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HEGEL AND THE CELESTIAL MECHANICS OF NEWTON AND EINSTEIN

My object here is, first, to review Hegel's criticism of Newton's 'system of the world' and then to examine critically the many aspects of it that seem to anticipate the approach to mathematical physics, which is today associated with the name of Einstein.

One must emphasize that Hegel's criticism was well informed. Certainly he knew the *Philosophiae naturalis principia mathematica* and *Opticks* first hand and had the requisite training in mathematics to comprehend what he read. Through hundreds of well-documented pages of his *Science of Logic* (large and small) and *Philosophy of Nature*, Hegel explores the meaning of Newton's fluxional calculus, his concepts of space, time, mass, inertia, centripetal and centrifugal forces, his laws of motion, his gravitational world-system, and, finally, his theory of light and colors. Particularly under the headings 'Quantity' and 'Measure' in the *Logic* and 'Mechanics' in the *Philosophy of Nature*, Newton's doctrine provides much of the empirical datum upon which the Hegelian philosophical dialectic operates. And that represents no small tribute to the achievement of Newton, especially when we bear in mind that, according to Hegel, "without the working out of the empirical sciences on their own account, philosophy could not have reached further than with the ancients" (*HP* **3**, p. 176).[1]

I

Unfortunately for Hegel's reputation, some of his pages on Newton have a vein of rather heavy-handed humor running through them that can easily be mistaken for *lèse-majesté* or, worse, an ethnic slur against the British people. Such passages are few, but ethnic pride and sensitivity have sought them out; and, at least among sanguine admirers of the greatness of Newton – *qui genus humanum ingenus superavit*[2] – their effect has been to draw upon Hegel an imputation of gross scientific ignorance and presumption.

Even at its worst, however, Hegel's criticism nowhere matches the sustained sarcasm of the anti-Peripatetics of the century before Newton – the Galileos and Bacons, for instance – who pilloried Aristotle for his 'bad' science, regardless of the fact that he had been revered for centuries as, in

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Dante's phrase (*Inf.* IV, 131), the "teacher of those who know" – *maestro di color che sanno.* Still, there is no denying that the Newtonian *sacramenta* are subject to much abuse in the pages of the German philosopher; and, despite the reigning relativism of our age, it is a bold scholar who will presume, as J. N. Findlay has, to qualify it as "much *fine* abuse."[3]

Admittedly hard to take, on a first reading, is Hegel's comparison of Newton with Molière's *bourgeois gentilhomme* – all to the advantage of the latter! Molière's M. Jourdain was "surprised to learn that he had talked prose all his life, not having had any idea that he was so accomplished"; but he, at least, learned – Hegel observes – whereas Newton seems never to have realized "that he thought in and had to deal with notions of the understanding, while he imagined he was dealing with physical facts" (*HP* **3**, pp. 323–324). On the same level is Hegel's discussion of what the English generally understand by the term Philosophy and why it is that among them "Newton continues to be celebrated as the greatest of philosophers." In England, he explains, not only the empirical sciences but also the mechanical arts are confounded with philosophy; "and the name goes down as far as the price-lists of instrument-makers." With grudging admiration, as well as irony, Hegel in the same passage commends the heirs of the tradition of Bacon and Newton for at least taking the name of philosophy seriously enough to apply it to the study of matters of the greatest importance to them – like political economy, free trade, and the imperial administration, as well as chemistry, mineralogy, natural history, agriculture, and the arts – whereas in most other lands "the name of philosophy is now generally used only as a nickname and insult, or as something odious" (*L* [W, 1975], § 7, pp. 11–12).[4]

More abusive, from a Newtonian standpoint, is Hegel's rejection of the *Principia*'s 'proofs' of Kepler's laws – proofs which he characterizes as "demonstrational jugglery and counterfeiting" (*SL* [J/S] **2**, p. 290); and most offensive of all, perhaps, is his assessment of the *Opticks*, where he speaks not only of *ineptitude, incorrectness*, and *thoughtless inconsistency*, but also of *stupidity, blind prejudice*, and *dishonesty* (*PN*, § 320, *Remark*, p. 199).[5]

It is no wonder, therefore, that, for longer than a century in Newton's English-speaking world, most scholars have responded by refusing to take Hegel's *Naturphilosophie* seriously, or even to read it at all – as, it is said, the seventeenth century Aristotelians of Padua refused to take Galileo seriously, or even to look through his optical tube. The fact is that, whereas the French and Italians, less sensitive to criticism of Newton, have had translations of the complete *Encyclopedia* of Hegel, including the *Naturphilosophie*, since the 1860s, the English-speaking academic community, on the contrary, has

delayed until this bicentennial anniversary of Hegel's birth the labors of filling the gap between the excellent versions of the *Logic* and the *Philosophy of Mind*, which Professor Wallace provided three generations ago.

But this year is destined evidently to mark a turning point in the fortunes of Hegel's *Philosophy of Nature*. Thanks largely to the sustained interest of Professor Findlay, we now have an excellent translation – that of A. V. Miller – presented to us by Findlay with a challenge that the Anglo-American academic community will sooner or later have to accept. Back in 1958, Professor Findlay had written of the *Naturphilosophie*:

> This part of the system is one that many Hegelians have thought fit to ignore entirely, mainly on account of the outmoded character of the science on which it reposes. Nothing can, however, be more unfit than this ignoring, and, in view of Hegel's undoubted greatness, more impertinent. The *Philosophy of Nature* is an integral part of Hegel's system, and one can no more understand that system without taking account of it, than one can understand Aristotelianism while ignoring the *Physics* or the *History of Animals*, or Cartesianism while ignoring the physical portions of the *Principles of Philosophy*. In Hegel's theory of Nature, as in the parallel theories of Aristotle and Descartes, one sees the philosopher's principles at work, casting their slant upon our talk and thought about the world around us. The complete misunderstanding of Hegel's idealism by British philosophers, and its reduction to a refined form of subjectivism, are probably due to their ignoring of the *Naturphilosophie*.
>
> . . . Hegel's grasp of contemporary science was, moreover, informed and accurate: the reading of the *Naturphilosophie* is made easy by its wealth of experimental illustration, and by its long citations from contemporary treatises. Hegel *gives* one the sciences of his own day, together with the interpretations he puts on them. [His views remain] as worthy of study, and of detailed scholarly comment, as are the views of Aristotle, or (in recent times) of Whitehead.[6]

In his foreword to the Miller translation, Professor Findlay says that his object in publishing it has been primarily utilitarian, to make its thought accessible "to students and teachers, particularly in regions where prejudiced simplifications might otherwise be their only route of access to it." The work itself is proof, he asserts, "that Hegel, like Aristotle and Descartes and Whitehead, is one of the great philosophical interpreters of nature, as steeped in its detail as he is audacious in his treatment of it." Praising its "thoroughgoing realism," Findlay concludes that what is to be admired most in it is Hegel's manifest "willingness, unusual in philosophers, to read, digest, and take full account of so much detailed scientific material, a willingness which puts him on a pinnacle of scientific information and understanding shared only by Aristotle" (*PN*, pp. viii-ix, xxv).

Thus, under unprecedentedly favorable auspices, we now have the

Philosophy of Nature before us in a thoroughly English context. There can no longer be, therefore, any excuse among us for the 'impertinence' of ignoring its doctrine – including the details of its criticism of Newton. Still, it remains to be seen how that criticism will fare under the closer scrutiny it is now certain to receive. Studied popularly in its fulness, it may appear to be all the more presumptuous and ill-informed and lead to a general discrediting of the rest of the Hegelian System – the *Philosophy of Mind* as well as the *Logic* – precisely on the grounds that the System is an integrated whole. "Nature, and the world or history of spirit, are the two realities" – says Hegel in the closing pages of his *History of Philosophy*; and the "ultimate aim and business of philosophy is to reconcile the thought of the Notion with reality" (*HP* **3**, p. 545). If the Newtonian perspective, which is also the Darwinian, is true, and the Hegelian perspective false, what is the use, apart from antiquarianism, of a renaissance of interest in the *Naturphilosophie*? If Hegel's notion of the reality of nature is inadequate, then there can be no truth, no *adaequatio intellectus et res*, in his general synthesis. And, except for truth's sake, why should the Anglo-American academic community take Hegel seriously when it can get as much of German dialectical philosophizing as it apparently needs in the doctrine of Karl Marx, which leaves the greatness of Newton and of Darwin intact?

II

Before focusing on Hegel's systematic elaboration of his criticism of Newton's science which is developed in the larger *Science of Logic* and culminates in the *Philosophy of Nature*, we would do well to consider briefly the condensed expressions of it in scattered pages of his *Phenomenology of Mind, History of Philosophy*, and smaller *Logic*. Newton is not named in the *Phenomenology*, but his chief contribution to the development of scientific thought – the concept of force – is taken up as part of the phenomenology of consciousness under the heading "Force and Understanding, Appearance and the Supersensory World (*Kraft und Verstand, Erscheinung und übersinnliche Welt*)." In attempting to understand the perpetual flux of the world of appearances (*phenomena*), consciousness labors to look through the phenomena to see what, in reality, sustains them. In the process of 'thinking through' appearances, the understanding, Hegel says, discovers or fashions for itself a supersensory model which stands for it in place of the complexities of the restless sensory world. As Hegel expresses it, continued reflection develops that supersensory model into a

"kingdom of laws," which is "no doubt beyond the world of perception – for this exhibits the law only through incessant change – but likewise present in it, and its direct immovable copy or image" (*Phen* [B], p. 195).[7]

In the first stages of this reduction of phenomenal complexity to the simplicity of reflection, laws of the understanding are discovered or formulated singly, to account for a relatively narrow range of phenomena. But the understanding longs for unified comprehension; and its tendency is, as Hegel says,

> to let the many laws coalesce into a single law, just as, e.g., the law by which a stone falls, and that by which the heavenly bodies move have been conceived as one law. When the laws thus coincide, however, they lose their specific character. The law becomes more and more abstract and superficial, and in consequence we find as a fact, not the unity of these various determinate laws, but a law which leaves out their specific character; just as the one law, which combines in itself the laws of falling terrestrial bodies, and of the movements of celestial bodies, does not, in point of fact, express both kinds of laws. The unification of all laws in universal attraction expresses no further content than just the bare concept of law itself, a concept which is therein set down as existing. Universal attraction says merely that all things retain their difference with respect to one another. The understanding presumes that in this it has found a universal law that expresses universal reality as such; but in fact it has merely found the notion of law in itself, though in such a way as to permit it to assert that all reality, in itself, is subject to law (*Phen* [B], pp. 196–197).

The important point to stress here is that Hegel exhibits this activity of the understanding as an essential moment in the phenomenological process. What Newton did *had* to be done by human consciousness. The idea of universal gravitation "is therefore of the greatest importance," Hegel concludes, "because it is directed against the unthinking way of representing reality that makes everything appear to have happened by accident, and for which qualitative distinctiveness has the form of merely sensory differentiation" (*Phen* [B], p. 197).

Newton thus comes off rather well in the *Phenomenology* – in marked contrast with the caustic treatment we get of him in the lectures on the *History of Philosophy*. There Hegel calls the author of the *Principia* an intellectual "barbarian" for having treated the basic concepts of his natural science as if they were physical facts – sensuous things, to be dealt with "as men deal with wood and stone." Especially barbaric, according to Hegel, was the Newtonian attitude summed up in the maxim, "Physics, beware of metaphysics," which amounts to saying, "Science, beware of thought." The worst of it is, Hegel continues, that physical scientists since Newton's time have for the most part

faithfully observed this precept, inasmuch as they have not entered upon an investigation of their conceptions, or thought about thoughts . . . . And this is even now the case. In the beginnings of physical science we read of the power of inertia, for instance, of the force of acceleration, of molecules, or centripetal and centrifugal forces, as of facts which definitely exist; what are really the final results of reflection are represented as their first grounds (*HP* **3**, p. 323).

Yet here again, Hegel acknowledges the value of Newton's scientific work in "introducing to physics the determinations respecting forces, which pertain to reflection." By setting "the laws of forces in the place of the laws of phenomena," Newton "raised science to the standpoint of reflection," and for that he deserves high praise. He is to be blamed, according to Hegel, only for imagining that he is still functioning on the level of sensory perception, free of metaphysics, when, by undertaking to 'compose' the empirically-derived laws of phenomena out of the interrelations of 'component' forces, he has obviously slipped back into metaphysics without knowing it – which is to say, ignorantly. The harshest part of Hegel's judgment here is his prophecy that physical science will make no significant advance in the theoretical sense until it gives up the naive Newtonian dogmatism that confounds abstract concepts of the understanding with the reality of nature (*HP* **3**, pp. 322–324).

That surely was a 'hard saying' in the first decades of the nineteenth century. Today, however, it has become the prevailing view of the most expert practitioners in the field. In his *Physics and Microphysics*, for instance, the Nobel Prize-winning physicist Louis de Broglie writes:

For scientists, and in particular for the theorists, there is a certain danger in trying to ignore the efforts of philosophers and especially their work as critics . . . . Thus many scientists of the present day, victims of an ingenuous realism, almost without perceiving it, have adopted a certain metaphysics of a very materialistic and mechanistic character and have regarded it as the very expression of scientific truth. One of the great services that the recent evolution of physics has rendered contemporary thought, is that it has destroyed this simplified metaphysics, and with the same stroke has caused certain traditional philosophic problems to be considered in an enterely new light . . . . For the development of science to continue, we must embark on, or at any rate touch upon, questions of philosophic import and sometimes consider their new and very original solutions.[8]

Discussing the reluctance of the Newtonians to abandon their long-cherished concepts of space, time, motion, and force, the same author observes that too many physicists even today would no doubt "prefer merely to perfect and amend the existing theories rather than be obliged constantly to reconstruct

them." But a willingness to abandon long-cherished concepts is, he concludes, "the condition and ransom of scientific progress."[9]

In the smaller *Logic*, Hegel does not explicitly discuss the Newtonian celestial mechanics. He does, however, discuss the logical presuppositions upon which any analysis of laws of phenomena (such as Kepler framed) into laws of forces (such as Newton framed) ought to be based, if it is to make philosophical sense. And this he does at considerable length under the subheadings 'Repulsion and Attraction', 'Quantity', 'Magnitude', 'Quantum', 'Number', 'Degree', 'Quantitative Ratio', 'Measure', 'Thing', 'Properties', 'Matter', 'Form', 'Phenomena', 'Forces', and 'Expression of Forces' – all of them terms we now familiarly encounter in contemporary treatises on post-Planckian physical theory.

Under the heading "Repulsion and Attraction," Hegel draws a parallel between Newtonian physics and the ancient atomism of Leucippus and Democritus. In both systems, particles of matter and an enveloping void are posited as the ultimate constituents of nature, with the void serving as a separating or repulsive principle. The Newtonian advance over the old doctrine consists in having posited "an attractive by the side of a repulsive force," which – Hegel acknowledges – "certainly gives completeness to the contrast" between the Democritean Full and Empty (*L* [W, 1975], § 98, p. 143). Still, what Aristotle criticized in ancient atomism remains to be criticized, according to Hegel, in the Newtonian doctrine.

The old atomists traced fixed patterns (equivalents of the Newtonian laws of forces) through all the manifold flux and multiplicity of the phenomenal world. But when required to say what, in the first place, caused the atoms to start bumping together, acting and reacting as they do in their great web of necessity, the reply of the Democriteans was simply: a primordial, fortuitous swerving, a whirl of indeterminate origin – which is another way of saying that, in the final analysis, like our modern Heisenbergians, Democritus ascribed all things to chance. ("*Democrito*," Dante wrote in the fourth canto of the *Inferno*, "*che 'l mondo a caso pone*" [who ascribes the world to chance][10] – and it can easily be demonstrated that, despite the popular view which holds that Necessity is the atomists' God, Dante's phrase is drawn straight out of the very precise Aristotelian analysis of the Democritean doctrine in Book IV of the *Physics* – an analysis upon which Hegel dwells in his Lectures on the *History of Philosophy*.) The Newtonians, when all is done, do precisely the same – Hegel argues; for, despite all their talk of matter and void, inertia and gravity, it is a *chance thrust* dating from some indeterminate moment of the remotest past that is assumed to have originally set the planets in course

to be pushed and tugged as they are by centrifugal as well as centripetal forces.

Hegel's concern in all of this is to indicate that the Newtonian mechanics, despite pietistic and deistic protests to the contrary, is essentially a materialist doctrine. He is, of course, aware that, as a man of God, Newton strenuously resisted the assimilation of his doctrine to that of the avowed materialists. "I feign no hypotheses" about final causes, Newton had pleaded in the celebrated General Scholium of the *Principia*, where, indeed, he explicitly rejects as untenable the Cartesian theory of vortices on the grounds that no merely mechanical causes could give birth to so much orderly motion as we can trace in the heavens. By asserting that such orderliness presupposes an intelligent creation, Newton had hoped, as Hegel remarks, to leave unimpaired the "honor of God as the Creator and Governor of the World" while at the same time excluding him from consideration in the actual search for underlying forces (*L* [W, 1975], § 136, p. 195).

Under the sub-headings 'Force' and 'Expression of Force' in the smaller *Logic*, Hegel discusses at length why it is that Newtonian science would sooner or later have to give up its veneer of theistic piety. "Contrasted with its deinfinitized world of independent forces and matters," he writes, "the only terms in which it is possible to describe God will present him in the abstract infinity of an unknowable supreme Being in some other world far away." And that, Hegel continues, is "precisely the position of materialism," from as far back as Democritus and Epicurus down to the "free-thinking" deism and agnostic atheism of the Enlightenment. The medieval Church, confronted with the renaissance of ancient doctrines, was in that respect right, therefore, Hegel says, in resisting the "search for underlying causes" as impious, as tending to deny to God the things that are God's, which are assigned instead to indeterminate causes. From the vantage point of religious faith, no less than from that of philosophy, it must be acknowledged, Hegel says, that "the finite forms of the understanding certainly fail to fulfill the conditions for knowledge either of Nature or of the formations of the world of Mind as they truly are" (*L* [W, 1975], § 136, p. 195).

Yet while religion has a right to be dissatisfied with the results, it has no right to frustrate the labors of the understanding, whose 'finite forms' are – for Hegel – indispensable moments in the development of consciousness to the level of truly scientific comprehension. In words that anticipate the scientific posture of Pierre Duhem in the concluding sections of his masterful *Aim and Structure of Physical Theory,* Hegel writes against the false claims of religious piety:

On the other hand, it is impossible to overlook the formal right which, in the first place, entitles the empirical sciences to vindicate the right of thought to know the existent world in all the speciality of its content, and to seek something further than the mere abstract faith that God creates and governs the world. When our religious consciousness, resting upon the authority of the Church, teaches us that God created the world by his almighty will, that he guides the stars in their courses, and vouchsafes to all his creatures their existence and their well-being, the question Why? is still left to answer. Now it is the answer to this question which forms the common task of empirical science and of philosophy (*L* [W, 1975], § 136, p. 195).

Defending the practice against the piety of the Newtonians, Hegel asserts that when religion appeals to the 'unsearchableness' of the decrees of God, it is, in effect, aping the agnosticism of the enlightenment rationalists. "Such an appeal," he concludes, "is no better than an arbitrary dogmatism which contravenes the express command of Christianity, to know God in spirit and truth, and is prompted by a humility which is not Christian, but born of ostentatious bigotry" (*L* [W, 1975], § 136, p. 196).

III

The larger *Science of Logic*, which provides what amounts to a running commentary on the terse paragraphs of the *Logic* of the *Encyclopedia*, takes us to the philosophic core of Hegel's criticism of the Newtonian celestial mechanics. No one pretending to assess the adequacy of that criticism can afford to ignore, or skim over, what Hegel has to say about Quantity, Quantum, and Quantitative Ratio in his book-length discussion of 'Magnitude', or about Specific Quantity, Real Measure, and the Measureless (as transition to Essence) under the heading 'Measure', or about Mechanism, Chemism, and Teleology under the heading 'Objectivity'. As in the smaller Logic, Hegel is here examining the preconceptions and methods of study of all sciences that take not abstractions but the concrete realities of nature and mind as their qualitatively determined objects.

Under 'Magnitude' and 'Measure', Hegel examines, among other things, the basic notion of the Newtonian-Leibnizian calculus and traces the history of the mathematical infinite and infinitesimals upon which that calculus is built; he considers at length the difficulties of assimilating analytical calculus to analytical geometry and of applying both to the analysis of accelerated rectilinear and non-uniform curvilinear motion; and, anticipating things to come in our own time, he speculates on the possibility of developing a mathematics of qualitative quanta which would be a science of measures, competent to deal with the qualities as well as the quantities of existent

things (as, for instance, Einsteinian and Planckian physics now deals with qualitatively determined quanta, or measures, of space, time, light, and a host of electro-magnetic phenomena).

The first explicit reference to Newton comes under the sub-heading 'Quantum' and it consists of singularly high praise. Considering the "chief determinations which have been offered in mathematics about the infinite," Hegel asserts unequivocally that "no correcter determination of the thought can be made than that offered by Newton." The problem of the mathematical infinite is ancient. It was first clearly defined by the Eleatics (notably Zeno) in their efforts to demonstrate the irrationality of the Heraclitean 'flux'; and Zeno's paradoxes have remained vital paradoxes for mathematical physicists to this day – Hegel insists – despite all the walking to and fro of old Diogenes and cynics of more recent times. That Hegel was competent to deal with the problem in its abstractest geometrical and algebraic as well as logical aspects, he has amply demonstrated not only in the *Science of Logic* itself, but also in the *History of Philosophy*, where he takes it up as often as it surfaces in his sources.

Newton tells us that he "invented the methods of series and fluxions in the year 1665," and his first published treatise on the subject, *Methods of Fluxions and Infinite Sequences*, appeared in 1674. But Hegel is concerned, as he says, with Newton's maturest thought on the subject, which is that of the *Principia*. Hinting at what he will later criticize, Hegel writes:

> I here set apart the determinations belonging to the idea of motion and velocity (from which latter chiefly he took the name of *fluxions*), for there the thought appears not in its due abstraction, but concrete and mixed with unessential forms.

In praise of the duly abstract thought, Hegel says:

> Newton explains these fluxions (*Princ. Mathem. Phil. Nat. L. i. Lemma XI, Schol.*) by saying that he takes them not as *indivisibilia* (a form used by earlier mathematicians, Cavalieri and others; it contains the concept of a Quantum determinate in itself), but as vanishing *divisibilia*; and, further, not as the sums and ratios of determinate parts, but as the limits (*limites*) of the sums and ratios. It will be objected, he says, that vanishing magnitudes have no final ratio, because the ratio before they vanish is not the last, and, after they have vanished, no longer exists. But by the ratio between vanishing magnitudes must not be understood the ratio that exists either before or after, but that *with which* they vanish (*quacum evanescunt*). And, similarly, the first ratio of becoming magnitudes is that *with which* they arise (*SL* [J/S] **1**, pp. 271–272).

After noting that the "magnitudes at the point of vanishing" are understood by Newton to be "quanta no longer," Hegel makes clear that, in his judgment,

Newton has here adequately expressed the notion of transition from quantity to quality which is so essential an element in the Hegelian dialectic. As much Newtonian as Hegelian is the statement that: "The limit of the magnitudinal ratio is that point where it is and it is not – or, more precisely, where the Quantum has vanished, and the ratio, therefore, is preserved only as qualitative quantity-ratio" (*SL* [J/S] **1**, p. 272).

But while Newton grasped the concept of the qualitative quantity-ratio and expressed it clearly, in practice – says Hegel – the author of the *Principia* let it slip through his fingers. And the same must be said of the other great mathematicians of the period, including Newton's master Barrow, as well as Fermat, Leibniz, Lagrange, Landen, Euler, and their successors. It seems, Hegel writes, that "when mathematicians turn to practice, the finite determinateness of quantity returns, and the operation can no longer do without the idea of a Quantum which is merely relatively small" (*SL* [J/S] **1**, p. 277). Indeed, the idea of the relatively small, of increment, of addition, "of growth of x by dx or i, and so on," Hegel concludes, "must be considered the fundamental evil inherent in these methods – as an enduring obstacle which makes it impossible to disengage the determination of the qualitative moment of quantity from the idea of ordinary Quantum" (*SL* [J/S] **1**, p. 274). In other words, the evil is that those "ghosts of departed quantities" (as Bishop Berkeley called them) are too easily mistaken for never-perishing *indivisibilia*, and the transition from quantity to quality is lost to thought.

If mathematicians could take another approach so as to develop a mathematics of qualitative quantity-ratios, Hegel observes, the result would be a magnificent instrument for the advancement of a truly physical as distinct from an abstractly mechanical science. Such a mathematics, he writes, would have to be in essence –

> a science of measures – a science for which much has been done empirically, but little in a truly scientific, that is philosophic, manner. Mathematical principles of Natural Philosophy – as Newton called his work – if they were to fulfill this determination in a philosophic and scientific meaning deeper than that which was reached by Newton and the whole Baconian generation, must contain quite other things in order to bring light into these regions, dark as yet, but most worthy of contemplation (*SL* [J/S] **1**, p. 361).

Later, in the *Philosophy of Nature*, Hegel will add on this theme:

> The truly philosophical science of mathematics as *theory of magnitude*, would be the science of *measures*; but this already presupposes the real particularity of things, which is found only in concrete *Nature*. On account of the *external* nature of magnitude, this would certainly also be the most difficult of all sciences.

Newtonian science, Hegel stresses, is not a science of measures. In fact, all that most needs to be measured in nature – the actualities of space, time, and the light by means of which spatial measurements are possible – is taken for granted by the Newtonians, exactly as defined in the abstract presuppositions of their calculus. That calculus was developed, it is true, to deal with motions of qualitatively determined phenomena; but, in the process, the traditional mathematical spirit of abstraction took over. Forgetting the qualitative forms of the phenomena of falling bodies and orbiting planets, the mathematicians focused on the terms of the ratios in the formulas – with the result that products of analysis (of the decomposition of the magnitude of a phenomenon, such as motion) there received, in Hegel's words –

> an objective meaning, such as velocity, accelerated force, and so on; according to this newly acquired objective meaning they were to produce correct propositions and physical laws; their objective connections and relations, too, were to be determined by analytic means; for instance, it was said that in a uniformly accelerated motion, there existed a special velocity proportional to the periods of time, while besides, an accretion was added uniformly from the force of gravity. In the modern analytical form of mechanics such propositions are regularly cited as results of the calculus (SL [J/S] **1**, p. 289).

Hegel was well aware that Newton had not arrived at the conclusions demonstrated in Book Three of the *Principia* (where the universal law of gravitation is expounded as the System of the World) by means of the analytical calculus and geometry he uses there. Newton himself says, at the beginning of that book, that the method of exposition there was an afterthought, and that he introduced it rather to prevent than to facilitate general understanding. He had at first, he says, written the entire book in a more direct, popular way; but afterwards, "considering that such as had not sufficiently entered into the principles could not easily discern the strength of the consequences, nor lay aside the prejudices to which they had been many years accustomed," Newton decided to avoid any direct confrontation with ignorance and prejudice by choosing "to reduce the substance of this Book into the form of Propositions (in the mathematical way), which would be read by those only who had first made themselves masters of the principles established in the preceding books."[11]

What might have become of the great law of universal gravitation of that Third Book, had Newton not *reduced* his exposition to the form of Propositions, in a mathematical way, one can hardly guess. But perhaps the Ernst Machs and Einsteins would have got at its absolute space and time, the essentially non-empirical character of its laws of motion, and its oddly

convenient equivalence of inertial and gravitational mass, much sooner. In the light of what has since become the fate of Newton's mathematical 'proofs', it was eminently fair and extraordinarily perceptive for Hegel to have said over 150 years ago:

> It will be impossible to deny that in this sphere much has been accepted as proof – chiefly veiled under the kindly mist of the infinitesimally small – on no other ground than that the result was already known beforehand, and the proof, which was arranged in such a manner as to produce the result, at least effected the illusion of a framework of proof – which illusion was preferred to mere belief or empirical knowledge. But I do not hesitate to regard this method as no better than demonstrational jugglery and counterfeiting; and I include even some of Newton's demonstrations, and especially such as belong to those just mentioned, for which Newton has been extolled to the skies and above Kepler, because what Kepler had discovered empirically *he* demonstrated mathematically (*SL* [J/S] **1**, p. 290).

Hegel then proceeds to explain that, by its very nature, the mathematics of Newton and his peers is unable to "prove the magnitudinal determinations of physics in so far as they are laws based upon the qualitative nature of the moments." The qualitative element is lost in the processes of the calculus; and it is rather a moral than a scientific question why, to many mathematicians, it has seemed against the honor of their discipline – so Hegel phrases it – to "acknowledge simply experience as source and sole proof of empirical propositions" (*SL* [J/S] **1**, p. 290).

Needless to say, Hegel has long since won his point on this score. Modern mathematicians and the best mathematical physicists of recent years are all of a mind in acknowledging – and indeed often boasting – that they no longer hold, with Galileo, Descartes, and Newton, that mathematics of itself, or mathematically conducted experiments, can lead to true knowledge of the realities of Nature. As Professor Tobias Dantzig expressed it in his *Number: The Language of Science:*

> The mathematician may be compared to a designer of garments, who is utterly oblivious to the creatures whom his garments may fit. To be sure, his art originated in the necessity for clothing such creatures, but this was long ago; to this day a shape will occasionally appear which will fit into the garment as if that garment had been made for it. Then there is no end of surprise and delight! There have been quite a few such delightful surprises. The conic sections, invented in an attempt to solve the problem of doubling the altar of an oracle, ended by becoming the orbits followed by the planets in their courses about the sun .... The absolute differential calculus, which originated as a fantasy of Riemann, became the mathematical vehicle for the theory of Relativity .... Mathematics and experiment reign more firmly than ever over the new physics, but an all-pervading skepticism has affected their validity. Man's confident belief in the absolute

validity of the two methods has been found to be of an anthropomorphic origin, both have been found to rest on articles of faith.[12]

Bertrand Russell, who (with Alfred North Whitehead) gave us an updated *Principia Mathematica* in 1914, has said to the same effect: "It is a curious fact that, just when the man in the street has begun to believe thoroughly in science, the man in the laboratory has begun to lose his faith"; and, again: "Science, which began as the pursuit of truth, is becoming incompatible with veracity, since complete veracity tends more and more to complete scientific scepticism."[13]

But the truly great scientists of our time, the Einsteins and Plancks, have not been content that mathematical science, which once boasted of its certainty, should now boast of its uncertainty. Einstein admits that, in its pursuit of the open questions of the Galilean and Newtonian mechanics, mathematical science has been led inevitably – as Hegel predicted – to Democritean, or Heisenbergian, indeterminism. But, according to Einstein, that is hardly an outcome to gladden the scientific heart. "Some physicists," he wrote in 1941, "among them myself, can not believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time."[14] Hegel, too, refused to abandon that idea. Like Aristotle long before him, he sought, by means of a dialectical criticism of the limits of mechanistic science and its mathematical methods, to prepare the way for a truly philosophic science of nature – a science that can not only represent but also comprehend in its truth the qualitative reality of nature, from the merest externality and duration of space and time, up through the great chain of inorganic and organic being, to the animal existence – birth, life, health, reproduction, disease, and death – of thinking man.

IV

With one notable exception, all references to Newton in the *Philosophy of Nature* are confined to the first part – Mechanics – where the object of study is matter in the abstract, as contrasted with the qualified matter of Physics and the living matter of Organics. Under Mechanics, the sub-divisions are: 'Space and Time' (including the abstract concepts of Place and Matter); 'Matter and Motion, Finite Mechanics' (including the concepts of Inert Matter, Thrust, and Falling); and 'Absolute Mechanics' (with Universal Gravitation, Kepler's Laws, and Transition to Physics as sub-headings). The

subdivisions and subheadings obviously represent a graded order, ranging upward from the simplest and most abstract object of study in mechanics (space) to what in Hegel's judgment is the most complex and least abstract (the solar system as described in Kepler's laws). The fact that Universal Gravitation is placed beneath Kepler's Laws in the graded order reveals at a glance that here, as elsewhere, Hegel will represent Newton's 'System of the World' to us as a 'reductionist' analysis of a higher into the terms of a lower determination.

In the whole range of Mechanics – Hegel writes – "bodies exist only as points; what gravity determines is only spatial interrelations of points. The unity of matter is only the unity of the place it seeks, not the unity of a concrete One. That is the nature of this sphere." And yet, on its highest level of development, Mechanics is able to transcend its own abstract character; for, in its descriptive laws of the solar system – tracing a pattern of elliptical orbits about an energizing center – it comprehends the notion of what matter, as manifest motion, must really be in itself. In a startling anticipation of the vision of Niels Bohr, Hegel writes:

> What the solar system is as a whole, matter is now to be in detail . . . . The determinations of form which constitute the solar system are the determinations of matter itself and they constitute the being of matter. The determination and the being are thus essentially identical; but this is the nature of the qualitative, for here, if the determination is removed, the being, too, is destroyed. This is the transition from Mechanics to Physics (*PN*, § 271, *Z*, pp. 83–84).

The whole of Newtonian science is comprehended within the abstract range of Mechanics, excepting only the theory of light of the *Optics* – Newton's one major attempt to make the transition from Mechanics to Physics (in Hegel's sense of the terms). Newton had confidently imagined that, with the method of the *Principia*, he could easily make that transition, and then move on from Physics into Organics to complete his Natural Philosophy. But in Hegel's judgment, as in the judgment of Einstein and his peers, Newton's attempt to comprehend scientifically the phenomena of light was a failure, and foredoomed to be a failure because of the inadequacies of its analytical, decompositional method. Just as Newton decomposed the ellipses of Kepler's laws into rectilinear components, thereby depriving them of their qualitative identity, so he decomposed the fluid transparency of white light into colored corpuscles, which he declared to be primary and simple; and, with that, the qualitative, distinctive actuality of light slipped out of his scientific grasp.

Hegel was aware that Light – which for him as for Einstein was the first physical manifestation of matter – united qualitatively the characteristics of abstract corpuscular and wave motions; he knew also that light, in reflecting, refracting, and otherwise manifesting itself, shows all the colors of the entire universe, including those revealed in the dark when a prism is set up, just right, as a divider between light and dark. But, about the corpuscular and wave theories, Hegel held that they were both one-sided, and therefore inadequate approaches to the dialectical notion of light in its qualitative unity. Hegel writes:

> Light is an interesting theme to treat; for we think that in Nature we have only the individual, *this* particular reality. But light is the very opposite of this .... In thinking of light, we must renounce all conceptions of composition and the like .... The expression 'bundles of rays' is merely one of convenience, it means nothing; the bundles are light in its entirety, which is only outwardly limited; it is no more divided into bundles of rays than is the Ego or pure self-consciousness. It is the same when I say: in *my* time or in Caesar's time. This was also the time of everyone else; but here I am speaking of it in relation to Caesar, and restrict it to him without meaning that he really had a separate ray or parcel of time. The Newtonian theory according to which light is propagated in straight lines, or the wave theory which makes it travel in waves, are, like Euler's aether or the vibration of sound, materialistic representations quite useless for the comprehension of light (*PN*, § 276, *Z*, pp. 93–94).

But the best, in this extraordinarily thorough anticipation of things to come in physical theory, is what follows – where Hegel rejects (as modern Quantum Physics rejects) the notion that the wave theory is superior to the corpuscular theory. According to the wave theory, he writes –

> the dark element in light [the color-producing element] is supposed to run through the movement in a series of curves which can be mathematically calculated; this abstract determination has been introduced into the theory, and is nowadays thought to be a great triumph over Newton. But this is nothing physical; and neither of these two ideas is in place, since nothing empirical obtains here. There no more exist particles of light or waved aether than the nerves consist of a series of globules, each receiving an impulse and setting others in motion (*PN*, § 276, *Z*, p. 94).

Hegel died, it is to be noted, more than a generation before the birth of the people who are usually honored in our catechisms of popular science for having discussed such matters for the first time. Also on the *speed* of light, Hegel anticipates the pioneers, writing:

> The propagation of light occurs in time, since, being an activity and an alteration, it cannot dispense with this moment .... The distances which light is supposed to travel involve time; for illumination, whether through a medium or by reflection, is a modification of matter requiring time (*PN*, § 276, *Z*, p. 94).

But the speed of light is not, according to Hegel, like the speed of other physically determinate manifestations of matter. In the sphere of *qualified* as distinct from abstract matter, light is primary – the first, and therefore *limiting* manifestation of matter in motion. The sun, says Hegel, does not pour out its light *incidentally* while serving as the central material point of the solar system. That system's orbital structure is the inner form of matter itself, as we have noted, and it is that circling about a center that shows itself physically as light. But, as each particle of matter is a microcosmic solar system, all matter is – for the eye that can discern its true, centralized orbital speeds – luminous. Again in a thoroughly Einsteinian vein, Hegel characterizes Light as the "self-contained totality of matter," explaining that, as an "existent, space-filling force," it is "absolute velocity, pure materiality which is everywhere present, real existence which remains within itself, or actuality as transparent possibility." "Light," he concludes, "brings us into the universal interrelation; everything exists for us in theoretical, unresistant fashion because it is in light (*PN*, § 275, *Z*, p. 88).

Einstein has told us that it was as a consequence of the labors of Faraday, Clerk Maxwell, and Hertz, but particularly of Maxwell, in the study of light and electro-magnetic phenomena, that modern science generally abandoned the established view that Galilean-Newtonian mechanics could stand as the "basis of all physics." Attempts to solve the difficulties of application of the Newtonian principles to the newly-developed spheres led first to formulation of the field theory of electricity, then to the effort to base all physics upon the concept of field, and finally to the theory of relativity, which is the "evolution of the notion of space and time into that of the continuum with metric structure,"[15] which is in our view then qualitatively determined. "The general theory of relativity," Einstein has said with his usual respectful regard for the overthrown Titan of classical mechanics, "formed the last step in the development of the programme of the field-theory. Quantitatively it modified Newton's theory only slightly, but for that all the more profoundly qualitatively."[16]

Already in Hegel's day, the phenomena of magnetism, electricity, and chemism, together with those of light, were calling into being a unified science very different in principle from Newtonian mechanics. Scientific 'law' in the mechanical sense means, he explains, "the combination of two simple determinations such that merely their simple interconnections constitute the whole relationship, and yet each must have the show of independence with regard to the other" (*PN*, § 270, *Z*, p. 72). But such a concept of law has, he insists, a very limited range – that of mathematical abstraction. It will not do

in the study of bodies as they *actually* fall, or as they actually orbit around an energized center; but the inadequacy there may be obscured by assuming that the bodies in those qualitatively determined relationships are really nothing more than points in the geometric sense. It is otherwise, however, with the phenomena of light, magnetism, electricity, and chemism.

In magnetism, for instance, Hegel writes, "the inseparability of the two determinations is already posited"; consequently there is not a co-relationship of 'law' in the mechanical sense (*PN*, § 270, *Z*, p. 72). Magnetic phenomena, he explains, are not gravitational phenomena which mathematical analysis can, for its arbitrary convenience, separate into inertial as well as gravitational components. "Magnetism," he writes, "differs from gravity in this, that it forces bodies into a quite different direction from the vertical." Motion in the sphere, or 'field' of magnetism is not that of rectilinear attraction; but it is also "not rotary, not a curve upon itself, like the motion of the heavenly bodies, which is accordingly neither attractive nor repellent" (*PN*, § 313, *Z*, p. 171).

Summing up his case against scientific 'reductionism' in this sphere, Hegel continues:

> In all higher forms [as contrasted with the forms of abstract mechanics] the individualized whole constitutes the third in which the determinations are conjoined, and we no longer have the direct determinations of two things which are in relationship with each other.

Laws in the mechanical sense are possible for the planetary motions, he says, because those motions involve two distinct phenomenal elements – not to be confounded with the non-empirical centripetal and centrifugal forces. Those two phenomenal elements are "the form of the path and the velocity of the motion." But if such laws are to be comprehended in a higher principle so as to embrace the phenomena of light and magnetism as well, the "thing to be done," he concludes, "is to develop this from the Notion. This would give rise to a far-reaching science and the difficulty of the task is such that this has not yet been fully accomplished." (*PN*, § 270, *Z*, p. 72).

The men who have undertaken to develop that "far-reaching science" in our time have all started from the premise that it would have to be built up from the very bottom – from a rectification of the first 'reductionist' error of classical mechanics, which consisted in its positing space and time as only externally interrelated in the phenomena of motion. Identifying the essential element in Einstein's labors of rectification, Bertrand Russell wrote:

The scientific merit of Einstein's theory lies in the explanation, by a uniform principle, of many facts which are unintelligible in the Newtonian system. The philosophical interest lies chiefly in the substitution of the single manifold, space-time, for the two manifolds, space and time.[17]

How the original 'reductionist' error came to be made, Einstein himself has explained as follows:

The lack of definiteness which, from the point of view of empirical importance, adheres to the notion of time in classical mechanics was veiled by the axiomatic representation of space and time as things given independently of our senses. Such a use of notions – independent of the empirical basis, to which they owe their existence – does not necessarily damage science. One may however easily be led into the error of believing that these notions, whose origin is forgotten, are necessary and unalterable accompaniments to our thinking, and this error may constitute a serious danger to the progress of science.[18]

Literally billions of words have been written on this theme since Ernst Mach and then Einstein opened it up for the academic community of mathematical scientists. Yet in all that literary production, which still floods the markets today, there is, I am confident, no discussion of the reductionist error as profound or as philosophically consistent as Hegel's in the opening sections of his Mechanics, from which point he pursues the process of philosophical *rectification* up through the whole range of mechanics into those higher spheres of nature where to mathematize at all is to commit the gravest sort of reductionist error – unless one's purpose is avowedly reductionist and utilitarian.

In reviewing Hegel's approach to Newton in the *Philosophy of Nature*, we have started from the 'difficulties' of the phenomena of light and electromagnetism only because it has been from that standpoint that our contemporary science, always working 'reductionistically', has found its way back to the beginnings, ironically getting a reductionist satisfaction out of the effort to rectify the original reductionist error of Newton. Hegel pursued a 'reductionist' course in his great intellectual voyage of discovery, the *Phenomenology of Mind*; but in his systematic exposition of the doctrine of Mechanics, as in all the philosophical sciences of his *Encyclopedia*, he reverses that course, working his way up from the most abstract to the most concrete conceptions.

V

Although we have the assurances of the greatest practitioners that, in

mathematical science, intellectual insight and discursive reasoning (*nous* and *episteme*) come first and mathematization follows, many of us are still reluctant to believe that we are dealing with truly scientific thought when its utterance is not in equations. For those of us who feel that way, the best approach to Hegel's Mechanics is, as we have suggested above, through close study of the several hundred pages on 'Quantity' and 'Measure' in the larger *Science of Logic*, which bristle with formulas and constructions of the analytical calculus and geometry. Hegel was, as we noted, well trained in the higher mathematics. But, as a great philosopher in the Aristotelian tradition, he knows that the place of mathematically-shaped abstractions lies between the purely logical and the sensory, and that such shaped abstractions can be used meaningfully in natural science only after first principles (in mechanics, the principles of space, time, matter, and motion) have been logically determined in thought.

Early in the Mechanics, Hegel sums up the range of concepts he is about to explore. "Self-externality," he writes (linking the *Naturphilosophie* with what precedes it in his System),

> splits at once into two forms, positively as Space, and negatively as Time. The first concrete thing, the unity of these abstract moments, is Matter; this is related to its moments, and these consequently are related to each other, in Motion. When this relation is not external, we have the absolute unity of Matter and Motion, self-moving Matter (*PN*, § 253, *Z*, p. 28).

When mechanistic physics speaks of material 'points' in Space (as Newton does), the concept of Time, Hegel explains, is incidentally introduced. For the mathematical point, having no dimension, is obviously a negation of Space, and that is precisely what Time is. And it is the point of Time in space that traces the 'lines' of spatial dimensionality as its *loci*. Anticipating the need for the Riemann-Einsteinian advance, he observes:

> There is no *science of time* corresponding to the *science of space*, to geometry. The differences of time have not this *indifference* of self-externality which constitutes the immediate determinateness of space, and they are consequently not capable of being expressed when the Understanding has paralyzed it and reduced its negativity to the unit (*PN*, § 259, *Remark*, pp. 37–38).

Here is where Hegel observes that a science of *measures*, competent to deal with time in its negativity, as the moving-point of space, "would be the most difficult of all sciences."

Hegel then points out that, in its traditional meaning (philosophically defined by Aristotle), the term Place has always expressed "a posited identity

of space and time." That is a profound as well as obvious observation. The moderns who speak of the *space-time continuum* for want of a suitable single word, might do well to consider the long historical development of the doctrine of Place – a doctrine which, according to Pierre Duhem, holds the future of natural science. In our ordinary usage, Hegel notes, a thing in 'place' is understood to be a thing in space-time, here and now, or there and then. Zeno's paradox of motion, we are reminded, was defined as a space-time paradox of places. A thing at rest or in motion is in 'place' always, even though, in motion, we distinguish (as Hegel says) "three different places: the present place, the place about to be occupied, and the place which has just been vacated" – in which distinction the "vanishing of the dimensions of time is paralyzed." Yet it remains clear in all of this, Hegel continues, that "there is really only *one* place, a universal of these places, which remains unchanged through all the changes; it is *duration*, existing immediately according to its Notion, and as such is Motion" (*PN*, § 261, *Remark, Z*, p. 43).

Zeno's paradox shows that rectilinear motion, out of one place into another, no matter how far extended, contains no *measure* of itself, and is therefore not really motion. Having no *measure* means that it has no time, which is the measure of motion. Curvilinear motion that returns to its former places, on the other hand, contains its own measure. The lines of a space-time continuum (as contrasted with the timeless space of Euclidean geometry) must, therefore, curve back on themselves. With 'Einsteinian' insight, Hegel writes:

> This return of the line is the circle; it is the Now, Before, and After which have closed together in a unity in which these dimensions are indifferent, so that Before is equally After, and vice versa. It is in circular motion that the necessary paralysis of these dimensions is first posited in space. Circular motion is the spatial or subsistent unity of the dimensions of time .... It is motion in its essence, motion which has sublated the distinctions of Now, Before, and After, its dimensions or its Notion. In the circle, these are in unity; the circle is the restored Notion of *duration*, Motion extinguished within itself. There is posited *Mass*, the persistent, the self-consolidated, which exhibits motion as its possibility (*PN*, § 261, *Remark, Z*, pp. 43–44).

The so-called *mass*-point, in other words, is 'circling motion' in itself. I doubt that anything more profound has been written in modern times on the abstract foundations of mechanics. To sum up, and hurry forward, we may say: Anticipating the language of Ernst Mach, Einstein, and Planck, Hegel defines space and time as positive and negative determinations of Motion, which, in its self-circling, is Mass. Time is the restless, ubiquitous point of space that negates dimensionality in itself while generating the same as 'loci'

of its Future and Past. Time gives 'place' to the lines, planes, and volumes of space. And Hegel dares to conclude that 'moving place' or, as we usually say, *loco*motion, is the sole constituent of Matter.

Every time-point is thus a mass-point circling in itself: an essentially *moving* place that tends restlessly to circle 'out of place' and back into it. Thus this universal gravitation of time-points is simultaneously a moving away and a moving toward, self-repulsion from one center and attraction toward another. As Hegel expresses it: "Matter is both moments [repulsion as well as attraction] and their unity, centralized in a point, is gravity." Matter itself is "tending toward a center, but – and here is its other determination – a center located outside itself." More precisely: Gravity is not mere attraction, which is the tendency to negate spatial separateness and produce continuity. On the contrary, "gravity preserves both separateness and continuity" as moments of its concept (*PN*, § 262, pp. 44–47). And these moments, apprehended abstractly as repulsion and attraction, are destined to be narrowly determined as independent forces, centrifugal and centripetal (*PN*, § 269, pp. 62–65).

Those who take space and time abstractly, who conceive of 'matter' as 'occupying' space and as being 'acted upon' by independent forces of 'inertia' and 'gravity' have, in other words, taken rectilinear uniform motion as simple, and accelerated and curvilinear motion as composed. From Hegel's standpoint these are to be reversed. And in what he has to say on this point, "there is undoubtedly [as Professor Findlay has said of his concept of light] a flavor of relativity-physics."[19] Hegel says:

> That movement in general is movement that returns upon itself may be concluded from the determinations of particularity and individuality in a body, which give it an internal focus of separateness together with a tendency to join a center outside itself. These are the determinations underlying the concepts of centripetal and centrifugal force; these are then taken abstractly as independent vectors which, brought to bear accidently on the same inert body, give it the empirically observed motion. Thus you have the transformation of physical reality into lines that really serve only to facilitate mathematical expression (*PN*, § 270, *Remark*, pp. 68–69).

Before the development of a 'field' theory of gravitation in our own time, Hegel's application of the dialectic to analysis of physical phenomena had no counterpart in the mathematical thinking of physicists or astronomers. But now even children are familiar with a concept of geometric space suffused with a time that varies with each point of space, and with pictures of the circling centers of atomic particles. In terms less rigorous than Hegel's but not inconsistent with them, Einstein has written:

We have two realities: *matter and field* .... But what are the physical criterions distinguishing matter and field? Before we learned about the relativity theory we could have tried to answer the question in the following way: matter has mass, whereas field has not. Field represents energy, matter represents mass .... From the relativity theory we know that matter represents vast stores of energy and energy represents matter .... the division into matter and field is, after the recognition of the equivalence of mass and energy, something artificial and not clearly defined .... What impresses our senses as matter is really a great concentration of energy into a comparatively small space. We could regard matter as the regions in space where the field is extremely strong .... There would be no place, in our new physics for both field and matter, field [in Hegelian terms, 'moving place'] being the only reality. This new view is suggested by the great achievements of field physics, by our success in expressing laws of electricity, magnetism, gravitation in the form of structure laws, and finally by the equivalence of mass and energy.[20]

We noted in passing that it was on the basis of the field theory that the Einsteinians rejected the Newtonian principles of rectilinear inertial and gravitational motion, adopting a four-dimensional geometry in place of Newton's calculus to express mathematically their conception of an astronomical order in which inertial and gravitational mass are identified and the fundamental motion is curvilinear. And, while we cannot dwell on it, we should at least mention here that, at one point in his larger *Science of Logic*, Hegel speaks of the possibility of developing a four-dimensional space-time geometry to do justice to Kepler's laws. Such a geometry, Hegel says, "might prove powerful with regard to free movement, wherein one (spatial) side is governed by geometrical determination (in Kepler's law $s^3:t^2$), and the other (temporal) side by arithmetical determination." The mathematics of that geometry, Hegel suggests, might serve to comprehend the elliptical motions of planets in their uncomposed naturality, in a manner consistent with the Hegelian concept of matter and gravity (*SL* [J/S] **1**, p. 324).

VI

Hegel, as we said, places Kepler's laws of planetary motions at the apex of the grand pyramid of Mechanics. On that apex, looking beyond itself, mechanistic science transcends the abstract, and the transition is made into the sciences of qualified matter. Just below that apex Hegel sets the Galilean laws of falling bodies.

Of these laws, Hegel says: "they are immortal discoveries which redound to the greatest honour of the analysis of the Understanding." Still, in themselves they are not enough. "The next step," he continues, requires "their

proof independently of empirical methods." And such proof, according to the Newtonians, has already been supplied – furnished, allegedly, "by mathematical mechanics itself, so that even a science based on empirically-ascertained facts is not satisfied with the merely empirically *pointing out* (demonstration)." What Einstein and Planck and their peers have undertaken to do mathematically, beyond the sphere of the empirically verifiable, Newton also attempted to do; but, according to Hegel, his method was inadequate. Newton's 'proof' of Galileo's laws, Hegel says, takes for granted what those laws describe: the empirically-established fact of the uniformly-accelerated motion of a freely falling body. Newton's analytical treatment of that given fact consists, Hegel says,

> in the conversion of the moments of the *mathematical* formula into *physical* forces, into an *accelerating* force imparting one and the same impulse in each unit of time, and into a force of *inertia* which perpetuates the (greater) velocity acquired in each moment of time – determinations utterly devoid of empirical sanction and equally inconsistent with the notion (*PN*, § 267, *Remark*, p. 57).

In other words, Hegel indicates that Newton treats a heavy, falling body, which *naturally* gravitates toward a center outside itself, as if it were an inert body responding inertly to an external thrust or force – as if it were *not* itself essentially gravitational. "The motion of falling," Hegel writes, "forms the transition and middle term between inert matter and matter whose Notion is absolutely realized, that is, absolutely free motion." Inert matter is the abstraction of a single material point, conceived as having no time in itself. It will remain at rest, or, if moved, will move inertially as if it were at rest, the two being equally timeless and therefore not really distinguishable as rest and motion. On the other hand, "heavy matter in the motion of falling," Hegel writes, is at least "partly adequate to its Notion, namely, through the sublation of the Many, as the effort of matter to reach one definite place, as center." The next step in the determination of matter is that 'falling *toward*' a center must also be seen as 'repulsion *from*' a center – which is what the so-called fixed stars manifest in their 'constellational' pattern. Though in themselves they are matter orbiting about an energized center, with respect to one another, they are simply held in a rigid equilibrium of attraction and repulsion. The stars, says Hegel, "belong to the sphere of dead repulsion .... Matter, in filling space, erupts into an infinite plurality of [luminous] masses, but this, which may delight the eye, is only the first manifestation of matter."[21]

Not in abstraction as inert, not in falling, not in the rigid equilibrium of

stellar repulsion and attraction, but only in the absolute mechanics of universal gravitation – in the grand mechanics of the sun and planets, moons and comets – is the true Notion of matter realized.

As in his discussion of the Newtonian calculus and the concept of force, so here in his discussion of Newton's concept of universal gravitation, Hegel praises before he criticizes. "Universal gravitation," he writes, "must be recognized as a profound thought in itself, though it is especially by reason of the quantitative determinations bound up with it that it has attracted attention and credit." So far from criticizing the concept, Hegel takes it up as an essential moment of his system, which (it should be recalled) is, like Aristotle's, a system of gravitation, in which all components, those of the *Logic* and *Philosophy of Mind* as well as those of the *Philosophy of Nature*, are drawn together and sustained by a single principle that operates on or in them like a magnet on metal filings; or, better, like the command of a commander-in-chief to all his armies – a command that exists apart, perfectly, in the commander-in-chief, but which is also present in all the purposeful activities of the army on all levels. Hegel is more concerned than Galileo or Newton were with the *cause* of such universal gravitation; but, as we suggested earlier, he does not deny the right of empirical science to study the filings in a magnet field (or the moving multiplicity of nature as a whole for that matter) as if there were no underlying, magnetic mover.

The trouble with Newton's use of the notion of universal gravity in his treatment of Kepler's laws is the same we identified in considering his treatment of Galileo's laws. In Newton's "law," Hegel notes, "there are included, as we have shown, two moments" whose unhappy fate it has been "to be regarded as separate *forces*, corresponding to the forces of attraction and repulsion, more precisely determined as *centripetal* and *centrifugal* forces. These forces are conceived as *acting* on bodies, and as accidently and independently brought to bear upon a third something" – the material point of the pattern of motion under study. "In this way," Hegel goes on, "whatever deeper meaning might have been in the thought of universal gravitation is again lost"; and he predicts that science will not be able to "penetrate into the theory of absolute motion so long as the much-vaunted discoveries of *forces* prevails there" (*PN*, § 269, *Z*, p. 63).

To make clear the line of Hegel's argument, we should remark here on the great cultural paradox that presents Newton to us as the fulfillment of a scientific development that is usually traced to him from the labors of Copernicus through those of Galileo and Kepler. That development from its inception aimed at creating a single physics, made up of a single set of

principles, to displace the old Aristotelian double physics with its double set of principles (celestial and curvilinear, terrestrial and rectilinear). Galileo, as any serious student of his works must know, opted for unity on the basis of curvilinear motion, so that all apparent rectilinear motion would be either an optical illusion (like that of falling bodies, where the rotational movement of the earth is shared by body and observer, and therefore cancelled out) or a resultant compounded of naturally curvilinear motions. Copernicus had abolished the entire realm of rectilinear motion by assigning celestial motion to the terrestrial orb. And Kepler, too, while laboring to eliminate the complexities of circles on circles in the Ptolemaic and Copernican systems, was none the less a champion of curvilinear physics. From Copernicus to Galileo and Kepler, the triumphant claim of science had been, therefore, that the physical universe is indeed One, and all celestial. But then came Newton to bring the whole business down with a Baconian thud: The universe is physically One, as required, but – according to Newton's doctrine – it is all earth, all rectilinear – so that all curves are either optical illusions or resultants of compounded, naturally rectilinear motions.

From Hegel's point of view both positions, the Galilean as well as the Newtonian, were one-sided abstractions of the Understanding – like the contradictory corpuscular and wave theories of light. Against both (and again in an Einsteinian vein), Hegel argues that the proper scientific course is to distinguish and preserve qualitative differences. Inert, falling, rigidly-fixed stellar, and the freely-moving matter of the solar system must be comprehended together in their qualitative differences. Altogether, Hegel concludes after a long discussion of principles,

> There exist three motions: (a) mechanical motion which is communicated from outside and is uniform; (b) the partly conditioned and partly free motion of falling, where the separation of a body is still posited contingently but where the motion already belongs to the gravity itself; and (c) the unconditionally free motion, the principal moments of which have been indicated, the great mechanics of the heavens. This motion is a curve. In it, the positing of a central body by the particular bodies, and conversely, the positing of these by the central body, occur simultaneously. The center has no meaning apart from the periphery nor the periphery apart from the center. This puts to rout those physical hypotheses which start now with the center and now with the particular bodies, sometimes making the former and sometimes the latter the original factor. Both points of view are necessary, but, taken separately, they are one-sided. The diremption into different bodies, and the positing of the moments of subjectivity, is a simple act, a free motion, nothing external like pressure and thrust (*PN*, § 269, *Remark Z*, p. 64).

That is a summation worthy of Einstein or Planck. On the lowest, abstract level are the inert, unorganized material entities: their motion comes to them

from the outside, is uniform, according to the pressure or thrust, but essentially random. Focusing by abstraction on the inert particle, we cannot know what forces may act on it from unknown sources not yet posited; focusing on posited *forces*, we cannot know what particles, if any, will be acted upon, here or there. But on the level of heavy, organized matter, the motion is not only random or mechanical, but also determined, by its organization around a center of gravity, as a weighing down of one organized mass toward other organized masses. Higher still, however, is the gravitational relation manifested in the organized equilibrium of the solar system – and that, as Hegel says, has nothing random or forced about it. On that level, he writes,

> we must not speak of forces. If we want to speak of force, then there is but *one* force, and its moments do not, as two forces, pull in different directions. The motion of the celestial bodies is not any such pulling this way and that but is free motion; they go on their way, as the ancients said, like blessed Gods (*PN*, § 269, *Remark*, *Z*, p. 65).

That last phrase, it should be noted, was cited by Sir Arthur Eddington in *The Nature of the Physical World* to epitomize his own doctrine of the planetary movements, in the light of the Einsteinian general theory of relativity.[22] Einstein himself has observed that in the "translation of the law of inertia into the language of the general theory of relativity" we get a new law of motion which is not rectilinear at all, being the law of "a system of total differential equations, the system characteristic of the geodetic line" which curves back on itself. Einstein says further: "In place of Newton's law of interaction by gravitation, we shall find the system of the simplest generally covariant differential equations which can be set up for the $g_{\mu\nu}$-tensor. It is formed by equating to zero the once contracted Riemannian curvature tensor ($R_{\mu\nu} = 0$)" – which means that all apparently rectilinear motion is henceforth to be understood as the segment of a vast curve.[23]

But from Hegel's point of view, this Einsteinian development is also one-sided. All that Hegel says against Newton's 'proofs' would apply also, *mutatis mutandis*, to the Einsteinian-Riemannian formulas, were they offered as 'proofs'. The philosophic virtue of the latter, in comparison with the *Principia*, is their philosophic modesty. The Einsteinians acknowledge that their mathematical analysis, which permits them to speak of non-empirical clocks slowing down non-empirically and about non-empirical rulers shrinking, proves nothing. But, if more were claimed for that analysis, it could hardly expect to fare any better at the hands of another Ernst Mach than Newton's analysis has fared.

In his fullest commentary of the relation of Newton's mechanics to Kepler's laws, Hegel makes the following points:

1. It is a mere mathematical translation that turns the $\frac{A^3}{T^2}$ of Kepler's Third Law into a product ($\frac{A}{T^2} \times A^2$) of which one of the factors is the ratio of Newton's law of gravitation.

2. Newton's 'demonstration' that a body moving around the central body in subjection to the law of gravitation pursues a *conic section*, does not, by any logical means, show the necessity for its being an *ellipse*. And the worst is that

> the conditions which make the path of the body a *specific* conic section are, in the analytical formula, *constants*, and their determination is referred to an *empirical* circumstance, namely, to a particular position of the body at a certain point of time, and to the *fortuitous* strength of an *impulse* which it is supposed to have received in the beginning; so that the circumstance which determines the curve to be an ellipse falls outside the formula that is supposed to be proved, and no one has ever dreamt of proving this circumstance (*PN*, § 270, *Remark*, p. 66).

3. Newton's law of the force of gravity has only an empirical, not a philosophical basis. There is, for instance, no *reason* given as to why the centrifugal force manages to 'overcome' the centripetal force just when the latter ought, by definition, to be the greatest (perihelion), and then manages to let itself be 'overcome' in turn just when the centripetal force ought to be weakest (aphelion). The explanation is that, the empirical fact being known in advance (as summed up in Kepler's laws), the analytical calculus is conducted accordingly. One of the most thorough analyses of the relation between Kepler's achievement and Newton's, in recent times, is that of Pierre Duhem in his *Aim and Structure of Physical Theory*. Pursuing a course of reasoning that comprehends Hegel's arguments, Duhem concludes:

> The principle of universal gravity, very far from being derivable by generalization and induction from the observed laws of Kepler, formally contradicts these laws. If Newton's theory is correct, Kepler's laws are necessarily false.[24]

VII

Summing up, we may say that the great value of Hegel's criticism of Newton's celestial mechanics consists in its emphasis on the error of scientific 'reductionism' upon which that mechanics was founded – an error that still plagues theoretical physics, obstructing its advance, and making impossible a philosophically-integrated Natural Science. The popularity of Einstein has

made this part of Hegel's criticism more acceptable now than ever before. Yet hardly less impressive than his criticism of Newton is Hegel's sustained polemic against the pre-Darwinian advocates of an evolutionary origin of species, which he conducts on the same grounds. Like the Newtonians in Mechanics, Hegel argues, so the evolutionists in biology are 'reductionist'. They 'decompose' the self-generative cycle of a species into two constitutive elements or vectors, one of which is the characteristic actuality of the species just below it in the unbroken chain of organic forms, while the other is a sort of fortuitous thrust (chance mutation) acting at right angles, so to speak, and thus deflecting the old species out of its old generative cycle into a new one. Summing up the lesson of his entire Philosophy of Nature from this standpoint, Hegel says:

> Now, here is what is really involved in this conception. What, speaking generally, we call inorganic nature is thought of as having an independent existence, while the organic is attached to it in an external fashion, so that it is a mere matter of chance whether or not the organic finds the conditions of existence in what confronts it . . . . The question is this: Is that the true concept of the inorganic, and do living things represent what is dependent? [On the contrary] this is the true relation: man is not an accident added on to what is first; the organic is itself what is first . . . . Regarded in this fashion, the universe is not an aggregate of many accidents existing in a relation of indifference, but is a system endowed, in its essential character, with life.[25]

Here we break off. The wealth of materials in Hegel's *Philosophy of Nature* that have a bearing on the theme of this paper is inexhaustive. As I have observed elsewhere, no scholar who has seriously occupied himself with the history of the sciences of celestial and terrestrial mechanics, and of inorganic and organic physics, can read Hegel on these subjects without a sense of awe; for that history, from its Greek origins down to the nineteenth century, lives in his pages. Those of us who have for decades poured over the sources, guided by Pierre Duhem and his peers, can hardly fail to recognize in Hegel an easy mastery of much of the relevant materials. For me, at any rate, the ten volumes of Duhem's *Le système du monde* serve as an historical commentary on Hegel's *Mechanik* and *Physik* which, in turn, serve to make philosophical sense out of the long development of scientific thought traced by Duhem through all its evolutions, revolutions, and involutions, through all its errors and aberrations, exhuming once-famous doctrines from long oblivion, showing how the science of each epoch is nourished by the systems of past centuries, indicating how often the scientific certainties of one proud age are laughed at as absurdities in the next, while as often today's absurdities are seen forcing themselves forward into acceptance as the high truths of tomorrow.

Duhem's history of science displays a *dialectical* development, and Hegel's *Philosophy of Nature* compels us to recognize the continuous presence of that dialectical past in contemporary empirical science. It is thus a work of permanent scientific as well as philosophic value.

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NOTES

[1] The translations cited here from Hegel's *Lectures on the History of Philosophy* have sometimes been adapted in accordance with the German text (Michelet, 1840).
[2] Inscription on statue in the ante-chapel of Trinity College, Cambridge.
[3] John N. Findlay, 'Hegel and the Philosophy of Physics,' in *The Legacy of Hegel: Proceedings of the Marquette Hegel Symposium, 1970*, ed. J. J. O'Malley, *et al.* (The Hague, Nijhoff, 1973), p. 83.
[4] The translations cited here from Hegel's *Logic* have sometimes been adapted in accordance with the German text (Henning, 1840, 1955).
[5] The translations cited here from Hegel's *Philosophy of Nature* have sometimes been adapted in accordance with the German text (Pöggeler, 1959; Michelet, 1847).
[6] J. N. Findlay, *Hegel: A Re-Examination* (New York, Humanities Press, 1958, 1976), pp. 167–8.
[7] The translations from Hegel's *Phenomenology of Mind* have been adapted in accordance with the German text (Hoffmeister, 1949).
[8] Louis de Broglie, *Physics and Microphysics* (New York, Grosset and Dunlap, 1966), pp. 238–9.
[9] *Ibid.*, p. 75.
[10] See V. Cioffari, *Fortune and Fate from Democritus to St. Thomas Aquinas* (New York, 1935), *passim*, for a review of the commentary on Dante's Heisenbergian line (*Inf.*, IV, 136) epitomizing the doctrine of Democritus.
[11] H. D. Anthony, *Sir Isaac Newton* (New York, Collier, 1961), pp. 140–141.
[12] Tobias Dantzig, *Number: The Language of Science* (New York, Macmillan, 1954), pp. 234, 335.
[13] Bertrand Russell, *The Scientific Outlook* (New York, Norton, 1932), p. 264.
[14] Albert Einstein, *Out of My Later Years* (New York, Philosophical Library, 1950), p. 110.
[15] Einstein, *Later Years*, p. 97.
[16] Albert Einstein, *The World As I See It* (New York, Covici Friede, 1934), p. 57.
[17] Bertrand Russell, 'Introduction,' in A. V. Vasiliev, *Space, Time, and Motion* (New York, Knopf, 1924), pp. xv–xvi.
[18] Einstein, *Later Years*, p. 69.
[19] Findlay, *Hegel*, p. 279.
[20] Albert Einstein and L. Infeld, *The Evolution of Physics* (New York, Simon and Schuster, 1961), pp. 256–58.
[21] *PN*, § 267, *Z*, p. 59; § 268, *Remark*, *Z*, pp. 61, 62.

[22] Arthur Eddington, *The Nature of the Physical World* (Cambridge, Cambridge University Press, 1948), p. 147.
[23] Einstein, *Later Years*, p. 80.
[24] Pierre Duhem, *Aim and Structure of Physical Theory* (Princeton, Princeton University Press, 1954), p. 193.
[25] *Hegel's Lectures on the Philosophy of Religion*, trans. E. B. Spiers and J. B. Sanderson (New York, Humanities Press, 1962), Vol. III, pp. 340–341.