Newton: Philosophy of Inquiry and Metaphysics of Nature

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In a talk at a conference some fifteen years ago, I argued (among other things) that certain rather prominent attacks on Newton's intellectual integrity were unjustified. My commentator treated the talk rather harshly, and at one point asked with a trace of scorn why I should be so concerned to defend someone like Newton: "Newton," he said, looking right at me (this actually did happen!), "*was not a nice guy*." I was taken aback at the time; but I now think that there is after all matter worth pondering in that challenge. I have never thought of Newton as a man who would have made a pleasant acquaintance; but I have come to realize that I *do* feel a kind of emotional tie to him, and for an interesting reason: namely, I feel genuine gratitude to Newton for what I have *learned* from him. In effect, he has been one of my teachers; and among the *best* of my teachers. I want to try, today, to indicate something of this.

When I was a quite young student, with a strong interest in physics as well as philosophy, a question (not, to be sure, the only one!) that I found very puzzling was, How do "we" "know"[1]—or, more modestly, what genuine *evidence* do we have—that the law of gravitation is true: that *every particle in the universe attracts every other particle* (and does so according to a known and simple quantitative law)? Attempts to obtain anything like a satisfactory answer from my teachers proved fruitless. The question formulated itself in my mind more sharply: *today* one can, waving one's hands, refer to the vast body of astronomical theory that is based on that law, and of evidence supporting that astronomy;

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[1] Quotes on both words, importing (a) a question as to how wide the community *is* that can lay valid claim to such "knowledge"; and, of course, (b) that the sense in which such a thing can be "known" is very much open to discussion.

but the law was—as one says—"discovered" by Newton: what evidence did *he* have?

It occurred to me—in this I was aided by some fortunate circumstances of my educational environment—that one might learn something about the matter by actually reading Newton; and I was pretty well astonished by what I *did* learn in that way. The *empirical* evidence available to Newton all concerned what one can reasonably describe as, first, "ordinary" behavior of "ordinary" terrestrial bodies (which of course contains no sign whatever of any such universal mutual attraction), and second, crucially, the changes of position—against the uniformly rotating dome of the "fixed stars" as background—of eleven bright objects in the sky,[2] and the changes in visible shape and/or luminousness ("phases" and/or "eclipses") of a few of these.[3] To say that these are, *prima facie*, scanty grounds for the astoundingly far-reaching conclusion Newton came to will surely be seen as no overstatement. The argument by which he arrived at that conclusion proved to be very carefully laid out, remarkably deep, and connected both with views about the way to conduct inquiry into nature, and views about the fundamental constitution of nature itself, that (as I think can be quite clearly shown) were highly original, but have gone largely unappreciated—this in spite of the dominant position Newton has held in the mythology of science.

The present is not an appropriate occasion to discuss in any detail the case of gravitation: to do anything like justice to that subject would involve more

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[2] The sun and moon; Mercury, Venus, Mars, Jupiter, and Saturn; and four satellites of Jupiter. (In the second and third editions of the *Principia* five satellites of Saturn figure as well, bringing the total to sixteen objects.)

[3] *Phases* of the moon and of Venus; *eclipses* of the sun and moon, and of the satellites of Jupiter and Saturn.—Perhaps, for completeness, there should also be noted the shadows cast on Jupiter and Saturn by their satellites (a kind of "partial eclipse" of those planets).

technicalities than seem desirable here, and more time than is available. What I want to turn to is another surprise I had in reading Newton—one that relates closely to what I have just said about Newton's philosophy of inquiry and his views about nature. This surprise was given me by Newton's account of his early investigations of *light*—the subject of his first scientific publications, which long antedated his theory of gravitation.

The very first of those publications was a communication to the Royal Society, in February of (as it was then the style to say) 1671/72, describing Newton's investigation of the "celebrated *Phænomena* of *Colours*":[4] his experiments, and the conclusions he drew from them, which in the version published in the Society's *Philosophical Transactions* are called Newton's "New Theory about *Light* and *Colors*."[5] What, initially, struck me as very odd was the fact that this "new theory" was announced by Newton[6] as "in my Judgment the oddest if not the most considerable detection wch hath hitherto been made in the operations of Nature." It seemed almost embarrassing to find such a claim coming from such a person as *Newton* about, apparently, nothing more than the discovery that sunlight is analyzed, by refraction through a prism, into colored constituents. But—and here I must admit that Hegel was not altogether wrong about *everything*—there was an antithetical surprise waiting for me: this "new theory" of Newton, familiar to schoolchildren today (at least one hopes so!), and supported by him

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[4] Orthography of Newton's letter of February 6 to Oldenburg, the Secretary of the Society (and publisher of its *Philosophical Transactions*); see *The Correspondence of Isaac Newton,* vol. I, ed. H. W. Turnbull (Cambridge University Press, 1959), pp. 92-102.

[5] Orthography of the version printed by Oldenburg in the *Philosophical Transactions* of the Royal Society; reprinted in *Isaac Newton's Papers and Letters on Natural Philosophy,* ed. I Bernard Cohen (Harvard University Press, 1958), pp. 47-59.

[6] In an earlier communication (January 18, 1671/2); *Correspondence*, I, pp. 82-3.

with very simple and decisive experiments, met with heated opposition from, and misunderstanding by, critics among whom were two of the ablest natural philosophers of the time. This thesis/antithesis pair was very instructive for me: reflection upon it, and study of the controversy, was of great help to me in shaping my understanding of Newton's accomplishments.

Again, however, this is not the place to go into the particulars of Newton's optical experiments, his reasoning from those experiments, and the controversies concerning them. I have to confess a fear that without those particulars, the account I give will lack vividness and essential force; but I am going to try to repair that lack, at least partially, by an account of the contrast that I see between, on the one hand, the philosophical atmosphere that surrounded Newton, and, on the other, his own procedures, presuppositions, and, so to speak, *meta*-presuppositions—his views *about* philosophical principles (in natural philosophy and in metaphysics or "first philosophy").

In Locke's *Essay concerning Human Understanding,*[7] an extremely pessimistic assessment is made of the possibility of a scientific physics; for brevity, I just quote two blunt entries in Locke's own Index: (1) "NATURAL Philosophy not capable of Science," and (2), under "SCIENCE," "No S. of natural Bodies." What

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[7] I have discussed Locke's position in relation to Newton previously; see "On Locke, 'the great Huygenius, and the incomparable Mr. Newton'," in Phillip Bricker and R. I. G. Hughes, eds., *Philosophical Perspectives on Newtonian Science* (Cambridge, Mass.: The MIT Press, 1990), pp. 17-47, and "On Philosophy and Natural Philosophy in the Seventeenth Century," in Peter A. French, Theodore E. Uehling, Jr., and Howard K. Wettstein, eds., *Midwest studies in Philosophy Volume XVIII: Philosophy of Science* (Notre Dame, Ind.: University of Notre Dame Press, 1993), 177-201; cf. especially pp. 30 (bottom)-33 of the former article, for evidence that, in response to Newton, Locke came to alter his position on the possibilities for genuine knowledge in physics quite radically.

is the basis of this pessimism? I believe it is not too oversimplified to put the matter this way: Locke shared with Descartes a conception of what "genuine physical science" must be—namely, *demonstrative* knowledge from *fundamental causes.* But Locke did not believe, as Descartes did, that human beings possess purely rational grounds for knowledge of fundamental causes of the processes of nature; he thought, rather, that our knowledge of such processes is derived entirely from sensory experience. And he also thought that sensory experience simply cannot provide knowledge of fundamental causes. But this last proposition has to be clarified; as I have just put it, it is misleading. Locke *did* believe that—let me say—"*something like*" what Descartes held about fundamental causes in physics was true: namely, that these, so far as we have any acquaintance with them at all, must lie in what he called the "primary qualities" of bodies. So to the extent that primary qualities are qualities of *sensation,* we *do* know something about fundamental causes.[8] And this residue of Cartesian doctrine Locke shared with the entire community of "new philosophers" (that is, natural philosophers who

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[8] One may ask how Locke thought we "know" this much about fundamental causes. Locke, in some of his more acute moments, asked this himself, and found no good answer; cf., e.g., *Essay,* Bk. II, ch. xxiii, §28: "[I]n the communication of Motion by impulse, wherein as much Motion is lost to one Body, as is got to the other, which is the ordinariest case, we can have no other conception, but of the passing of Motion out of one Body into another; which, I think, is as obscure and unconceivable, as how our Minds move or stop our Bodies by Though" (contrast this with Bk. II, ch. v, §11: "The next thing to be consider'd, is how *Bodies* produce *Ideas* in us, and that is manifestly by *Impulse,* the only way which we can conceive Bodies operate in).—In my opinion, one thing that makes Locke a singularly interesting philosopher is his willingness to confront, with honesty, some of the *cruces* of his own doctrine—even when the confrontation is inconclusive.

rejected traditional "scholastic" or "peripatetic" principles). It follows from this, Locke argues, that since we have no sensory access to the minute interior complexion of the primary qualities of the *parts* of which bodies are composed, there is an insuperable bar to scientific knowledge of their properties and interactions.

In the pessimism Locke expresses, he is perhaps unusual for his time; but his central position is not unusual. He quite allows, and encourages, a program of investigating nature experimentally, not only to gather information that may be of practical use (and he does say that practical use is what our minds are really adapted *for*: "The Candle, that is set up in us, shines bright enough for all our Purposes"),[9] but also as a basis upon which we may form, with more or less probability, *conjectures* about the causes of natural processes.[10] This is in essential agreement with the position stated by Christiaan Huygens[11] ("the great Huygenius," as Locke called him): one may reasonably say that there is merely a verbal difference between the two philosophers, Locke refusing the honorific term *science* to what is merely "probable," whereas Huygens was quite happy to dignify with that title results that are systematic and probable—at least if they are *highly* probable. The crucial agreement is that the way to achieve the best understanding of a natural phenomenon that human beings are capable of is the seeking of what in a later time came to be called a "mechanical model," and what Huygens—in his criticism of Newton's first optical paper—called a "hypothesis by motion," to explain the phenomenon.

That conception of the situation of the natural philosopher actually had its roots in the writings of Descartes, although the latter had proclaimed early on (for instance, in the *Rules for the Direction of the Mind*) that all hypothesis or conjecture—whatever is at best probable—is to be rejected as entirely worthless.

[9] *Essay,* Bk. I, ch. i, §5.

[10] *Essay,* Bk. IV, ch. xvi., §12.

[11] See his *Treatise on Light,* Preface, ¶3.

Whether Descartes eventually retreated to the view that science is after all to be pursued by hypothesis and content itself with probability is, in my own view, debatable (although I believe that most commentators now think such a retreat on his part is clear); but in his published works—notably in the *Dioptrique,* one of the three "Essays in this Method" published with the famous *Discourse*, and in the *Principia Philosophiæ*—Descartes clearly did avail himself of hypotheses and of appeals to the "probable";[12] so by his example, if not by his precept, and even if against his real intent, he did encourage such a conception of natural-philosophic inquiry.[13]

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[12] (Indeed, of Descartes's arguments not a few could be characterized as "probable" only by the exercise of considerable charity.)

[13] Although it is apart from the subject of today's symposium, and although there is certainly insufficient time to discuss the matter in today's talk, I shall include here, at least as a footnote, a few words on my own reasons for doubting the current view that Descartes had really abandoned his claims to certainty. As I have just said, one reason—and in itself one that might appear conclusive—for the view I do not accept is Descartes's procedure in the *Dioptrique,* which is patently hypothetical, and which is even based on what is presented, not as a coherent mechanical model of optical processes, but as a fluctuating collection of mutually conflicting "analogies."

There is a letter from Descartes to Mersenne, dated 5 October 1637, replying to objections that had been raised against the *Dioptrique* by a person Descartes refers to as "one of your friends"—and who in fact was no less a figure than Fermat. The first of Fermat's objections is to a principle, of a rather scholastic kind, that Descartes invokes in the course of his argument (one which, although it concerns the theory of motion, bears a somewhat striking resemblance to a principle that enters crucially into Descartes's famous version of the ontological argument for the existence of God). Here is Descartes's reply to Fermat's objec-

That, moreover, this same conception was shared by a thoroughgoing Baconian experimentalist is clear from the following pronouncement of Robert Hooke's, made in a draft that bears upon his optical controversy with Newton: "I judge there is noething conduces soe much to the advancement of Philosophy as the examining of hypotheses by experiments & the inquiry into Experiments by hypotheses. and I have the Authority of the Incomparable Verulam to warrant me."[14]

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tion: "I am convinced that he conceived this doubt because he imagined I was doubtful on the point myself and because I put these words on page 8: 'It is very easy to believe that the tendency to move must follow … the same laws as does the movement itself.' He thought that when I said that something was easy to believe, I meant that it was no more than probable; but in this he has altogether mistaken my meaning. I consider almost as false whatever is only a matter of probability; and when I say that something is easy to believe I do not mean that it is only probable, but that it is so clear and so evident that there is no need for me to stop to prove it." (Quoted in the translation by Dugald Murdoch, in *The Philosophical Writings of Descartes,* vol. III, The Correspondence, tr. John Cottingham, Robert Stoothoff, Dugald Murdoch, and Anthony Kenny [Cambridge University Press, 1991], pp. 73-4.)—I have mentioned this letter to several Descartes scholars, who proved not to have previously noticed it. It offers a number of points for reflection, but I shall content myself here with calling attention to Descartes's continuing rejection of the merely probable. My own view is that he considered what he revealed in his publications to be only a partial sketch of results that in his own mind were, in their major parts, established with certainty on the basis of indubitable arguments from clear and distinct first principles.

[14] From a MS judged to date *c.* June 1672, apparently intended for William, Lord Brouncker; see *Correspondence of Isaac Newton,* I, p. 202.

Newton, however, did *not* share this conception; on the contrary, he deprecated conjectures and probabilities in terms almost as strong as those of Descartes—and this not just after controversies had arisen, but in his optical lectures delivered as Lucasian Professor of Mathematics in Cambridge University in 1670 (when Newton was twenty-seven).[15] In the third of these lectures—it is astounding to picture the audience to which these words were spoken!—Newton digresses to excuse the introduction of such a subject as *colors* into the lectures of a professor of mathematics: "[S]ince an exact science of [colors]," he says, "seems to be one of the most difficult things that Philosophy is in need of, I hope to show—as it were, by my example—how valuable mathematics is in natural Philosophy. I therefore urge geometers to investigate Nature more rigorously, and those devoted to natural science to learn geometry first. Hence the former shall not entirely spend their time in speculations of no use to human life, nor shall the latter, while working assiduously with a preposterous method, perpetually fail to reach their goal. But truly with the help of philosophizing Geometers and Philosophers who practice Geometry, instead of the conjectures and probabilities that are being marketed everywhere, we shall finally achieve a natural science secured by the highest evidence."[16]

Do not misconstrue this as a proposal that natural science be sought and established *more geometrico*, and thus as a revival of something akin to Descartes's original program. One does sometimes meet with claims of that kind,[17] but they

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[15] (To be precise: Newton was born on Christmas day, 1642, and the first of these lectures was delivered in January, 1670.)

[16] *The Optical Papers of Isaac Newton,* vol. I, ed. Alan E. Shapiro (Cambridge University Press, 1984), pp. 87, 89 (Latin original on pp. 86, 88); I have departed slightly from Shapiro's translation.

[17] For example, John Heilbron, in his *Electricity in the 17th and 18th Centuries: a Study of Early Modern Physics* (University of California Press, 1979), p. 31, says of

are grossly mistaken; indeed, the investigation that Newton has described in the lectures preceding the passage I have quoted was an *experimental* investigation, not a geometrical one: that is the reason for his apology. It may be useful to contrast specifically the method laid out by Descartes for the study of questions about light and the method employed by Newton.

Under "Rule Eight" of the *Regulæ ad Directionem Ingenii*, Descartes informs us that a certain problem in optics requires a knowledge of the law of refraction; that to learn what this law is, it will not do to ask an expert, and neither conjecture nor experiment would be of any use.[18] Rather, before one can hope to

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the physics developed in Descartes's *Principia Philosophiæ* that "its form—applications of firmly grounded rules of motion—is precisely that of Newton's." It would be hard to overstate the inaccuracy of this: the "rules of motion" of Descartes's *Principia* (Part II, §§36-53) are not "firmly grounded," indeed they are neither correct nor even really *coherent*; nor is the physics of Descartes's *Principia* arrived at by "applications" of these rules (indeed, Descartes himself says—letter to Chanut of 26 February 1649; *Philosophical Writings,* III, p. 369—"there is no reason to spend a lot of time examining the rules of motion in articles 46 and following of Part Two; they are not needed in order to understand the rest"); and as for Newton's physics, *that* is grounded crucially in *careful attention to phenomena*—attention of a kind that occurs rarely in Descartes's writings, and not at all in his *Principia Philosophiæ.*—For a recent statement of the view that Newton's method was essentially the same as Descartes's, see Freeman J. Dyson, "A New Newton" (review of James Gleick, *Isaac Newton*), *New York Review of Books,* **50**, #11 (July 3, 2003).

[18] That one should not conjecture or inquire of an expert ("propose to learn [this relation] from the philosophers") is a consequence—in fact an instance—of Rule Three: "Concerning objects proposed for study, we ought to investigate what we can clearly and evidently intuit or deduce with certainty, and not what other

find the law in question, it is necessary that one attain to a knowledge of *the nature of light itself* ("a knowledge of the nature of the action of light"). This Descartes believed himself to have accomplished—it is the subject of the first part of what narrowly missed being his first published work, *Le Monde*; and the hypothetical and "probable" arguments of the later *Dioptrique*—in which Descartes claims to establish the law of refraction—are quite obviously based on the theory of the nature of light of *Le Monde,* which Descartes does *not* state in the *Dioptrique.*[19]

The investigation that Newton reports to the Royal Society in the letter I have mentioned starts from a series of experiments, and draws—directly, as

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people have thought or what we ourselves conjecture." That experiment is useless is a rather more startling claim, and Descartes's explanation is cryptic: "the problem … is composite and relative; and it is possible to have experimental knowledge which is certain only of things which are entirely simple and absolute, as I shall show in the appropriate place." That demonstration—and, one might hope, some clarification of this requirement—was presumably to be given in the last third of the *Regulæ,* dealing with what Descartes calls "imperfectly understood problems"; and this was apparently never written. I believe one can at least roughly interpret Descartes to hold that experiment can never establish exact relations among continuous magnitudes, but can only decide among well-understood discrete alternatives.

[19] He does state it in the *Principia Philosophiæ,* Part III, §§55ff., and says (in §64) that all the properties of light can be deduced from this theory.—To prevent misunderstanding: the arguments for the law of refraction in the *Dioptrics* are "obviously" based on this theory, in the sense that the analogies to which Descartes there appeals are clearly motivated by the theory; but those arguments do *not* establish that the law *follows* from the theory—in point of fact, it doesn't.

Newton emphasizes, from the results of these experiments—these inferences about light[20]:

(1) *Ordinary* light—daylight, sunlight—does *not* accurately obey the received law of refraction: that the ratio of the sine of the angle of refraction to that of the angle of incidence, for light passing from one to another particular medium, is fixed.

(2) On the other hand, there is a kind of light different from ordinary light, and, of this kind, an "indefinite variety"—sensibly, a continuum— of particular sub-kinds, which can be obtained *separately* by suitable experimental procedures. These separate particular kinds Newton calls "homogeneal," "uniform," "similar," or "uncompounded."

(3) Ordinary—"white"—light can be produced by combining together (in suitable proportions) all the kinds of homogeneal lights; and the latter are obtainable *from* white light (indeed, that is the way Newton did obtain them).

(4) The homogeneal lights have each an array of properties in which they differ from one another, and which (on the evidence of many experimental attempts to alter them) are immutable for each separate homogeneal kind. These properties include *degree of refrangibility,* and— here I use Newton's very careful initial formulation—"their disposition to exhibit this or that particular colour."

(5) When homogeneal lights are combined, the result may be ordinary white light, or—if the combining proportions are different—it may be light that "exhibits" some other color; this is the usual case of the colors of the objects we see. *All* lights are characterizable as

[20] I formulate them in terms a little different from Newton's, but in substance I follow him closely.

> homogeneal, or as "composed" of homogeneal lights in some definite proportions; and those homogeneal components remain immutable *in* the compound, in the sense that whatever homogeneal kinds went into that compound, all the same ones—and no others—can be retrieved from it again, by (for instance) exploiting their different refrangibilities as a means for separating them.

As I have said, the announcement of these results—the claim that light has an *internal constitution* characterized by the proportions, in it, of the distinct homogeneal kinds—gave rise to heated controversy, and one point about that controversy—to me, a striking and also a rather amusing one—may here serve as evidence of the contrast I am drawing between Newton's philosophy of inquiry and the then received wisdom. Note first that the results I have just summarized deal exclusively with *kinds* of light, and *properties* of these; bodies and motions of bodies are not mentioned at all. In his detailed exposition, Newton speaks of *Rays* of light—e.g., he says that light consists of "*Rays differently refrangible,*" or, more generally (that is, not confining attention to refrangibility), of "*difform* Rays." Towards the end of his paper, Newton does suggest that his discovery perhaps makes it indisputable that "Light is a Body." Now, the first critique of Newton's paper was that of Robert Hooke, who had the responsibility to check all experiments reported to the Royal Society and to make a critical report on them. Hooke emphatically confirms that the experiments go just as Newton said ("as having," he says, "by many hundreds of tryalls found them soe");[21] but rejects Newton's interpretation of those experiments, as *founded* upon the *hypothesis* that light is a body[22] (Hooke thus assumes that when Newton speaks

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[21] See *Correspondence of Isaac Newton,* I, pp. 110-14; for the phrase quoted, p. 110.

[22] See *ibid.* pp. 113-14: "But grant his first proposition that light is a body [etc.], I doe suppose, there will be noe further difficulty to demonstrate all the rest of his curious Theory."

of "Rays" of light, he means *corpuscles*). On the other hand, a still more eminent critic—Christiaan Huygens—who reacted at first quite favorably to Newton's paper,[23] later demurred to Newton's principal conclusions in the following terms: "Neither do I see, why Mr. Newton doth not content himself with the two Colors, Yellow and Blew; for it will be much more easy to find an *Hypothesis* by Motion, that may explicate these two differences, than for so many diversities as there are of other[24] Colors. And till he hath found this *Hypothesis,* he hath not taught us, what it is wherein consists the nature and difference of Colours, but only this accident (which certainly is very considerable) of their *different Refrangibility.*"[25]

Since both Hooke and Huygens accept, and praise, Newton's experimental results, one might conclude that the controversy is not very serious. That would be to miss an essential point. Hooke and Huygens are also united—although they differ in their reading of Newton's theoretical intentions—in rejecting his conclusion that there is an "indefinite variety" of kinds of "simple," uncompounded, light; they in fact both continue to believe that light *par excellence* is ordinary white light, and that besides this there are only *two* variant simple modes, or colors, which suffice for the compounding of all others. Hooke, in other words, thinks that Newton's theory of the *constitution* of light depends on a hypothesis—the corpuscular hypothesis—about the *nature* of light; and since the latter he thinks, and rightly thinks, has not been established, he rejects the former; whereas Huygens, recognizing that Newton has *not* really advanced a

[23] See the quotation in a letter from Oldenburg to Newton of 2 July 1672, *ibid.*, p. 207.

[24] (Here correcting an obvious slip in the text published by Oldenburg, which reads 'others' at this point.)

[25] Oldenburg's translation, published in the *Phil. Trans.*; quoted from Cohen (ed.), *Papers and Letters of Isaac Newton*, p. 136.

theory of the nature of light, concludes from *this* fact that Newton cannot have established anything at all about light's constitution.[26]

Think, now, of Locke's pessimism, and its basis: that there is an insuperable bar to scientific knowledge of the constitution of bodies, in the fact that we have no sensory access to the interior complexion of the primary properties of their parts. Plainly, we have no sensory access to any sort of interior complexion of a light-beam; and Newton's theory of the constitution of such a beam makes no reference to Lockean primary properties of its parts. Yet, some eighteen years before Locke published that estimate of the prospects for a scientific natural philosophy, Newton claimed—and I will defend his claim against any challenger—to have "detected," through his experiments, an interior constitution of such a beam; and one that can be described with precision in terms *themselves* based upon *observations of light,* independently of any view about the fundamental constitution of nature in general or of light in particular.

I should like to call attention to one further circumstance in Newton's investigation. His conclusion that "homogeneal" light is the *basic* kind of light — the "element," one may say, out of which light is constituted—indeed, in effect, in *this* theory, what, together with its properties, plays the role that Locke thought would have to be played in any genuine science by the parts of bodies and their primary qualities—this conclusion rests upon the fact that, as Newton's experiments show, the "homogeneal" kinds have fixed properties and obey simple and precise laws, while the behavior of the kinds he characterizes as

[26] In 1690, when Huygens published his *Treatise on Light,* he wrote in the Preface that he has not exhausted the subject, as appears (among other things) "from matters which I have not touched at all, such as Luminous Bodies of several sorts, and all that concerns Colours; in which no one until now can boast of having succeeded."—Christiaan Huygens, *Treatise on Light*, tr. Silvanus P. Thompson (reprinted: University of Chicago Press, 1945), p. vii.

composite can be *calculated* from the independent behaviors of their "homogeneal" constituents. But what *is,* in particular, the *law of refraction* of any one "homogeneal" light? The first crucial observation that Newton makes in this account of his experimental investigation is that the received law of refraction *cannot* be accurately true of white light; yet it is only from the study of white light that that law was found. *Is* the received law true, then, accurately, of homogeneous light? The investigation certainly does not show this, and Newton does not assert it.[27] But he does show convincingly that the homogeneous kinds obey *some* definite law of refraction. This experimental "existence theorem," to borrow a suggestive term from mathematics, is established in the following way: behind the prism that, by itself, effects the dispersion of the beam of white light into a spectrum, Newton places a second prism, identical in construction, in a position the reverse of that of the first one. When the light traverses only the first prism, as we know, the spectrum is produced; but when it traverses both, neither colors nor a distortion of the expected image occurs. Newton's conclusion is that

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[27] Even in the *Opticks*, first published in 1704, Newton gives no more than *plausible* reasons in favor of the assumption that the law of a constant ratio of the sines indeed holds for "homogeneal" light (see Bk. I, Part I, Proposition VI, with the discussion following the statement of that proposition).—The experimental argument Newton gives there for the correctness of the law of sines for "homogeneal" light is in fact seriously defective, as has been pointed out by Johannes Lohne—see Lohne, Johannes A., "Newton's 'Proof' of the Sine Law and his Mathematical Principles of Colors," *Archive for History of Exact Sciences* **1** (1961), 299-405. (On the other hand, Lohne's discussion is rather seriously flawed, and Newton's error, although indeed serious, is not *quite* as flagrant as Lohne maintains [—but to show this would require a mathematically detailed discussion, of which I have written a draft but not a finished treatment].)

whatever happens in the first prism, *exactly the reverse* happens in the second; and therefore, that "what happens" in each of these cases is something *determinate*—regular—or in later jargon, "law-like." This seems worth repeating (or rephrasing): we have an early instance of the sort of experiment that physicists later came to recognize as especially informative, an experiment that crucially produces a null result:[28] the fact that the two prisms together make *no* change in the incident light establishes quite clearly that, as Newton expresses it, the effect of one of them alone cannot be due to any "contingent irregularity."

All this would perhaps be enough to justify Newton's characterization of his discovery as unprecedentedly "odd" and "considerable." But there is something more—something quite astonishing. One of the properties of the several kinds of "homogeneal" light that Newton had discovered was a *length,* different for the different kinds, constant and unchangeable for each kind in any given medium, but varying from medium to medium in inverse proportion to the index of refraction of the medium.[29] The actual value determined by Newton for the characteristic length for "the Rays which paint the Colour in the Confine of yellow and orange" is "the 1/89,000th part of an Inch."[30] Now, the length that

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[28] A very famous example is the experiment of Michelson and Morley, in which the observation that *no displacement* of interference fringes occurs is the decisive circumstance.

[29] This result was announced by Newton in December, 1675—thus nearly four years after his first paper; see Cohen (ed.), *Papers and Letters of Isaac Newton*, pp. 177-205, especially Observation 6, p. 205. However, it is clear from his letter to Oldenburg of 21 May 1672 (*Correspondence of Isaac Newton,* I, pp. 159-60) that the result had in fact been obtained by him before the first paper was written.

[30] The clearest formulation of the results about the characteristic length is to be found in the *Opticks,* Book II, Part III; the quantitative determination cited here is taken from that source—Proposition XVIII.

Newton measured is what we know as half the wave-length (in air) of the light in question. The value he obtained is equivalent to approximately 570 nanometers —5700 Ångström units—for the wave-length. That is a wave-length quite nicely in the yellow (although perhaps short of yellow-orange).[31]

Let me review a few points that seem to me remarkable in this. First, in a fashion that was entirely outside what was thought possible at the time, Newton had indeed discovered very fundamental structural properties of light, independently of any theory of what light itself, fundamentally, is. Second, he had discovered a structural property of a kind that, without the process Newton called "deduction from phenomena," it would have seemed what one now calls a "category mistake" to attribute *at all* to a kind of light; nor did he himself have a well-founded conception of what, *in* the light, was the "bearer" of a length (on this point Newton did offer an interpretation; but it eventually proved to be quite wrong; and yet his conclusion that there *is* such a length, and his actual determination of it, were entirely sound). And third—in dramatic refutation of what Locke said about the insurmountable barrier to what we can ever learn of the minute interior structure of things—Newton had determined the value of a length that is *far* below what human senses can directly perceive. He had in fact made the first determination in history of a submicroscopic quantity. (It was also the *last* such determination for a very long time; the last such *reliable* determination until near the end of the nineteenth century, or even perhaps the first decade of the twentieth.)

I have the uncomfortable feeling, on the one hand, that I have said too little—for instance, I am strongly tempted to explain *how* Newton succeeded in determining that minute quantity, in order to avoid what may seem something

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[31] Consulting a table that happens to be at hand, I find there, for the D-lines of the spectrum of sodium—a characteristically yellow-orange light—approximately 589 nanometers.

of a mystification, and in order also to give an example of his ingenuity in finding, with very simple resources, to overcome formidable experimental difficulties. On the other hand, an audience not primarily interested in the history of science may well consider that it has already been given more technical information than belongs in a talk on Newton's *philosophy*. But I hope that, before the end, it will have become clear that a real connection exists between what I have called Newton's philosophy of inquiry and a most original approach he took to question of metaphysics—one that I think penetrating, and possibly instructive still for us today. Let me here make a somewhat abrupt transition to his metaphysics.[32]

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[32] Much of what follows is based upon the now celebrated manuscript fragment known (from its opening phrase) as *De gravitatione et aequipondio fluidorum* (and, more familiarly, as "De grav."). This was first published in A. Rupert Hall and Marie Boas Hall (eds.), *Unpublished Scientific Papers of Isaac Newton* (Cambridge University Press, 1962), in the original Latin followed by a(n unfortunately very defective) English translation. Quotations below from this piece are my own revisions of the Halls' translation; page references are double—to the Latin and the corresponding English passages in the Halls' edition. (I have discussed this fragment, first with respect to a part of its discussion of space and time, in "Newtonian Space-Time," *The Texas Quarterly* [Autumn, 1967], 185-6—reprinted, with the correction of a serious typographical error, in Robert Palter [ed.], *The* Annus Mirabilis *of Sir Isaac Newton, 1666-1966* [Cambridge, Mass.: MIT Press, 1970]—the relevant passage in the latter volume is on pp. 269-70. I have discussed it further, with regard to its doctrine of body as well as extension, in the article "On the Notion of Field in Newton, Maxwell, and Beyond," in Roger Stuewer [ed.], *Historical and Philosophical Perspectives of Science* [Minnesota Studies in the Philosophy of Science, vol. VIII; University of Minnesota Press, 1970]—see pp. 273-8; in the articles cited in n. 7 above; and in my chapter "Newton's meta-

Its first chapter, as one might say, concerns space and time. Of these, Newton makes a statement that appears *prima facie* to support a once common view that his theory of the nature of space and time is grounded in his theology: he says of *extension*—later applying the statement to time as well as to space—that "it subsists, not absolutely of itself, but as so to speak an emanative effect of God, and a certain affection of every being."[33] One knows, of course, of Newton's relationship to Cambridge Platonism in the persons of Henry More and Ralph Cudworth, and it seems to me beyond doubt that there is here an echo of Neoplatonist terminology; but there is not the slightest obscurity as to Newton's meaning, in the light of an explication he offers a little farther on:

> Space [he says] is an affection of a being just as a being *(Spatium est entis quatenus ens affectio).* No being exists or can exist that does not have relation in some way to space. God is everywhere, created minds are somewhere, and bodies in the spaces that they fill, and whatever is neither everywhere nor anywhere is not. And hence it follows that space is an emanative effect of the first-existing being; for if I posit any being whatever I posit space. And the same may be affirmed of Duration: namely both are affections or attributes of a being [*entis affectiones sive attributas*] in accordance with which the quantity of the existence of any individual is denominated, as to amplitude of presence and perseverance in its being. So the quantity of the existence of God, according to duration has been eternal, and according to the space in which he is present, infinite; and the quantity of the existence of a created thing, according to duration has been just so much as the

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physics" in I. Bernard Cohen and George E. Smith [eds.], *The Cambridge Companion to Newton* [Cambridge University Press, 2002].)

[33] *De grav.*, pp. 99/132; for the application to time ("duration") as well as space, see pp. 103/136.

> duration since its first existence, and according to the amplitude of its presence, as much as the space in which it is.[34]

—One sees, then, that when Newton says that "*B* is an *emanative effect* of *A*," what he means is that if one posits *A*, one posits *B* as well: the existence of *B* follows from that of *A*. One sees further that one aspect of the peculiar metaphysical status of space and time is this: that *appropriate relation* to them is a condition of the existence of anything. And one also sees that—entirely in accordance with this conception— Newton's assertion that space is "so to speak an emanative effect of God" is based upon the propositions (a) that if anything is posited as existing, space is as well; (b) that therefore space is an emanative effect of whatever my be the first-existing being; and (c) that *God* is the first-existing being. God enters, therefore, only in step (c) of this argument: an atheist could follow Newton in propositions (a) and (b), and have the same conception of space as Newton's.[35]

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[34] *De grav*., pp. 103/136.

[35] "Well, yes," a critic might object; "but could the atheist have the same *grounds* for this conception that Newton had?"—This is an interesting point: it raises the question, what *were* Newton's grounds for believing propositions (a) and (b)? Since Newton no more tells us this than he tells us what he thinks the evidence is for the basic principles of geometry (except to say that those principles are "founded in mechanical practice"—see his preface to the *Principia*), a discussion of the subject can only be conjectural. I think a plausible case can be made that Newton considered these views of his to be the outcome of reflection on experience of the world—including, to be sure, reflection on what is found in those documents he deemed to contain records of Divine revelation (but actually without giving this last kind of reflection a decisive place in regard to the fundamental principles of his theory of nature). But that case would remain highly conjectural; and there is no room for it on the present occasion (aside from

I have referred to "the peculiar metaphysical status of space and time." Another aspect of that peculiar status is that, according to Newton, extension is neither *substance* nor *accident*; nor is it "nothing at all" (i.e., *non-being*, as in the atomists' doctrine); rather, "it has a certain mode of existence proper to itself, which suits neither substances nor accidents" (that is, as an affection of every being as such). But why—since Newton is emphatic that extension does not *require* anything else in particular to support its own existence—does he say that it is not a substance? His answer is that extension "does not stand under the kind of characteristic affections that denominate substance, namely *actions,* such as are thoughts in a mind and motions in a body." And he adds that "although Philosophers do not define substance to be a being that can act upon something, nevertheless they all tacitly understand that of substances, as is plain for instance from this, that they would easily concede extension to be a substance like a body if only it could be moved and could exercise the actions of a body; and on the other hand, they would by no means concede a body to be a substance if it could neither be moved nor arouse any sensation or perception in any mind."

The next chapter, the crucial one, of this metaphysics concerns bodies. In the manuscript from which I have been quoting, Newton presents his views on the fundamental constitution of corporeal nature in the form of a creation story: *how God might create a body.* Not how he *did,* but how he *may have* created bodies. I

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brief remarks to be made below). As to the possibility of an atheist holding Newton's conception of extension, however: this is in fact *explicitly* affirmed by Newton himself; see *De grav.,* pp. 109/142-3, where he contrasts, in this respect, extension—the "Idea" of which we have as "absolute [and] without any relation to God, so that we could postulate it as existing … while we feign that God does not exist"—with the "Idea" he has sketched of bodies, which he claims is essentially dependent on God. (On this last point, I venture to disagree; cf. n. 36 below.)

emphasize this distinction, as one of the most characteristic features of the view: Newton thought the nature of space and time was entirely clear; not so the nature of body. I want to present the matter in Newton's own theological terms, and in a parallel, non-theological, translation or gloss.[36] Newton asks, "What could God have done to produce *those natural phenomena* that we perceive as involving what we call "bodies"? He does not mean to provide the description of a technological process—to answer the question, what (say) *we* might do if we wanted to design a body-factory. He isn't proposing to give a description of the actual means of such creation; only an account—but a *clear and adequate* one—of the *effect* to be achieved. According to Locke, for instance, this effect must be the existence, where nothing was before, of a *material substance* in which certain primary qualities occur inseparably together; and he indicates, repeatedly, that what that really *means*—what a "substance," functioning as the "support" of coexistent qualities, *can itself be*—is obscure.[37] In Newton's answer to his question, this notion of "substance," as substrate or "support"—which Newton equates with the scholastic conception of "prime matter"—does not appear at all; and he cites its elimination as one of the virtues of his account.[38]

In brief, Newton's answer is this: God may, first, in effect *fence off* a particular region of space from penetration by any bodies already in existence.

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[36] In this (cf. n. 35 above) I do something Newton would have objected to: he himself affirms, as part of the "usefulness" of the "Idea" of bodies he has described, that "we cannot postulate bodies of this kind without at the same time postulating that God exists, [etc.]" (*De grav.*, pp.109/142).

[37] Thus—referring once again to Locke's index—we find there, under "SUBSTANCE," the entry: "S. no Idea of it."

[38] *De grav.*, pp. 106-7/140-41, ¶¶ (1)-(4); and cf. pp. 111/144-5, where he goes so far as to suggest that an analogous account of God himself may be possible "without any substantial subject" in which his attributes inhere.

This already would produce an important part of the appearances—the *phænomena*—of body: test bodies (as a physicist of our own time would say), projected towards this region, would be "scattered" from it. Second, for these impenetrable regions to exhibited more fully the behavior of bodies, we have to suppose that God makes them *mobile*: more fully, what Newton posits is that each such—let us say—*spatial distribution of impenetrability* maintains through time an invariable size and shape, but is able to *migrate* from one part of space to another, and this in accordance with certain laws, likewise imposed by the divine will. These laws must, in particular, determine what happens if one such extended impenetrability should encounter another, since it has been laid down that they cannot come to overlap; the laws, therefore—"laws of motion"—include, *ipso facto*, laws of *interaction.*

To pause for a moment: it is surely clear how the reference to God's creation could be "bracketed" in this account: To say that "this may be what God *really did*" in "making" bodies is just to say that this may be what bodies, fundamentally, *are*; and this is perfectly intelligible whether the bodies were "created" or were, simply, *there*. In other words—although this is very far from Newton's own intention—we might substitute for his reference to God something more like Spinoza's *Deus sive Natura*, and for "what God may have created," "what the fundamental constitution of nature may be."

But there are two extremely important additions to be made to this account. The first is made by Newton in the same fragment I have been quoting from. Once again, comparison both with Descartes—a comparison that is very strongly emphasized by Newton in this text—and with Locke can be highly instructive. What Newton is trying to do is to give an account of the "essential attributes" (Descartes), or the "primary qualities" (Locke), of bodies. He has already made a crucial addition to the Cartesian doctrine in stressing impenetrability itself (which Locke calls "solidity") as something not contained in the "Idea" of *extension* but—according to the sketched theory—"essential" to bodies. If he had stopped there, he would have provided an account exactly suited to the so-called mechanical—or "corpuscularian"—philosophy, recommended by Locke as "that which is thought to go farthest in intelligible Explication of the Qualities of Bodies."[39] But Newton says that this is inadequate. To make clear why, just reflect upon the fact that the account of "creation" I have reported is described by Newton as the creation of a *new* body, which should be indistinguishable in nature from bodies already existent. This "new" body is detected by its ability to "scatter"—what? Answer: *old* bodies. So it is already assumed that we are somehow able to *perceive* these old bodies. If we are to have here an intelligible account of creation *in principio*,[40] we cannot assume that there is *any* "fundamental" difference between the "new" and the "old" bodies. What Newton says is that if we are to imitate Descartes in asking what properties of bodies we can or cannot "strip away" from them without robbing them of their character *as* bodies, we have to recognize that among those properties is their ability to affect our perceptual apparatus—and also, their susceptibility to being *moved by* our minds (since we move our own bodies—and, in Newton's view, any material particle *could* come to form a part of one's body).[41] So this first amendment to the

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[39] *Essay*, Bk. IV, ch. iii, §16.

[40] (This is intended as a pun—perhaps weak as a piece of wit, but important as a piece of philosophy: not only creation "in the beginning," but, what matters more, creation *in principle*.)

[41] *De grav.*, pp. 106/140; and—especially—the following (pp. 112/145-6): "Moreover, that I may respond more exactly to Descartes's argument: let us take from body (as he bids) weight hardness and all sensible qualities, so that nothing at length remains but what pertains to the essence thereof. Will extension alone be left now?—by no means. For we may further remove that faculty or power by which they move the perceptions of thinking things. For since the distinction between the Ideas of thought and extension is so great that there does not appear

corpuscularian doctrine makes the *power to interact with minds* as much a fundamental aspect of the nature of bodies as the power to interact with one another. This raises a question about the position of mind itself in Newton's philosophy, and it will be worth returning briefly to the subject. But there remains what I have called the second amendment, which concerns corporeal interactions themselves, and which does not occur in the source I have so far been drawing upon—although it is entirely compatible with what Newton has said there. Let me re-emphasize two points: that in Newton's view, a characteristic mark of anything that merits to be called a *substance* is the power to *act and be acted upon*; and that such powers (including even impenetrability—the power of a body to exclude other bodies from sharing any part of the place it occupies) are *not* transparent to our intellect or intuition. The amendment concerns a classification of the powers that bodies do have to interact with one another. Since these powers are encoded in the "laws of motion" with which the bodies are endowed by God

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to be any connection or fundamental relation save what is caused by divine power: that faculty of bodies can be removed preserving extension, but it cannot be removed saving the corporeal nature. . . . But should anyone object that bodies not united to minds cannot directly arouse perceptions in minds, and that hence . . . this power is not essential to them: it is to be remarked that there is no question here of an actual union, but only of a faculty in bodies by which they are capable of a union through the forces of nature. From the fact that the parts of the brain, especially the finer ones to which the mind is united, are in a continual flux, new ones succeeding to those which fly away, it is manifest that that faculty is in all bodies. And to take away this, whether you consider divine action or corporeal nature, is no less [a violation of the nature with which God has endowed bodies] than to take away that other faculty by which bodies are enabled to transfer mutual actions amongst one another—that is, to reduce body to empty space."

(or by the fundamental constitution of nature), and since the laws are not specified in detail in the earlier account, Newton has left a space in that account into which this classification fits without difficulty. The amendment dates from the investigation that produced Newton's *Principia*, and indeed—in my opinion—is essentially connected with that investigation in a double sense: the amendment reflects a fundamental discovery made during that investigation, and played a crucial role in *guiding* that discovery.[42]

In the terminology of this expanded theory—now incorporated explicitly into Newton's *physics*—each fundamental law governing the motions of bodies, and thereby constituting the *natures* of those bodies, is called a (particular) *natural power*, or *force of nature*; and of these, there are two main classes. The first appertains to all bodies, and is called their *intrinsic force*. Newton characterizes it also as a *passive force,* and calls it the "force of inactivity" or *vis inertiæ.* The *law* associated with it is the *conjunction* of the three "Laws of Motion" formulated in the introductory section of the *Principia.* The other major class of natural powers—or forces—or "Principles of Motion"—is called by Newton that of "active Principles." The exercise of an active principle upon a body is what in the *Principia* Newton calls an "impressed force"; and it is a crucial point in this amended account that each such exercise is an action *between two bodies*, governed by the third Law of Motion: an impression, by each of two bodies upon the other, of equal and opposite "motive forces." Thus the fundamental laws of

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[42] This sounds involved; and indeed it *is* involved! Elucidation certainly exceeds the limits of the present occasion; I have discussed the matter, from various angles, in several places: in the articles cited in n. 32 above, and also in "'From the Phenomena of Motions to the Forces of Nature': Hypothesis or Deduction?" *PSA 1990,* vol. 2, 209-222.

nature—"by which," Newton says, "the Things themselves are form'd"[43]—are laws of *interaction*: and the exercise of an active principle by one body on another implies that *each* of these bodies is both an agent and a patient of the power involved.—The double connection with the investigation underlying the *Principia*, then, is this: without this new conception Newton could not have discovered the law of universal gravitation, as the regulator of all celestial (and some terrestrial) phenomena; but without his discovery of that law—and without the *evidence* that *convinced* him of that law—he would have had no basis for the new conception of a natural power in general. (Note that, although I have certainly not here shown how all this is so, we do in this make contact with the puzzle I spoke of in my opening paragraphs.)

In regard to the interactions of bodies, Newton's legacy was a beautifully articulated framework of concepts, and a program of investigation: to seek to discover the forces of nature, and to seek them in the form indicated by the framework of concepts. He is explicit that both the program and the framework are tentative. He tells us, in the unpublished work describing the deeper aspects of the metaphysics I have summarized, that the account he gives of the nature of body is only of what, on the basis of what was known at the time, that fundamental nature *may* be, not what it *must* be; he relates this uncertainty to his view that bodies, unlike space and time, were created by God—are, therefore, products of God's *will*; and God might have chosen to produce all the effects known to us by ways other than the ones he (Newton) has thought of. And the same tentative note is struck in his later major published works, the *Principia* and the *Opticks*.[44] But clearly the framework and program are presented *not* merely as an

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[43] Newton, *Opticks* (4th ed.; reprinted New York, Dover Publications, 1952), p. 401.

[44] In the Preface to the first edition of the *Principia*, Newton says that he is "induced by many reasons to suspect" that besides the characteristics of the "Sys-

empty schema, to be filled in by posterity: Newton himself had given a mighty impetus to the program, and I have stressed my opinion that it was only in his successful attack upon the problem of the celestial motions that the framework of concepts and the program of investigation emerged in his own mind.

The situation is quite different as regards that aspect of the nature of body, as characterized by Newton, that concerns the interactions of bodies and minds. Here, Newton leaves us with no more than the firm statement that without powers of such interaction, bodies would not—could not—be what we perceive them to be; and with the clear implication, as well, that without correlative powers of interaction with bodies, *minds* would not be what we perceive them to be; he says nothing of what the powers *are*, except for the general indication that they are powers of bodies to stimulate perceptions in minds, and of minds to induce motions in bodies.

Now, a superficial reading of this might lead one to suppose that that is all Newton thought *necessary* to characterize the relations of bodies and minds—that it is, in the jargon of our own day, Newton's proposed solution to the mind-body problem. To suppose Newton capable of such a superficial move would be vastly

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tem of the World," which are studied in Book III of that work, "the rest of the phænomena of Nature . . . may [likewise] all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards each other and cohere in regular figures, or are repelled and recede from one another"; and so holds out the hope that the search for such forces may lead to increased understanding. However, he does not say that attaining the aim he has described is the *only* hope for understanding nature; his concluding words on the matter are: "But I hope the principles here laid down will afford some light either to that, or some truer, method of Philosophy." The comparable passage in the *Opticks* is on pp. 401-2 of the edition cited in n. 43 above.

to underrate him as a philosopher. He *does* suggest that an analysis similar to that he has given of the nature of bodies might even allow us to conceive of the attributes of God, and their interconnections, without positing any unintelligible "substantial substrate" of those attributes: having singled out, as the one obscure point in his supposition that God has endowed spatial regions with particular properties properties, the fact that we don't have any notion of *how* God does this; and having argued that that is not a valid objection "since the same thing occurs in respect to the way we move our limbs, and yet we do none the less believe ourselves able to move them";[45] Newton says: "In the same way, if we should have an Idea of that Attribute or power by which God, through the sole action of his will, can create beings: we should perhaps conceive that Attribute as it were subsisting of itself, without any substantial subject, and involving his other attributes."[46] He immediately adds, however: "But so long as we cannot

[45] *De grav.*, pp. 107/141.

[46] Cf. n. 38 above.—It is worth quoting more of the relevant text than I have yet done in my publications on the point; this, then, from *De grav.*, pp. 109-111:

> [I]f we consider the vulgar Idea or rather non-Idea of body, namely that there is hidden in bodies some unintelligible reality that they call substance in which their qualities inhere: This (besides that it is not intelligible) is attended by the same inconveniences as the Cartesian view. . . . Nay indeed on a view all round there hardly appears anything else productive of Atheists than this notion of bodies as if possessing complete absolute and independent reality in themselves, such as nearly all of us if I mistake not are accustomed from childhood to hold uncritically in thought, so that it is just verbally that we declare [that reality] to be created and dependent. . . . [T]he Idea [of created substance] no less involves the concept of God than the Idea of accident [involves] the concept of created substance. Therefore [created

form an Idea of this Attribute, nor even of our own power by which we move our bodies, it would be rash to say what is the substantial foundation of minds." As Newton sees it, the hope for a *genuine* contribution to the "metaphysics of

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substance] ought to include in itself no other reality than a derivative and incomplete one. Thus the prejudice just mentioned is to be laid aside, and substantial reality rather ascribed to Attributes of that kind, which are real and intelligible in themselves and do not require a subject in which they inhere . . . . And this we can manage without difficulty if (besides the Idea of body expounded above) we reflect that we can conceive of space existing without any subject, when we think of a vacuum. . . . In the same way, if we should have an Idea of that Attribute or power by which God, through the sole action of his will, can create beings: we should perhaps conceive that Attribute as it were subsisting of itself, without any substantial subject, and involving his other attributes. But so long as we cannot form an Idea of this Attribute, nor even of our own power by which we move our bodies, it would be rash to say what is the substantial foundation of minds.

It is worth making two remarks about this—a small one and a large one: First, there seems to be, in the reference to the prejudices of childhood, an allusion to Descartes (see his *Principia*, Part I, §71). Second, Newton clearly argues for a radical and "substantial" difference in kind between God and created things; but—in accordance with his metaphysical position in general—he thinks this is to be understood as a difference, not of "substantial *substrate*," but of "substantial *attributes*": that is, attributes that concern the power to *act*.

mind" depends upon the hope for an improved understanding of the relations among corporeal and mental phenomena. And Newton knows that, for him, this is something beyond the horizon of actual knowledge. I think it typical of him, and I hold it out as both rare and exemplary, that he neither deludes himself into thinking he can solve the problem of "what constitutes the substantial foundation of minds," nor takes the defect of present knowledge as a reason to despair of eventual progress in this domain.

As to the connection I have claimed to hold with Newton's philosophy of inquiry, and in particular with the characteristics of his optical investigations, I hope what I have said is enough to make the fact of this connection, and its nature and interest, fairly discernible (*adequately* would be too much to hope). But let me try to make a few points explicit:

(1) Since in Newton's view understanding of the *fundamental* character of anything can only come from knowledge about that thing, gained from experience, he sought experimental knowledge of light, for example, that would provide, not in the first instance support for a prior theory of its nature, but *some systematic basis* for *further investigation*—and—*possibly*—an eventual more fundamental theory.

(2) A corollary of this "open" stance towards theories—a corollary I have discussed elsewhere in some detail but have not had time to illustrate today—is that Newton, who leaned strongly towards the "corpuscular" theory of light, had *at the same* reflected deeply enough upon the principal alternative, the wave theory, to make extraordinarily valuable suggestions for such a theory—suggestions that were largely ignored at the time, but were taken up fruitfully more than a century later.[47]

[47] I have discussed this in two related, still unpublished, papers: "On Metaphysics and Method in Newton," and "Further Reflections on Newton's Methods."

(3) A second corollary is that among the things to hope for as results of an investigation is the discovery both of *new questions* that may be profitably pursued and *new instrumentalities* for conducting further investigations. Another reason, which I have not here touched on, for the importance Newton ascribed to his first optical discovery, is that he viewed the interactions with bodies of homogeneous light as a possible means for obtaining information about precisely that minute internal structure of bodies which Locke had thought forever inaccessible to us.[48]

(4) More generally, where Locke sought for the most basic information we can have about natural things in their *perceptible qualities*, Newton looked to what Locke called "qualities mediately perceived": i.e., to information about the *interactions* of things. This is certainly related to his view of substance as that which is capable of "action" (although its experimental application is not dependent upon this metaphysical view).

(5) In Newton's account of the nature of body, *laws* play a central role; and it is *regularities – laws of behavior* – that he primarily sought in his study of phenomena. It is these that make the results of the investigations what I have called "systematic." And it is this goal that underlies Newton's emphasis upon the role "geometers" have to play in the study of nature. He says of the optical principles he has discovered that they are "such that on them mathematicians may determin all the Phænomena of colours that can be caused by refractions": the emphasis is not

[48] This is apparent (although it has not been widely noted) in Books II and III of the *Opticks*; I have discussed the matter in the papers referred to in the preceding note.

primarily on the *quantitative* nature of the results, but on the fact that they form a basis for *mathematical reasoning*.[49]

(6) Not only deeper knowledge in physics, but deeper knowledge of what Newton calls "the substantial foundation" of things, can be consequent upon investigation of phenomena; I have claimed here—and elsewhere have argued—that the great investigation that gave us the *Principia* involved a *simultaneous* and *mutually interdependent* development of new "metaphysical" principles and new physical principles.

But in my discussion today of Newton's philosophy of inquiry there is one unavoidable but regrettable gap: I have not attempted to show that, and how, Newton's claims are indeed—genuinely—*justified* by the empirical evidence he cites for them. This is a subject that in my opinion richly repays investigation; and I should not like to close today without at least mentioning the very rewarding studies that have been made in recent years by William Harper and

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[49] Once, when in a talk I spoke of the importance of the notion of a *law of nature* in Newton's philosophy, it was objected that we still have no clear conception of what constitutes a "law." I answered that to tell this to Newton would be like telling a musician that we have no clear conception of what constitutes a tune. My answer may seem frivolous; but what I contend is that there is a clear enough conception of law for Newton—and, since Newton, others!—to have made very good use of, even if philosophers of science have been unsuccessful in their attempts at a general definition. Indeed, I contend (a) that this is a fact; (b) that it is not the only instance of a useful working conception that philosophers of science have so far failed to explicate; and (c) that that is a circumstance philosophers of science ought to be aware of.

by George Smith, dealing with Newton's procedures in what he calls his "deductions from phenomena."[50] On this note, then, I *do* close.

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[50] See William Harper, "Newton's Classic Deductions from Phenomena," *Philosophy of Science Association* **2** (1990), 183-96; "Isaac Newton on Empirical Success and Scientific Method," in *The Cosmos of Science*, ed. John Earman and John D.Norton (Pittsburgh: University of Pittsburgh Press, 1997), pp. 55-86; "Measurement and Approximation: Newton's Inferences from Phenomena versus Glymour's Bootstrap Confirmation," in *The Role of Pragmatics in Contemporary Philosophy*, ed. P. Weingartner, G. Schurz, and G. Dorn (Vienna: Hölder-Pichler-Tempsky, 1998), pp. 65-87; "The First Six Propositions in Newton's Argument for Universal Gravitation," *The St. John's Review* **45**, no. 2 (1999), 74-93; "Howard Stein on Isaac Newton: Beyond Hypotheses?" in *Reading Natural Philosophy* (Chicago: Open Court, 2002), pp. 71-112; "Newton's argument for universal gravitation," in *The Cambridge Companion to Newton* (Cambridge University Press, 2002), pp. 174-201; and George E. Smith, "Fluid Resistance: Why Did Newton Change His Mind?" in *Foundations of Newtonian Scholarship*, ed. Richard Dalitz and Michael Nauenberg (Singapore: World Scientific, 2000), pp. 3-34; "The Newtonian Style iin Book III of the *Principia*," in *Newton's Natural Philosophy*, ed. Jed Z. Buchwald and I. Bernard Cohen (Cambridge, Mass.: MIT Press, 2001), pp. 249-313; "From the Phenomenon of the Ellipse to an Inverse-Square Force: Why Not?" in *Reading Natural Philosophy* (cited above), pp. 31-70; and "The methodology of the *Principia*," in *The Cambridge Companion to Newton* (cited above), pp. 138-173. (With no derogation to the merits of the other articles cited here, I should lke to call poarticular attention to the cited paper of George Smith in *Reading Natural Phiilosophy* as an especially illuminating study of Newton's methodological procedure in a crucial point of his argument.)