How does physics bear upon metaphysics; and why did Plato hold that philosophy cannot be written down?[†]

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I

To begin with, a remark about the second question: I think it would be foolish of me to

[†]The paper was delivered by Stein as a talk at a faculty colloquium (an informal affair) of the Department of Philosophy at the University of Chicago in November 1995. The present version includes Stein's own handwritten corrections and additions to the original manuscript, given to Erik Curiel and Tom Pashby in May 2020. Footnotes indexed by numerals are present as such in Stein's original manuscript; footnotes indexed by symbols are additions by Curiel and Pashby (sometimes at the behest of Stein). This version is based on the version first typeset by Curiel and Pashby in March 2019, a verbatim copy of an original typed manuscript given to Curiel by Stein in 1996, excepting only the following five changes. (1) All words in ancient Greek, garbled in the original, have been properly typeset. (2) The word 'Draft' that appeared in the upper righthand corner of p. 1 does not appear in this version. (3) On p. 8 of the original, item 2 of the characterization of Newtonian space-time, the clause "if p and q belong to one moment of time, and if p' and q' belong to another, the time-intervals from p to q and from p' to q' are equal" is clearly a typo. It should read "if p and q belong to one moment of time, and if p' and q' belong to another, the time-intervals from p to p' and from q to q' are equal." That is how it now appears on p. 10 of this version. (4) On p. 22 of the original, the phrase "some of what philosophers often rather glibly to speak of" should clearly be "some of what philosophers often rather glibly speak of", as it now appears on p. 24 of this version. (5) On p. 25 (last page) of the original, 2nd line from the bottom, 'commentdb' should clearly be 'comments', as it now reads in this version on p. 27. Bibliographic references for citations of universally known works (by Plato, Aristotle and William Blake, and Newton's *Principia*) have not been given, in keeping with the conversational style of the paper. A scan of the original 1996 version can be found here: <http://strangebeautiful.com/other-texts/stein-physics-and-metaphysics-original.pdf>; the March 2019 version can be found here: <http://strangebeautiful.com/other-texts/stein-physics-and-metaphysics-201903.pdf>.

try to give a decisive answer, because all one has to start from is what Plato *did* write down. This paper is in any case not primarily about Plato; yet I find what he has written—or may have written—in many ways very suggestive. Let me remind you what he wrote—or may have written—about the writing of philosophy.

The source whose authenticity I assume to be without serious challenge is the *Phaedrus*. There (274c *ff.*) Socrates tells Phaedrus that he has heard, but cannot vouch for its truth, that it was the Egyptian god Thoth (Θεύϑ) who invented—note the collocation—numbers and reckoning and geometry and astronomy, also draughts and dice, and notably writing; that Thoth maintained that in writing he had discovered "an elixir of wisdom and of memory"; but that the king of the country, Θαμοῦς, the god whom the Greeks call Ἄμμων, rejected this contention, saying that writing is merely an elixir of reminding, not of memory, and that it would produce only the reputation, not the truth, of wisdom. Socrates then himself takes up the interpretation of the judgment of Θαμοῦς/Ἄμμων. He blames the written word primarily for its *unresponsiveness*: its inability to reply to questioning; its insistence upon saying continually the same thing, with no regard for its audience. In an agricultural comparison, he likens writing to the planting of seeds for purely ornamental purposes, in conditions not suitable for the proper growth and ripening of fruit; and concludes that one who has knowledge of some things (in particular, of the just and the beautiful and the good) "will not then write them, in earnest, in black fluid, sowing by means of a pen with arguments that cannot defend themselves by argument." Such a person will rather, he says, "sow gardens with letters for the sake of amusement; and will write, when he does so, to treasure up reminders for himself when he comes to the forgetfulness of old age, and for others who follow the same path; and will delight in seeing the plants putting forth tender leaves. When others use other amusements, refreshing themselves with drinking parties and the like, he will, it seems, instead of these, pass the time playing at those I speak of." And the conclusion of all this is that whoever does appreciate the limited worth of writing, and is able both to support his own writings in discussion and to show their defects, deserves the title, not of "wise"—σοφός—but of a lover of wisdom—φιλόσοφος.

So writing ranks in one sense with draughts and dice rather than with number, reckoning, geometry, and astronomy. But its dismissal is not by any means so drastic as, say, the expulsion of the poets in the *Republic*: as an amusement, it is in fact praised. More than this, there is a pregnant irony in Plato's remarks. For Socrates, who is represented as engaged in live discussion with Phaedrus, speaks, at the end, of that discussion itself as an entertainment or pastime. And in the *Laws*, that very long and sober discourse which the Athenian Stranger characterizes (685a) as "an old man's sober playing of a game of laws," we also read (803c-d) that human beings are playthings of the deity, that accordingly every man and woman ought to spend life playing at the finest games, that in particular people err in regarding *warfare* as *serious work*: rather, the most serious things for us are παιδιά—play—and παιδεία—education, when they are genuine and worthy of the name.

So much, then, for Plato's play with *this* point; but there is another passage that bears upon the question of the written word that seems to me very illuminating—although here the authenticity of the work is open to question. I think it may be allowed into the discussion, even if only in the spirit in which Socrates let in the story about Thoth. I have in mind the seventh of the reputed letters of Plato. There he (or whoever it may be, in his name) explains why there does not and will not exist any treatise of his on what he seriously pursues. The explanation takes the form of a roughly sketched *semantical theory*. There are, one reads (342a *ff.*), of anything that is, three requisites for knowledge; five things in all, then, counting the knowledge itself and its object—what is truly known. First there is a *word*, or *name*, or *noun* (ὄνομα)—for instance, 'circle'; second a *formula* or *definition* (λόγος), composed of nouns and verbs—in the case at hand, "that in which the distance from extremity to center is everywhere equal" would be the λόγος of that whose name is *rotund* and *round* and *circle*; third is the *image* (εἴδωλον)—here what is drawn and erased and turned on the lathe and destroyed. But none of these εἴδωλα is the circle that is the object of knowledge (a point that hardly needs to be amplified, whether on Plato's behalf or on that of mathematics itself). *Between* these first three and the veritable object of knowledge the writer inserts the fourth, which he now describes as "knowledge (ἐπιστήμη) and intellectual grasp (νοῦς) and true opinion (ἀληθὴς δόξα) concerning these things—which have to be posited as one further thing, existing not in sounds or shapes of bodies but in minds [or *souls*—ἐν ψυχῇ]." Thus the view is expressed that the whole apparatus of what we might call "object-semantics," involving both linguistic signs and ordinary things (Plato's "images"), cannot suffice to determine meaning and truth, without some essential involvement of the *language users* and their *conceptions and beliefs*; and the writer goes on to assert that this determination can occur reliably only in *discussion*, with questioning and answering "free from envy"—and that, indeed, over a long time: a process which, in favorable conditions, can lead to a shining forth of the light of understanding and intelligence (φρόνησις and νοῦς). (One further point deserves to be mentioned: the writer remarks that names have no fixed connection to objects, and therefore by their use alone obscurity cannot be avoided; nor can it be so by λόγοι, since these are made up of nouns and verbs. I believe that Plato would have been unimpressed by the causal theory of reference and the postulate of rigid designators; I wish we had the Socratic dialogue on this subject.)

II

Having begun with a digression, I continue with another, shorter one: I want to cite three sayings of a man who may be regarded as an unlikely one to invoke when the subject is science and its bearing on our view of the real. I mean William Blake—who would probably not listen with any patience to what I have to say, but who nevertheless seems to me sometimes to strike just the right note. The sayings are these:

(1) If others had not been foolish, we should be so.*

(2) Reason or the ratio of all we have already known, is not the same that it shall be when we know more.†

These two statements have an obvious affinity; the second of them—I think the first also—bears on the notion of philosophy as concerned with the establishment of "conceptual necessities." The third passage concerns skepticism; it reads:

(3) If the Sun & Moon should doubt
Theyd immediately Go out.‡

There is of course more than one kind of doubt. In so far as Blake means to include the doubt practiced by Socrates in his dismissal, I do not agree.

III

Now to physics and metaphysics. Aristotle—who did not use the *noun* 'metaphysics'—offers us (at least) three *formulas*: "the science"—or *is* it a science?—"of being as such" (not

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* *The Marriage of Heaven and Hell*, plate 9, l. 19

† *There Is No Natural Religion*, [b], II

‡ *Auguries of Innocence*, ll. 109–110

perhaps very illuminating); or "of first principles and causes"; or "of the substance with the highest kind of actuality"—in which connection he also calls it "theology." But one must be careful to try to understand what Aristotle means by this. The substance in question, eternal and unchanging, unmoving, because it is entirely "actual" and in no way "potential," Aristotle associates with the heavens and their (allegedly) unchanging regular motions. It is not the substance *of* the heavens—the substance of the heavens is a kind of *body*; and although its motions are stable, they are yet *motions*. The divine substance is, rather, the constantly actual, never changing, *cause* of the regular motions of the heavenly bodies. Thus what Aristotle calls "theology" may be seen as his version—a little remote, to be sure—of what we should rather call "astrophysics." He even tells us (VI.1.1026a28–31) that, since first philosophy is to deal with the most fundamental causes, if there were no such substance, "separated" from matter, from potentiality, and *therefore* unchanging, as, he argues, there is, then natural science—physics—would be the primary and highest philosophy.

Before I put a *Q.E.D.*, claiming to have proved out of the mouth of its first author that, in view of modern ideas about the world, physics is not merely relevant to, but *is* what used to be called "metaphysics," I shall indulge in yet another pair of quotations; this time from a (fairly) modern physicist with a mind charged with Socratic skepticism and a wonderful prose style. In volume 19 of *Nature*, James Clerk Maxwell reviewed a somewhat whimsical book called *Paradoxical Philosophy*. At one point in his review, Maxwell cites the opinion on the relation of matter to thought of the biologist Karl Wilhelm von Nägeli, expressed in an article in *Nature* two volumes previously, that is related to a position discussed in the book:

> He [von Nägeli] can draw no line across the great chain of being, and say that sensation and consciousness do not extend below that line. He cannot doubt that every molecule possesses something related, though distantly, to sensation, "since each one feels the presence, the particular condition, the peculiar forces of the other, and, accordingly, has the inclination to move, and under certain circumstances really begins to move—becomes alive as it were;"[1] . . . "If, therefore, the molecules feel something which is related to sensation, then this must

[1] Of this view, that "all matter is, in some occult sense, alive" (expressed in *Paradoxical Philosophy* by one Dr. Hermann Stoffkraft), Maxwell had said just before: "This is what we may call the 'levelling up' policy."

> be pleasure if they can respond to attraction and repulsion, *i.e.* follow their inclination or disinclination; it must be displeasure if they are forced to execute some opposite movement, and it must be neither pleasure nor displeasure if they remain at rest."

And Maxwell's comment:

> Professor von Nägeli must have forgotten his dynamics, or he would have remembered that the molecules, like the planets, move along like blessed gods. They cannot be disturbed from the path of their choice by the action of any forces, for they have a constant and perpetual will to render to every force precisely that amount of deflexion which is due to it. Their condition must, therefore, be one of unmixed and unbroken pleasure.*

A similar point is made in his review (*Nature*, vol. 20) of the second volume of an important work by two good friends of his—*Elements of Natural Philosophy*, by Thomson (i.e., Lord Kelvin that was to be) and Tait. "The capacity of the student," Maxwell says, "is called upon to accept the following statement" (one that in fact was quite standard—a close paraphrase of Newton):—"Matter has an innate power of resisting external influences, so that every body, as far as it can, remains at rest or moves uniformly in a straight line." Referring to this as a "Manichaean doctrine of the innate depravity of matter," he asks:

> Is it a fact that "matter" has any power, either innate or acquired, of resisting external influences? Does not every force which acts on a body always produce exactly that change in the motion of the body by which its value, as a force, is reckoned? Is a cup of tea to be accused of having an innate power of resisting the sweetening influence of sugar, because it persistently refuses to turn sweet unless the sugar is actually put into it?†

A question that these passages point to is this: What has been meant—and what role has been played—in the succession of doctrines of physics we have had since the seventeenth

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*See *The Scientific Papers of J. C. Maxwell*, ed. W. Niven (Cambridge University Press, 1890), vol. II, p. 761.

†*Ibid.*, p. 779.

century, by notions (not necessarily technical) of "power" and of "cause"?

IV

To approach this question, let me turn first to a thinker who is one of my favorites for instructive foolishness: Descartes; but not to one of his truly spectacular pieces of foolishness, rather to a bit of not entirely implausible analysis of "conceptual necessity" that ought to help indicate the serious pitfalls of such proceedings. Descartes, of course, held—as a point of conceptual necessity—that the essential attribute of *body* is just *to be extended*. This poses rather serious problems for the understanding—the conceptual analysis—of *motion*; but Descartes did not feel the difficulty, and for the present discussion I waive the point: let us merely note that Descartes took it for granted that it makes sense to speak of "parts of the extended" as *changing their positions* relative to one another. He also took it for granted that these "parts of the extended" are *impenetrable* to one another; and so was led to the view that it is clearly and distinctly intelligible that if moving bodies meet, the motion of one or both must change. This, he claimed, is not only an intelligible mode of interaction of bodies, but is the *only* intelligible mode of their interaction; and he concluded that he had identified the "absolute" principle of "natural powers in general"—that is, had characterized, for the material realm, just what *are* the "first principles and causes."

This view of causation was shared by a large number of seventeenth-century natural philosophers—it formed an essential part of the "new," or "mechanical," philosophy. Among the proponents of this philosophy, an important group rejected Descartes's identification of matter with the extended, and rejected its corollary that the world is a plenum, holding rather with the ancient atomists that matter comes in the form of discrete and indivisible fundamental particles, separated by void space. (It is this "corpuscularian Hypothesis" that was favored by Locke—as, he tells us, "that which is thought to go farthest in an intelligible Explication of the Qualities of bodies".[2] [I WAS RATHER ASTONISHED AT A COLLOQUIUM

[2]But it is, for him, *only* a hypothesis. He adds, "and I fear the Weakness of humane Understanding is scarce able to substitute another, which will afford us a fuller and clearer discovery of the necessary Connexion, and *Coexistence*, of the Powers, which are to be discovered united in several sorts of them [i.e., *bodies*]. This at least is true, that which ever Hypothesis be clearest and truest, (*for of that it is not my business to determine*,) [etc.]" (*An Essay concerning Human Understanding*, Bk. IV, ch. III, §16; emphasis added).

talk not long ago to hear Locke's account of primary and secondary qualities called a case of "physics envy." Here is Locke on physics: "I am apt to doubt that, how far soever humane industry may advance useful and *experimental* Philosophy *in physical things*, *scientifical* will still be out of our reach"; and why?—"because we want perfect and adequate *Ideas* of those very Bodies, which are nearest to us, and most under our Command" (*Essay*, III, iii, §26). It is, in fact, the theory of the "*Ideas*" of primary and secondary qualities that determined Locke's *skepticism* of the possibility of a scientific natural philosophy. That skepticism was later ameliorated by what Locke learned from Newton—of this there is hardly a trace in the *Essay*—but that was precisely through an advance that *violated* the principle of Locke's distinction between ideas of primary and of secondary qualities.]) On the corpuscularian view—since all the "new" philosophers, Cartesian or corpuscularian, held that a body in motion will of itself continue to move uniformly in a straight line—the processes of nature are governed by the *collisions* of bodies; and thus one could say that in this philosophy "causal efficacy" consists precisely in what Locke called *impulse*; that is, *the power by which the motions of bodies are changed when they collide.*[3] It is worth noting that this theory makes acts of causation in the process of nature *discrete occurrences*; and if one describes as the "effect" of a collision the *consequent motions* of the colliding bodies (rather than their *changes* of motion), it places the effects, in time, *after* the causes. That, I believe, has continued to be the dominant view among philosophers—reinforced, for instance, both by Hume's analysis of causation and by that of Kant (in the Second Analogy).

The mechanical philosophy was a failure. The only class of natural phenomena to which

[3]With his characteristic ability to see all sides of a question—but without sorting them out clearly—Locke first describes "impulse" as "the only way which we can conceive Bodies operate in" (*Essay*, II, viii, §11); but later says, quite emphatically, that we no more understand how motion is communicated from body to body by impulse than how motion is excited in a body by a mind; of these, he says, "we are equally in the dark" (ibid., II, xxiii, §28).

it can be applied with reasonable success is that of the behavior of gases at low pressure.

V

I turn next to the Newtonian conception of the fundamental constitution of the world. That label demands two qualifications, of which I state the first here, and reserve the second for later. One of the most basic features of Newton's own account is his conception of *space* and its relation to time and to bodies. He tells us near the beginning of the *Principia* that the aim of that work is to show "how we are to collect the true motions [that is: motions *in absolute space*] from their causes, effects, and apparent differences; and *vice versa*, how from the motions, either true or apparent, we may come to the knowledge of their causes and effects." The account I shall give makes use of more modern mathematical conceptions that allow one to formulate the Newtonian physical principles without postulating absolute space. The theater of natural processes is instead taken to be a four-dimensional manifold $\mathcal{W}$, with the following properties:

[DRAW DIAGRAM]*

(1) $\mathcal{W}$ possesses what is called an *affine geometric structure*: there is an associated four-dimensional real vector-space $\mathcal{V}$ [THIS IS ITSELF A QUITE ELEMENTARY ALGEBRAIC NOTION] that acts as a "simply transitive transformation-group" on $\mathcal{W}$—this means that (a) for every point p of $\mathcal{W}$ and vector v of $\mathcal{V}$ there is a unique point q of $\mathcal{W}$ that is *the point reached from p by applying the vector v*; and (b) for every pair of points p, q, of $\mathcal{W}$ there is a unique vector v of $\mathcal{V}$ that, applied to p, reaches q.

(2) There is a distinguished linear mapping of $\mathcal{V}$ onto a one-dimensional real vector-space, the space of *durations* or *time-intervals*; thus for any pair of points p, q, of $\mathcal{W}$ one can speak of "the time-interval from p to q"—namely, the duration of the vector that goes from p to q. It follows that there is a distinguished three-dimensional subspace of $\mathcal{V}$ that comprises the vectors of *duration zero*; these, as having (one may say) a vanishing time-component, are called *spatial vectors*. The relation "the vector from p to q is spatial" is then—as is easy to check—an *equivalence-relation* on $\mathcal{W}$; its equivalence-

*[Eds. note: here the author instructed himself to draw a diagram for the audience during the talk.]

classes give us a decomposition of $\mathcal{W}$ into three-dimensional subspaces of what one will then call *simultaneous* points; and we shall also speak of each of these equivalence-classes as a *moment of time*. (It is important to notice that if p and q belong to one moment of time, and if p' and q' belong to another, the time-intervals from p to p' and from q to q' are equal; thus we may speak of the time-interval from one moment to another.)

(3) On the set of spatial vectors there is a *Euclidean metric structure*, allowing us to speak of the "length" of any spatial vector and the "angle" between any two such vectors [AGAIN IT IS EASY TO CHARACTERIZE THIS NOTION IN PURELY ALGEBRAIC TERMS]. We may therefore speak of the "spatial distance" between a pair of points p, q, of $\mathcal{W}$ *provided they are simultaneous*; but *only* under this condition.

That is the theater; the actors are *bodies*. These are conceived, first of all, as systems of "material points"; and it is postulated that each material point has associated with it a unique *line* of the manifold $\mathcal{W}$, and one that has exactly one point in common with each moment of time: that is, each material point has a "location" in $\mathcal{W}$ at—or *in*—each moment, and these locations constitute a continuous curve, the *world-line* of the material point. Further conditions upon the "realm of body (or matter)" and its relation to the theater of space-time (that is, the manifold $\mathcal{W}$) can involve one in somewhat intricate issues, and mathematical subtleties, if one wishes to accommodate all the possibilities of a theory of matter as a *continuous* medium. In any event, there must be a distinguished class of *sets of material points* that can reasonably be called *bodies*; and over this set there must be a *measure*, called by Newton the "quantity of matter," or *mass*. Newton's own view—although never asserted by him as more than "probable"—agrees here with the corpuscularians: He thinks that what I have called the "realm of body" is the disjoint union of sets of material points that may be called "corpuscles" or "particles," on each of which separately a *metric* structure is determined (so that one may speak of the "distance" between two points of any one particle)—a metric under which each particle is congruent to a set of quite simple structure in Euclidean three-dimensional space (say, to the closure of a bounded, connected, open set); and that in particular each particle is congruent, in this sense, to the set of space-time points occupied by it at any moment. What this means in simpler terms is that each particle is a *rigid unbreakable body*—an *atom*, in the classical sense of the word.

Newton further assumes that the atoms are impenetrable—that no point of space-time can be occupied by interior points of two different particles.

Given the theater and the actors, *what is the script*? Here the contribution enters of the great discovery that Newton made in the summer and fall of 1684, after Halley visited him at Cambridge and posed the question of what the path would be of a body moving under the influence of a force that varies inversely as the square of the distance from a fixed point. Newton already knew the answer; but the question set him thinking further, and what he arrived at was simultaneously what he called an "*a priori* proof of the Copernican system" (this explains his statement that the aim of his treatise was to show how to determine the true motions, etc.); an utterly unprecedented universal law of nature—that of universal gravitation; and *a new set of metaphysical principles*—of first principles and causes. These really did emerge *simultaneously*, the several constituents supporting one another like the stones of an arch; but here, more cut-and-dried-ly, is the result:—

According to Newton, of first principles and causes in nature—of what he calls "natural powers" (cf. Descartes), or "forces of nature"—there are two large classes: the *intrinsic force of bodies*, which he also calls their *force of inactivity (vis inertiæ)*, and the *active forces*. Each force—active or inert (Newton also says "passive")—is characterized by a *law of nature* of a suitable form. The law that characterizes an active power has to specify, for any given *pair* of bodies in any given situation, a pair of vectors called the *motive forces impressed*, in that situation, by each body upon the other (the "active" laws are, thus, laws of *interaction*). The law that characterizes the *vis inertiæ* is the *conjunction* of Newton's three Laws of Motion: it says in effect (since the first Law of Motion is superfluous) that (a) the rate of change of the quantity of motion of a body at any given moment is proportional—equal, if units are properly chosen—to the net, the vector sum, of all the motive forces impressed upon it at that moment; and (b) the motive forces impressed upon each other by any pair of bodies at any moment are equal and opposite (one may want to add: and directed along the line joining the two bodies).[4]

[4]Note that clause (b)—the third Law of Motion—is in effect a *condition* placed upon the form of the laws of the *active* forces.

[The following paragraph was added by Stein in 2020.] In this summary of Newton's view of the structure of nature—and the conceptual framework for its investigation—I follow his late account near the end of the final "Query"—number 31—at the close of Book III of his *Opticks* (reprinted by Dover Publications, 1952; see pp. 397 and 400–402). This—first published in 1717—refines significantly upon the formulation in the *Principia* (*e.g.*, by taking the three Laws of Motion *together* to characterize the "passive" force, the "intrinsic

That laws of interaction of this type fit within the architecture of the "theater" I have described can be seen as follows. In the first place, the laws of active force must express the impressed motive forces at any moment as functions of the situation of the bodies at that moment. To describe this situation, *we have available all the normal resources of geometry*: for all the relations of Euclidean geometry are defined for simultaneous space-time points.[5] The vectors that represent the motive forces are *spatial* ones, "directed along the line joining the two bodies" at the given time—a well-defined notion. The most pressing question that arises is how to understand the phrase "rate of change of the quantity of motion." The quantity of motion—momentum, as we now say—of a body is defined by Newton (and in ordinary textbooks) as the product of the mass of the body and its velocity. But in space-time as I have presented it, there is no concept of (absolute) velocity: since there is no defined "spatial distance" between two points at *different* moments, one cannot speak of the distance a body has traversed over an interval of time. This circumstance is the fundamental reason why Newton felt himself *compelled* to base his discussion on a notion of space as *persisting through time* (with a structure independent of the bodies that are located in it). The structure of $\mathcal{W}$, however, allows us to associate with each material point at each moment a vector of the *four-dimensional* vector-space $\mathcal{V}$—provided the world-line of that point is "smooth" at that moment: namely, the *unit tangent-vector* to that world-line—i.e., the tangent-vector, "pointing forwards" in time, of unit duration.[6] Such vectors do not represent velocities; but the *difference* of two such vectors precisely corresponds to what, in the "absolute" theory, would be the *difference* of two velocities; and this whether the two vectors represent the states of motion of one particle at different moments, or of two particles (at the same or different moments). Therefore one has the result, at first appearance paradoxical (although—as I have explained on two occasions rather long ago[*]—Christiaan

force of matter"). It seems to me Newton's own clearest statement of the principles underlying the *Principia* itself.

[5]I have used the somewhat imprecise word "situation"; one might, however, need to take into account the *relative velocities* of the bodies at a moment. This can be done, in light of the circumstance about to be explained.

[6]I here take it for granted that the tangent-vector is not *spatial*—which would correspond to an infinite velocity at the moment in question.

[*]"Newtonian Space-Time", in R. Pelter (ed.), *The Annus Mirabilis of Sir Isaac Newton, 1666–1966* (MIT Press, 1970), p. 267; "Some Philosophical Prehistory of General Relativity", in *Foundations of Space-Time Theories* (Minnesota Studies in the Philosophy of Science, vol.VIII), J. Earman, C. Glymour and J. Stachel (eds.), pp. 9–10.

Huygens seems most remarkably to have anticipated it), that it is possible in the indicated structure—and thus, according to the theory it belongs to, *in the world*—to define "velocity difference," despite the absence of any conception of "velocity." Analogously, we are able to define the rate of change of the quantity of motion: in place of the quantity-of-motion vector of Newton, which should be *space-like*, we have the "time-like" quantity of motion, the product of a body's mass by the unit tangent-vector to its world-line. (I here treat the body—that is, the *particle*—as if it were itself a single *material point*. This can be avoided; but the complications involved are a bit too much to consider for present purposes.)

There is another way to look at the Newtonian active natural powers—one that in fact played a critical role in his own discovery of the power of gravitation. Although it has not been stipulated in the rather general characterization I have given, it is rather natural to suppose that a *law of interaction* of *pairs* of particles should make the forces any two given particles impress on one another depend, not on the "situation," as I have called it, of *all* particles at a given moment, but just on the geometrical relationship of the two particles concerned. Then when we consider either of the two—let us call it A—as the exerciser of action upon the other, we may ask, of *any* second particle B subject to the natural power in question, what force would be exerted upon it by A at *any given place* (relative to A). Newton indicates—although in a fashion somewhat special to the case of gravitation with which he is dealing—that when A is regarded in this way as a "source" of the exercise of a given force of nature, one should think of the law of that force as specifying "as it were a certain efficacy diffused from the center to all places round about, to move the bodies that are in them"; in other words, the law associated with a force of nature specifies, for each body A that exercises that force, what we now call a *field of force* surrounding A. The principle of interaction implies, of course, that the bodies capable of *exerting* a given force must be precisely those that are *subject* to it; Newton emphasizes indeed that the interaction should be thought of as *one single* process; and it effectively follows that there must be a parameter that simultaneously measures the strength of A as an exerter of this force and its susceptibility to the impression of this force by any other body B. We have, therefore, what may be called a *metaphysics of stable*—or *static*—*fields of force*, *rigidly associated with particles*.[7] One point should perhaps be made in passing: namely, that on Newton's

[7]"Rigidly" because the law of "diffusion" to the places round about can depend on nothing but the distance of the place from the center A.

conception of rigid atoms, there must be a law of a rather different kind that governs what happens in a collision of such atoms—precisely the kind of event that on the corpuscularian theory was seen as *the* mode of fundamental interaction. On Newton's view, such collisions of atoms are extremely rare. The law governing them can be thought of as the characterization of one particular natural power, *impenetrability*; and Newton's own opinion, late in his life, was that the law in question should be that of *inelastic impact*: from a collision of atoms there is no rebound: "Impenetrability," he says, "only makes [bodies] stop" (*Opticks*, Bk. III, Query 31; p. 398).

VI

Now let us reflect upon the implications of this world-picture for our conception of causality. I think the usual view—the naive view—is that, in Newtonian physics, *causes* are just what Aristotle called *efficient* causes—causes or sources of motion; and that such, in Newtonian physics, are the *motive forces*. And, to be sure, it is *interactions involving motive force* that have replaced, in this physics, the *impacts* that were the causes in the corpuscularian view. But there are remarkable differences. For one thing, impressed motive forces do not *precede* the changes of motion associated with them. This, to be sure, is in accord with the doctrine of Aristotle, for whom the effect of an efficient cause is *simultaneous* with the action of the cause; but it is in sharp contrast with the standard Humean analysis of the relation of cause and effect. Furthermore, the force exerted by body A on body B is certainly not a distinguishable thing—event, action, what have you—identifiable in the world *as* a cause. According to the Newtonian law of gravitation, my weight towards the earth is, fundamentally, not a single force exerted upon me by the earth; it is the resultant of the attractions exerted upon me[8] by all the particles of which the earth is composed, taken severally—in very different directions and of very different magnitudes. But these elementary components are in no way discernible—it is only through the theory that the assertion of their presence and, in *some* sense, causality, finds any grounds at all.

I do not mean to argue, then, that the view that motive forces can be seen as efficient causes is indefensible; only that it is not the *primary* notion of cause in the Newtonian scheme. There is another view, quite fashionable toward the end of the last and early in

[8] More accurately, upon each particle of my body.

the present century, that considers modern physics to have been *purged* of *any* notion of cause at all; holding that this physics asserts only what were sometimes called “functional connections.” Well, the *name* by itself doesn’t matter; but what of the *logos*. In the reasoning by which Newton arrived at the law of gravitation, an essential step was his claim, *on the basis of evidence*, that the force that regulates the motion of the moon in its orbit is *the very same force* as that which we call “weight.” He did not of course mean that the impressed motive force on the moon is the same as that which causes a dropped object to fall; he meant that the *causes of* those two impressed forces—the natural power governing both processes—is the same. And what does that mean? The criterion is: that *the same law* is involved. But now this is *not* merely a question of the assignment of a name: for Newton’s evidence showed, under his analysis, that the two processes are analogous in *certain* respects—that, to state the case a little schematically, the laws are *in part* “the same”; he thought the partial agreement was enough to warrant the inference that the two laws were *in all ways* “the same”; and this led to a quite novel conclusion: that the weight towards the earth of a terrestrial body would *diminish* if the body were lifted above the earth’s surface, and indeed would vary inversely as the square of the distance of the body from the earth’s center. For that there was *no evidence* before Newton’s argument; and Newton, as I have said, inferred it from his conclusion that the two forces—the two natural powers—are one and the same.

Another crucial step—the most momentous of all—in Newton’s path to the law of universal gravitation was his decision to treat the forces on, e.g., the moon and terrestrial bodies, towards the earth; the planets, towards the sun; the satellites of Jupiter and Saturn, towards those planets; in each case as one side of an *interaction* with, in each case, *the central body concerned*; to treat the earth, for instance, as “attracted by” the sun, not “pushed towards” the sun by some hypothetical medium. This was in fact a very risky step; Newton had at the outset *no* evidence to support it. But his argument led with amazing swiftness to the conclusion that—*if* his supposition were true—there must be a *universal force of attraction* between *any two particles of matter whatever*; and (with the help of the detailed analysis of phenomena that had preceded) that this force must be proportional to the masses of the particles and inversely proportional to the square of the distance between them. In other words, it led to a full statement of the law governing an “active force of nature”—the first of its kind (that is, the first fundamental, universal “active force”) ever discovered; and still, let me remind you, one among what physicists today refer to as the four—perhaps one can say three, or even (if a so-called Grand Unifying Theory is true) two—"fundamental forces." It was, in turn, the successful application of this law to the principal phenomena of the solar system, showing that the gravitational interactions alone of the major bodies suffice to account for all their observed—"apparent"—motions, that allowed Newton to give what he called an "a priori proof of the Copernican system": *because* (to a very close approximation) *only interactions with one another* are involved, the common center of mass of all the bodies of the solar system must be (to a very close approximation) without acceleration; and the sun is always close to that center of mass.

So I have been arguing that it is the notion of a natural power as characterized by a law of nature that is Newton's truly most fundamental notion of a "cause"; not just by verbal formula, but by its role in substantive and very powerful reasoning. Now I want to report to you two encounters I have had with a philosopher of science of some repute over this notion. In the more recent exchange, he objected that this idea of a law of nature is simply too obscure to be of any value. To say that to Newton strikes me as a bit like telling a musician that the idea of a tune is obscure. In the earlier encounter, I had referred to Newton's application of the third law of motion to the earth and sun, and had said that the test—the "proof," in Newton's language—of the correctness of that application was just the confirmation of all the empirical consequences of so applying it. The philosopher I am speaking of objected that that is just no good: the third law applies to bodies A and B when the force on *B really is exerted by A*; so the question has to be, not whether the consequences tally with observations, but "whether it really is the sun that's *doing* it to the earth." I was, frankly, dumfounded—speechless! How does he think that's to be determined? What does he think it *means*? I believe—subject to a qualification to follow later—that Newton's law of gravitation is true. I therefore believe that when I now wave my hand, the weights of all of you in this room change slightly—and the motion of Jupiter in its orbit is affected. But is my testimony of any value, if I tell you that "I am doing" that? I have to confess that I have no distinct consciousness whatever, either of an effort to achieve those effects, or of the success of any such effort. But on the other hand, does that mean I am *not* "doing it"? The claim I am really making is that in Newton's scheme of the world, it is not the prior identification of the sun as "doing it" that warrants the application of the third law—because no such warrant is *imaginable*; rather, it is the successful application of the third law—or, more fully, the subjection of the process, as one of a very large *class* of processes, to a *general law of* *interaction*—that allows us to say "who or what is doing it." As to the ease, and the lack of special consciousness, with which I, with such virtuosity, modify the paths of the planets—it is just a special case of Maxwell's remark: that the molecules *and* the planets simply move "like blessed gods."

Another way of putting my central point about this matter is that the Newtonian forces of nature—*and* their successors, the "fundamental forces" of contemporary physics—are in effect most analogous to Aristotelian *formal* causes; and that the account of the world in modern physics, at least in the early modern physics of Newton, is rather like a highly sophisticated version of Aristotle's "theology," applied—and with amazing success—not just to the heavens, but everywhere. How can such causes be "efficacious"? Well, I do not know—nor, I suppose, do you—how the universe is what it is. I don't even know (a point Newton makes, in a most interesting place*) how I lift my arm (and thereby influence the planets). But I asked: Given the theater and the actors, what is the script?—and in the Newtonian universe, the forces of nature—the laws of nature—*are* the script. One can hardly say more than that the "efficacity" of the script consists in its being followed; I not only don't know what "makes" it be so, I don't have any idea what an answer to that question might possibly look like. I hope you won't think it a little spooky if I say that this doesn't seem so very different from the peculiar puzzle about how Aristotle's first, unmoved, mover can "work": how an eternal motion can occur "because" the heavenly bodies "imitate"—as an end—the activity of "thought thinking itself." The difference lies not in our understanding how such causes work; it lies in the informativeness—and truth—of the statement *that* they work.

VII

I said that a second qualification was needed of my characterization of what I have been discussing as the "Newtonian conception of the fundamental constitution of the world"—the first having been just the modernization of the space-time theory. You all know, of course,

*See *De gravitatione et æquidpondio fluidorum*, in A. R. Hall and M. B. Hall, eds., *Unpublished Scientific Papers of Isaac Newton* (Cambridge University Press, 1962), p. 104, numbered ¶ (4) (the original Latin) and pp. 140–41 numbered ¶ 4. (*sic*—no parentheses but a period) (English translation). [Eds. note: Stein himself produced a translation of several important passages from *De Grav* correcting errors in the Hall & Hall translation, with interpolated commentary. Available at http://strangebeautiful.com/other-texts/newton-de-grav-stein-trans.pdf.]

that the Newtonian picture is now—in fact, in several ways—outmoded. But there is good reason to think that Newton, if he were still with us—and despite his reputation for extreme jealousy (I mean this in its old sense—passionate possessiveness) of his intellectual property—would regard this situation with equanimity, indeed with great satisfaction. For whereas Newton was very strong in his assertion of the solid standing of his scientific theories—his theory of light and colors; his theory of universal gravitation—what he says about the *general* scheme of the laws of the natural powers is that it is a *program* rather than a doctrine: he says, in the preface to the Principia, after describing his vision of philosophical investigation: "But I hope the principles here laid down will afford some light, either to that, or some truer, method of Philosophy."

The first step in what was to be a real break with the Newtonian framework was taken between 1855 and 1864 by James Clerk Maxwell, in developing the fundamental theory of what we now regard as the *second* of the fundamental forces, that of electromagnetism.[9] Maxwell himself had no thought of departing from the Newtonian framework, except in so far as he tried to develop—and succeeded in developing—a theory of electromagnetic interactions as "nearby" interactions, rather than "actions at a distance." It was one of the merits—an aspect of the versatility—of the Newtonian framework that it was perfectly capable of accommodating such interactions: the prototype or paradigm was the theory of *continuous material media*—solid (theory of elasticity) or fluid (Newton's own theory of hydrodynamics and aerodynamics in general—of sound waves in particular). And it is a striking example of a kind of dialectical interplay of ideas that one of the ways in which the theory of elasticity was developed—especially at the hands of French theorists of the early nineteenth century—was with the help of models of such media as systems of *discrete particles*—interacting by *short-range* forces; i.e., at a distance, but only a very near (microscopic) distance. Such a medium, whether fundamentally continuous or molecular in structure, was, according to Maxwell's hypothesis, responsible for electromagnetic phenomena.

But Maxwell had no decisive account of the detailed structure of the medium he postulated. Instead, he was led to take the electric and magnetic fields *themselves* as the "objects" of his theory. What does this mean? Whereas what I have described as fields in connection

[9]Of course one had, by the end of the eighteenth century, Coulomb's laws for electrostatic and magnetostatic interactions; but the discovery of electromagnetism showed that these could not be regarded as the fundamental and *general* laws of the subject.

with Newton are representations of the actions exerted by bodies on other bodies, so that the *laws* of those fields are to be understood fundamentally as laws of the interaction of bodies, and the fields are (as I have said) *rigidly* associated with the bodies "whose fields they are," Maxwell's hypothesis was that the electric and magnetic fields are *not* rigidly associated with the bodies that exercise and undergo electric and magnetic forces; rather, the fields are functions of the fundamental state of an underlying medium—the field-vectors at any point functions of the state of the medium *at that point*, not of the arrangements of particles anywhere else. But all Maxwell knew about the supposed medium was what he knew about the fields themselves. What he succeeded in doing was finding laws (I don't know about his musical prowess—Newton evidently had none at all; but in physics, both of them were very good at finding the tune) that relate the *distributions of the fields in the immediate vicinity of any given point*[10] to the *rates of change* of the fields at that point (and also to the local densities of charge and current). Furthermore, on the mere supposition that there *was* an underlying "mechanical" system (in the sense, of course, of Newtonian mechanics—not of the mechanical philosophy), of which the field magnitudes expressed something about the mechanical states, with the help of known relations of the field magnitudes to *energy*, Maxwell in part, and his successors with full success, were able to show that Maxwell's laws of the field could be *subsumed under*, not (directly) Newton's original mechanical principles (the three laws of motion), but mathematical transformations or generalizations of those that had long since been derived (essentially by Lagrange in the late eighteenth century) as aids for the treatment of mechanical problems. In other words, Maxwell (to oversimplify here) succeeded in producing what he himself called "a dynamical theory of the electromagnetic field"—a theory in which the electromagnetic field itself was treated as a dynamical system—without describing the presumed underlying *material* dynamical system.[11]

By the early years of this century, it had become apparent that there could not be an underlying Newtonian mechanical system that supports the electromagnetic field. And this was a metaphysical revolution; it changed our conception of the actors in the theater—and

[10] More exactly, their spatial directional derivatives.

[11] Of the Lagrangian generalized formulation of classical mechanics, Whitehead remarked: "The beauty and almost divine simplicity of these equations is such that these formulae are worthy to rank with those mysterious symbols which in ancient times were held directly to indicate the Supreme Reason at the base of all things." (*Science and the Modern World*, pp. 62–63.)

thus, necessarily, our conception of the form of the script as well. In fact the revolution was accompanied by a change in our conception of the theater: namely, by the advent of the special theory of relativity. But before I talk of this—that is, of Einstein-Minkowski space-time—let me make a few remarks about what I have called the change in our conception of the actors (dare I say, of what is "real"? Yes, I dare!—following the example of Einstein, who called this change "Clerk Maxwell's contribution to the concept of physical reality").

VIII

There is a very strong tradition (which continues as a very strong tendency in contemporary philosophical thought)—a tradition that derives from ancient atomism and materialism—that takes something like "ordinary matter" to be the basic "real" constituents of the world. What one means by this is less clear than is often supposed; but in the semi-sophisticated context of popularized modern physics, this leads to the view that the real constituents are particles; that fields are fictitious entities, merely representing in convenient form the interactions of the particles. That is a view that may actually have some merit—physicists themselves do take it seriously, as one possible way to deal with some of the conceptual difficulties that exist in current theory; although a quite contrary view—that *only* fields are truly basic—is a very live competitor. At any rate, the view in question is completely untenable as a reading of the theory I am speaking of: the theory that emerged from Maxwell's around the turn of the century. Here, according to that theory, is what is occurring in the theater of the world: The material points are as before; and between them there are (in Maxwell's theory, *before* relativity) some forces of interaction—gravitation, at any rate—that have the Newtonian character: they depend upon the instantaneous relations of the particles. But besides the particles, there is *throughout "space" at each moment* the electromagnetic field, with its values at each point; and the "elements" of this field—a perhaps misleading term, since the field is distributed *continuously*—interact, *only where they are in contact*, both with one another, and with the particles. The consequence is that the space between the particles is full of an extraordinarily richly structured and eventful tissue of occurrences—in fact, the *electromagnetic waves*. But perhaps my description may seem hyperbolic; I suppose we all carry around—not, to be sure, at the forefront of consciousness!—an elementary picture of plane wave-fronts of sinusoidal vibrations marching staidly forward; and this doesn't look so spectacularly rich. What, however, must we really take to be going on, in the electromagnetic field, for instance at a point in this room? Well, for one thing, according to Maxwell's own great discovery, we have what Aristotle called "the actuality of the transparent *qua* transparent": we have something that makes it possible for us all to see things—to see *each other*—through the air. At any given point of the room, the electric and magnetic field vectors are executing extremely complicated—I will not say *vibrations*, but *dances*. And these are so coordinated from point to point that the eyes and neural apparatus of *each* of us, affected on the retina by the dance being executed *right there* and, so to speak, analyzing those local dances, receive information about *whatever* ordinary objects our eyes are turned towards. That such a process—of the *simultaneous propagation*, through *every point* in *every direction*, of information as complex as that we receive by sight—deserves to be called extraordinarily richly structured and eventful, will I hope be granted.

(In fact there is more. There is something all around us in this room that *would not have been* in a room, say, with Maxwell, when he was developing his theory. For the *very same* dance of electric and magnetic vectors that carries the information of sight to our eyes carries, at the same time and in the same place, whatever we can hear with the help of a radio that we bring into the room—on any AM or FM station—for instance, possibly, a fantasia of Orlando Gibbons, Berg's *Lulu*, an account of the latest disasters in [*deleted*: Bosnia and Israel/Palestine] the world—I emphasize again: *all* these things. Moreover "we"—I speak impersonally: it isn't actually true of me—know how to build a device, the radio I have referred to, that is able to respond selectively to one coherently chosen strain in what *prima facie* would seem a pandemonium: so that we can hear the Gibbons fantasia and be entirely oblivious of the rock and rap and talk that are being executed simultaneously in the dance.)

[I have a qualm: that I may seem in this to have been peddling popular science under the guise of philosophy. But I think that a philosopher who claims to discuss the nature of reality ought to have some appreciation of what is real *and detectable* all around us—our knowledge of which (and in part its very *existence*) is owed to a natural philosophy of the kind Locke thought in principle impossible.]

Besides this change in the dramatis personæ, the transformed Maxwell theory entails a drastic revision of our *understanding* of some of the fundamental concepts of classical, Newtonian physics. For not only do we now have a system, the electromagnetic field, that is not describable in terms of the motions of material points but still *is* subject to the "abstract" laws of Lagrangian dynamics, one is also led to ascribe to this system what may be called the "concrete" *mechanical properties* of momentum, angular momentum, and energy, distributed continuously through space with densities that are determined by the field magnitudes. Thus, for instance, the fundamental principle of the conservation of what Newton called the quantity of motion is no longer a consequence of the third law of motion (since this is not applicable to interactions of charge and field, or of the field with itself), and no longer concerns the quantity of motion as Newton defined it (product of mass by velocity); instead it concerns a quantity of which Newton's definition characterizes one subspecies, but of which another subspecies is a certain function of the electric and magnetic field-intensity vectors.

I have here emphasized that this is a revision of our *understanding* of these concepts. On the one hand, I do not think that there is any profit in asking such a question as whether Newton's use *singled out a certain "natural kind"* as the "reference" of his term "quantity of motion," and, if so, *whether that natural kind includes* the electromagnetic momentum. On the other hand, I would repudiate in the strongest terms the suggestion that we are here dealing with a mere "convention," or even an *evasion* performed in order to hide the fact that "the laws of physics *lie*." I think Plato was quite right: it's not the nouns and verbs alone that do the job; we have to know how to *think* with and about them. There is here a real conceptual change; but one *sees*—shall I say, *grasps by* νοῦς—that the revised conservation law is as it were the legitimate successor to the original.

IX

It is worth turning back for a moment to the question of the notion of causation in the Newtonian framework; for I have not yet mentioned one important aspect of that. I have emphasized that fundamental interaction is *simultaneous* in that setting, not "an antecedent determining a consequent"; it should be noted, too, that such interaction is *continual*, and is conceived generally speaking as of unrestricted spatial scope. Nevertheless, there is an important way in which one can introduce a notion of something like "lines of causal influence" in a Newtonian system: namely, one can consider an entire process within this framework, and then ask *if a certain change* were introduced—conceptually, as a thought-experiment—

at a certain moment, how would the *new* entire process differ from the old? (It is after all in this sense that I could say earlier that my wave of the arm "influenced" the motions of the planets: had I *not* waved my arm, the motions—according to the theory—would have been very slightly different.) When this kind of consideration is applied to the processes in an elastic medium, one is led to the notion of "propagation of effects" in such a medium "with finite speed"—e.g., to the notion of sound waves (in ordinary media) or light waves (in the hypothetical "luminiferous ether"—or the "electromagnetic ether" of Maxwell).

This propagation with finite velocity, in the context of an underlying Newtonian dynamical system, is not a "fundamental" process, but an *artifact* of *instantaneous* interaction within systems of a particular sort. But when the material support of Maxwell's field has been abandoned, while the architecture of the Newtonian "theater" remains, one has to conceive of *two quite different modes* of *fundamental* interaction: the instantaneous interactions between particles, and the propagation of field effects with finite velocity. But velocity *relative to what*? Our version of the Newtonian theater has no such concept as velocity!

The issue implied by that question was wrestled with during the closing years of the preceding century.* A strong—but curiously ambivalent—voice in the discussion of the problem was that of Henri Poincaré, who insisted on the one hand (to very constructive effect) that makeshift solutions to the issue would not do, that a rigorous theory was required; and insisted *at the same time* that the issues of space and time involved in the question "relative to what?" are matters of *pure convention*, not at all of the "real" structure of the world. The resolution we owe, of course, to Einstein, who changed our conception of the theater. So we come to a third picture: [DRAW DIAGRAM] Point (1) of our previous version remains: there is still an affine structure on space-time, which essentially determines—as it did in the Newtonian version—a distinction between "uniform" and "non-uniform" motion (straight *vs.* curved world-lines); but in the place of (2) and (3)—the time-interval function, and the spatial distance at a moment—we have, as Minkowski taught us to recognize, a new kind of "quasi-metric" on the four-dimensional vector-space $\mathcal{V}$, which separates space-time directions into those that are "time-like," those that are "space-like," and—the boundary between those—directions *"along the light-cone,"* which are the loci of the propagation of influence in the electromagnetic field. (Time-like vectors have, then, "time-like length"; space-like vectors have "space-like length"; and vectors along the light cone have "zero length"—hence

* *I.e.*, preceding the 20th Century.

are called "null vectors.") In this theater, material points are represented as before, by world-lines *whose tangent-vectors are everywhere time-like*—which now, however, means: everywhere directed *into the forward lobe of the light-cone*; so that their possible velocity-differences have a *finite upper bound*, the velocity of light.

A point of central importance about this changed architecture is that particle interactions of the Newtonian type are not even *conceivable* in the new framework: there is simply *no such thing* as a "moment," and therefore no such thing as an "instantaneous situation" or "configuration" of particles; nothing in the space-time geometry that can allow one to *describe* an "instantaneous direct interaction" between particles, satisfying Newton's third Law of Motion. The state of affairs is perfectly adapted to the already existing theory of electromagnetic interaction—which, of course, is the theory that led to this transformation of the space-time framework to begin with. There, the field laws of Maxwell, in the form into which they were put by H. A. Lorentz, already determine internal interaction within the field at each point in such a way that effects are propagated—strictly speaking, *everywhere—along the light-cone*; and it turned out that the law stated by Lorentz for the force exerted by the field upon a charged particle has a unique "natural" expression within the new framework (this was first pointed out by Planck). In this formulation, the analogue of the Newtonian "motive force" is a space-time vector *perpendicular*, in the sense of Minkowski's geometry, to the world-line of the particle: it represents the time rate of change, with respect to what is called the *proper time* of the particle, of the unit tangent-vector to that particle's world-line. Influence is still propagated in two ways: namely, through the field, along the light-cones; and by the motion of the particles, within the light-cones; but *neither* involves direct interaction of particles; and, in this theory, for *both*, the velocity of light is an upper limit to the speed of transmission.

X

The theory we are now considering has remarkable consequences in point of explaining, and correcting, some of what philosophers often rather glibly speak of as "our intuitions," and the "conceptual necessities" that are sometimes based on them.

For example, returning to our case of merely mild foolishness by Descartes, one conclusion he drew from his analysis of natural power was that the action of a body on the plenary medium surrounding it has to be propagated instantaneously; if I push one end of a stick, he says, it is clearly and distinctly evident that the other end must move at the very same time. Now this is actually correct for such a medium as Descartes envisaged: influence in an incompressible medium is indeed propagated instantaneously, for just the reason Descartes gives (that unless all parts of an extended region of the medium move simultaneously, no part will have a place it can move into).[12] Such a medium, and the associated process of instantaneous propagation, is, if not as Descartes thought *necessary*, at any rate *conceivable*. But one has to be careful about these modal words: such a process, *and therefore such a medium*, is *not* possible—is not *conceivable*—within the space-time framework of special relativity.

Let us consider this problem in a wider perspective: let us first imagine pushing a stick in the Newtonian theater. Here the possibilities stand open. It is possible to consider the stick as *rigid*—as Newton supposed his fundamental particles to be. In that case, the *length* of the stick is an intrinsic and unalterable property; from which it follows that if one end moves, all the rest of the stick (with the possible exception of one line of points that might serve as an axis of rotation) must move at the very same time. On the other hand, it was known—on subtle but good evidence—to such far-sighted seventeenth-century investigators as Huygens and Newton, that "ordinary" bodies simply are *not* rigid, but *elastic*. One may conceive of an elastic solid body as comprising a system of Newtonian particles, in a configuration of *stable equilibrium* under the forces they exert upon one another: that is, in such a configuration that (a) the net motive force upon each particle is zero, and (b) any slight change of the relative distances within the system will give rise to forces—and for elasticity that approximates rigidity, one should say: very strong forces—that act in such directions as tend to restore the relative distances to their previous values. In any system of this kind, a small local change from the equilibrium configuration will give rise to a change propagated with finite velocity: the velocity of elastic waves—*alias* sound waves—in that system. If I push against one end of a stick, supposing it to be a system of this kind, what happens is that an *elastic ripple* travels through it, at the rate of transmission of sound in the material it is made of; and no part of the stick begins to move, or is affected in any way

[12] To be quite accurate: a finite velocity of propagation of effects is possible in a medium of fixed density; but only if the medium has elastic resistance to shear (or torsion)—not in such a medium as was envisaged by Descartes, where the only mode of communication of motion is by pressure.

by the initiating push, until that ripple reaches it.

A second aspect of this kind of interaction—the very paradigm of our "experience of efficient causation," of "what is really doing it," in the bodily realm—also arises already in the Newtonian context. I have mentioned that Newton considered collisions of ultimate particles to be extremely rare. But then, *what does happen* when I press my hand against a stick and push? Another opinion of Newton's—for which, again, he had subtle but good evidence—was that ordinary "hard" bodies do *not* generally come into actual contact with one another (that is, their respective particles do not do so); that they are, rather, kept from actual contact by extremely powerful repelling forces. So, again, *what happens when I push the stick*, like the process within the stick to which that initial push gives rise, is conceived to be something quite different from what it seems: the complex effect of the behavior of a large number of particles, none in contact, governed by Newtonian laws of interaction. And what I *feel* when my hand presses the stick is the effect of *motions communicated to particles within my hand by the same process*, and transmitted through the nerves to the brain: it is this communication of motion through repelling forces that constitutes the *very nature* of what we call the "contact" that we perceive.

But now, when we view the same physical process from the perspective of the special theory of relativity, we are led to the view that this communication of influence, at the very most fundamental level, is never between particles directly at all—whether particles in contact, or particles interacting at a distance; that, indeed, all "efficacy" of bodies upon one another—including, to repeat, their "efficacy" upon our organs of perception—is *mediated by fields* (having their own independent existence—as it were, as "substantial" beings, without corporeal "support"), and, at the fundamental level, propagated with the speed of light. We have arrived at the veritable Hegelian antithesis of Locke's view that *impulse*—that is, *impact*—is the *only way bodies act* because the only way we can *conceive* bodies to act; but the *confirmation* of his *other* view, that how bodies act on one another—*even* if it is in some sense "by impulse"—is something of which we are no more endowed with a clear "fundamental" grasp than how bodies interact with minds.

XI

"And now my story's begun!"—*certainly* not *done*; but I have to bring it to a stop. One more thing I cannot refrain from mentioning. It might be asked: Given that both my moving of bodies and my perceiving them (allegedly) "has to be" mediated by *fields*, do we have any idea by *what* fields this is accomplished? The answer is that we do—but only thanks to yet another transformation of the most fundamental concepts of "first philosophy"—the most drastic to date. Within the framework of classical physics, and of the "revolutionized" physics of the early twentieth century (the special and general theories of relativity), the question, which Newton had envisaged as crucial to natural philosophy, *What are the forces that produce the cohesion of bodies, and the phenomena of chemical interaction?*, had remained not only unanswered, but without a *clue* to an answer: no "forces of nature," no laws of force, had ever been found that *could* have such effects. But the development of quantum mechanics completely changed that situation, and we can claim today to *know* that the phenomena in question—and thus all the properties of the "matter" with which we are familiar—result from *just the electromagnetic interaction*; indeed, to a preponderant degree, from mere *electrostatic* forces. So once again, a most crucial role is played, in our understanding as well as in our control of the world, by *the form of the script*: our most elementary experiences of causal efficacy require for their explanation that strangest of Platonic forms to emerge in the development of physics, the conceptual framework of quantum mechanics—and this form has made it possible for the mere electrostatic law of Coulomb, which in the context of classical physics is incapable of producing *any stable equilibrium*, to account both for the stability and the change characteristic of physico-chemical structures and systems.

But the story, as I have said, is not done; nor would it be if I were able to bring it entirely up to date. We are advised from time to time that physics is about to come to an end; and I should not wish to declare positively that such a thing will never happen. The *impossibility* of secure and final knowledge is not something that a mitigated unremitting skeptic such as I should take as certain (as J. B. Cabell wrote—I presume following Arcesilaus—"to hold that we know nothing assuredly, and never can know anything assuredly, is to take too much on faith"[*]. But we have not reached that final point, and there is reason to believe that we may be in, still, for changes *in our most fundamental notions* that equal or exceed in magnitude those I have described here. Moreover, in any case, there is *no* reason to believe that the importance of continued reflection *on the position attained in knowledge* will itself terminate. I began with comments on a series of quotations; let me end with a comment

[*]James Branch Cabell, *Jurgen, A Comedy of Justice* (reprinted Dover Puiblications, 1977), p. 148

on two more. Aristotle tells us (Posterior Analytics I 9) that *it is hard to know whether one knows*, and (Metaphysics I 2, 982^b12, 983^a12-21) that *philosophy begins in wonder, but ends in the contrary state.* Plato never wrote the hinted-at sequel to the *Theaetetus*, *Sophist*, and *Statesman*, to have been called the *Philosopher.* I have long cherished the fantasy, anachronistic though it be, that in that work Socrates, questioning Aristotle, would have led him to admit that it is impossible to know whether one knows, and that if wisdom is the contrary state to wonder, then philosophy never ends.