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> Every science must have its fundamental ideas—modes of thought by which the process of our minds is brought into the most complete harmony with the process of nature—and these

> ideas have not attained their most perfect form as long as they are clothed with the imagery, not of the phenomena of the science itself, but of the machinery with which mathematicians have been accustomed to work problems about pure quantities.[13]

That he regarded Faraday's ideas as what he calls here a "new mathesis" is clear from another passage:

> It is true that no one can essentially cultivate any exact science without understanding the mathematics of that science. But we are not to suppose that the calculations and equations which mathematicians find so useful constitute the whole of mathematics. The calculus is but a part of mathematics.
>
> The geometry of position is an example of a mathematical science established without the aid of a single calculation. Now Faraday's lines of force occupy the same position in electromagnetic science that pencils of lines do in the geometry of position. They furnish a method of building up an exact mental image of the thing we are reasoning about. The way in which Faraday made use of his idea of lines of force in co-ordinating the phenomena of magneto-electric induction shews him to have been in reality a mathematician of a very high order—one from whom the mathematicians of the future may derive valuable and fertile methods.[14]

An interesting question is raised here about the extension of "mathematics" beyond its familiar associations, but this is a topic outside the present concern. Elsewhere he stated that the tendency of the purely calculative mathematician is to "entirely lose sight of the phenomena to be explained," and that the corresponding danger of the approach that would make use of a "physical hypothesis" is that "we see the phenomenon only through a medium [i.e., the hypothesis], 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 analytic subtleties, nor carried beyond the truth by a favourite hypothesis [emphasis added].[15]

And there are these intriguing remarks about the purely mathematical (in the calculative sense) approach:

> Mathematicians may flatter themselves that they possess new ideas which mere human language is as yet unable to express. Let them make the effort to express these ideas in appropriate words without the aid of symbols, and if they succeed they will not only lay us laymen [!] under a lasting obligation, but, we venture to say, they will find themselves very much enlightened during the process, and will even be doubtful whether the ideas as expressed in symbols had ever quite found their way out of the equations into their minds.[16]

To summarize Maxwell's views as traced in these quotations: A complete process of theoretical science that stays balanced and on track has three characteristics: (a) it keeps the phenomena in view, as the experimentalist does; (b) it develops quantitative-mathematical theory and puts it to the uses that are appropriate; and (c) it develops the elements of new physical conceptions suitable for these phenomena, elements out of which to build a language of description and explanation, as opposed to a "language" of mathematical symbols—and this project is mathematical in the sense of the origination of the elemental conceptions and construction out of these elements, not in the sense of the manipulation of "pure quantities." Faraday exemplified (a) but also the equally legitimate dimension (c). Maxwell thought that *both* what he called physical analogies—artificial models such as the system of spinning vortices—*and* quantitative formulas are properly employed for their *suggestive power* in furthering this program, though neither can securely orient inquiry. It is important to recognize the complete open-endedness with which Maxwell thought about the future of theory:

> We are probably ignorant even of the name of the science which will be developed out of the materials we are now collecting, when the great philosopher next after Faraday makes his appearance.[17]

(In the historical perspective taking shape here, this next philosopher would be A. N. Whitehead.)

Throughout his life Maxwell held Faraday and his theoretical methods in undying esteem, and evidently thought that the search for a genuine physical understanding was something that need always *complement* the methods which he himself had undertaken.

Another piece of evidence for my view of Maxwell as unequivocally causalist is his attitude toward Newton. He spoke of "the unimprovable completeness of that mind without a flaw."[18] The Newton he thus held up was not the Newton often associated with action-at-a-distance theories, but the Newton of the letter to Bentley. In his scientific papers Maxwell was given to quoting the famous passage from the letter quoted above together with a reference to a certain complementary passage from Newton's biographer Maclaurin. Maclaurin said that the reason Newton did not publish his attempts to explain gravity by pressures in a medium "proceeded from hence only, that he found he was not able, from experiment and observation, to give a satisfactory account of this medium, and the manner of its operation in producing the chief phenomena of nature."[19] Maxwell is at pains to uphold Newton as a natural philosopher concerned with physical explanation though aware of the inadequacy of his vision on the matter.

Though Maxwell is usually viewed as a precursor to the twentieth-century phase of physics, in which the broad-scale quest is for the complete field laws (pure aspect [2] theory), it seems clear that he would not have been at all comfortable with the complete absorption of physics within aspect (2) that was to come about. To him, "physical explanation" in the case of forces and radiation appears to have meant the fulfillment at some future time of the causalist intuitions of Newton and Faraday.

The New Era of Physics and the Reign of the Cult of Surfaces[20]

We have seen that the program of physical science that I have called "causalist" was resolutely upheld in Newton's and Maxwell's concepts of science (not to mention those of many other reknowned scientists), and is particularly well-exemplified in the life-work of Faraday. For most early researchers into electricity and magnetism, such as Benjamin Franklin, causalism was simply presumed at the philosophically naive level of experiment and physical conjecture, without being either explicitly stated or called into question philosophically as an approach to science. Faraday shared this naive causalism, but leapt beyond it scientifically by rejecting mechanistic models for the explanation of forces; but apart from cautious and occasional speculations, his positive ontology was limited to the abstractions of a "new mathesis." What I have traced so far is a solid intuitive commitment to the belief that the possibility of explanation/understanding in the case of forces and radiation lay with the description of some kind of complexes or configurations of entities or processes in (or of) what would otherwise be regarded as empty space, whether or not this would ultimately involve an "ether" of omnipresent substance.

Despite this powerful tradition, in the twentieth century aspect (1) evaporated from the official science of physics, as if never to be taken up seriously again (with the qualification that one can resort to talk of action at a distance to give the discussion a causal flavor while evading real explanation). Causal-narrative explanation appears deceased in spite of the fact that many physicists are speculatively quite venturesome in reaction to the new enigmas and mysteries. The most basic reasons for this are as follows: First, the notion of an all-pervading material serving as a medium for light transmission—the ether—was repudiated, for reasons discussed below. Second, the properties of light transmission as revealed by new experiments thwarted the effort toward a coherent and complete physical explanation using the idea of vibrating material or moving objects (for short, this is the "breakdown of mechanistic models"). Third, despite Faraday's intuition that space itself might transmit forces, the fundamental assumption has never ceased to hold sway that if a causal process is such that it cannot be described in terms of some kind of motion of matter, then it cannot be "narratively" described at all (and perhaps has no physical reality!). In Maxwell's words, with the new determinations and discoveries nature had presented a "fresh revelation" which required the "awakening" of "new powers of thought"; but with hindsight this proves to be an understatement. Richard Feynman described the new situation this way:

> . . . the more you see how strangely Nature behaves, the harder it is to make a model that explains how even the simplest phenomena actually work. So theoretical physics has given up on that.[21]

"Simplest phenomena" means, for instance, the fact that "when very weak monochromatic light (light of one color) hits a detector, the detector makes equally loud clicks less and less often as the light gets dimmer."[22] This seems simple enough, but under standard assumptions it appears entirely incompatible with the fact that light shows many features of wave phenomena. The abandoned question here—what sort of wavelike process could generate this pattern of effect?—is not a puzzle to be solved by a formula, nor does it call for a merely useful interpretive model, which is hardly unavailable to a physicist. This phenomenon with very weak light is the port of entry to the mystery of radiation in the first chapter of Part Two, where I argue that what "strange behavior" means initially is simply that light is *neither* motion of particles arriving at the detector *nor* vibrations in an omnipresent substance (though it is of course some causal process analogous to a wave). Considered in broader scope and context, the strangeness of radiation microphenomena means that physical science has encountered a level of nature that exceeds in its subtlety all possible applications of what had been assumed to be the irreducible and essential conceptual elements in any physical story: given local space and present material (or even immaterial localized structure such as lines of force). In view of this truly extraordinary encounter, physicists cannot be blamed for pursuing a technological (experimentally advancing) and mathematical science and turning away from the genuine "Why?" and "How?" questions, as a pragmatic alternative to an inauspicious and less technically productive effort to bring their discoveries into conformity with "common sense." The upshot is that a basic account of radiation is no more in hand than a basic explanation of forces, which makes it clear that a background or ontological lacuna of understanding exists.

A lone figure whose work in physical theory stands in contrast to the abandonment of causalist natural philosophy by theoretical physics is Alfred North Whitehead (1861–1947). The reader is advised that the ensuing discussion of Whitehead throughout this book is at some points a strongly extrapolative interpretation of this thinker, and I neither insist upon its definitiveness nor renounce all claim to its correctness. Whitehead's physical theory is best known as an idiosyncratic alternative to Albert Einstein's groundbreaking work on relativity; his own theory was inspired by Einstein's work but differed from it in fundamentals. He was not a theorist of radiation, and discussed the early "quantum" developments in physics (which I have referred to as the breakdown of mechanistic models) only in very general and somewhat metaphysical and metaphoric terms.[23] But he did in his own way respond concretely to the challenge to narrative explanation represented by the physical "field"; this response has to be wrested from the texts with some effort. Since it is known that the context of occurrence or "medium" of radiation is the electromagnetic field, it is clear that the question of the nature of light propagation would proceed inseparably from the question, what is the physical field? how is it to be identified in and for a causal-explanatory ontology?

Whitehead's approach to explanatory problems of physics was to adopt an ontology in which the category "natural events" has knowable extension beyond cases of given, present matter undergoing change of quality or change of place, so that the physical field would consist of events not conforming to any concept of a material event; but it is debatable whether and to what extent he managed to carry physical explanation beyond the representational imagery of materialistic explanations. The intuition, however, was to discuss events whose structure and interrelations are conceived in a way that dispenses with the requirement that systems of spatial position and material presences (the "extended substance" of Descartes) be pregiven. It is not that certain events are thought to comprise a realm apart from physical objects, but roughly that events are viewed as physical conditions of objects rather than the reverse. Whatever its original aim, such a procedure (if feasible) would open investigation both into events composing transmissions that propagate through or across *empty space* in a genuine sense, that is, such that this process does not involve present material, and into events forming a depth-composition of *atomic matter* which does not consist of a further subdimension of localized objects. He spoke of an "ether of events," conceived explicitly outside the conceptual framework of "grids" of spatial locality and occupying matter, that is, so conceived that its description cannot be constructed out of the elements of mechanistic causal stories.[24] Whitehead said that his conception of the field "is practically the familiar one of tubes of force, with one exception," this being the fact that a tube (or line) of force is "conceived statically as a simultaneous character stretching through space," whereas for Whitehead the entity in question is *essentially a structure of activity,* not involving *presence in* space, that is, side-by-side relations of parts, and as such is misconceived already if its concept entails a backdrop of extension in localized space (occupied or unoccupied) uniformly subsisting through time.[25]

In my understanding, Whitehead sustained an essential causalist intuition by treating the field as the trace or mark of generative antecedence in observed field phenomena such as the movement of iron toward a magnet. It is whatever generates the movement. This unobjectionable basic account of the field was elaborated not in mechanistic models, but in a general view about observation and about nature and the comprehension of nature: the truly elemental facts of physical observation are not motions and changes of and in material bodies, but the "passage" of events into other events. Thus an observed event (such as the acceleration of an object) discloses not only itself to observation, but discloses "by relatedness" other events, such as those of immediate causal antecedence. To give another kind of example, I observe that the beam from a flashlight makes a spot on the wall, or that it illuminates dust or smoke in between; I do not and cannot see the light transmission itself (which I am told is wavelike in structure); but *that there is an effective causal transmission* is disclosed to me just as surely as is the spot on the wall or the trace through intervening particles. As discussed in the ensuing chapters, the class of "things observed" for traditional theory of science is drastically restricted by comparison, so that this example would have to be viewed differently.

Concerning the field, on the Whiteheadian view one observes events marked by causal derivation from a concurrent background of events. *Transition* in what Whitehead called the "passage of nature" is the irreducible structural element by which nature is ultimately known, and is the essential basis for a new understanding in physics. According to this approach the field is causally enigmatic for traditional science because of its status as a physical ultimate in the sense that this unique transition, *which alone identifies the form of activity of the field*, is a natural structure lying physically and genetically prior to the merely manifest or "derivative" linear stretches of space and intervals of time, for example, those entering into a physicist's measurements; thus the field consists of generative physical activity in a different category from local motions, since the concept of the latter presupposes such linear spans of time and space. The intuition that a motion attributed to a force is the terminus of some antecedent physical occurrence is to be steered entirely away from materialistic models and toward the suggestion that physical actuality is fundamentally "passage," intrinsically transitional in the sense of a process, and thus has a dimension extending beyond simple material givenness that is not itself reducible to any postulated material givens. This fundamental "process" dimension of the physical is the context and constitution of fields.

Presumably the concept of this "causal past" observed as a generative trace in the phenomena must somehow support a variety of specific structural possibilities, if the various species of field and modes of effect are to be accounted for; but Whitehead discussed the composition and interrelation of his "events" only in highly abstract terms, being oriented instead toward developing his own theory of space and time in response to the new relativity physics and deriving therefrom an alternative mathematical model. My own neo-Whiteheadian physical inquiry, elaborated in Part Two, seeks to counterbalance this emphasis by focusing on the understanding of radiation. It suggests a way in which the background events of the field and radiation can be conceived concretely as physical transitions in a sense that escapes the conceptual precondition of a purely spatial extendedness that comes with lines or tubes of force (and with "matter in motion"). But I do not employ Whitehead's abstract methods, nor do I promote his metaphysical ideas.

Thus Whitehead's physical ideas are well situated candidates for those new fundamental conceptions that Maxwell predicted would follow upon Faraday's scientific thought. He continued the causalist program—in spite of the fact that its abandonment by physics was in progress—in an original way by suggesting that a concept of physical "events" needed to be developed explicitly outside the confines of mechanism. Even so, these ideas—found mainly in the three works *An Enquiry into the Principles of Natural Knowledge, The Concept of Nature,* and *The Principle of Relativity with Applications to Physical Science*—are another kind of "new mathesis," limited to the abstraction "events" and the geometry of specially defined "event" relations. It needs reformulating in a fleshed-out interpretation before it amounts to narrative causal explanation, that is, to something fully comparable to old-fashioned aspect (1) science. (For this reason, physical ontology cannot conceive its task simply in terms of the explication and rehabilitation of Whitehead's