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LEIBNIZ'S PLACE IN THE HISTORY OF PHYSICS*

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The Roots of Einstein's Leibnizianism. A Problem

Leibniz is a terse and puzzling writer whose works are strewn with highly suggestive ideas, the real worth of which can be fully appreciated only in retrospect. This, it seems, is a fairly common appraisal. The intriguing question is, how many of these ideas have borne fruit? The present essay will center on one of Leibniz's most suggestive ideas concerning physical reality, viz., his speculative view of space not as an autonomous substance—as taught by Democritus, Plato, Euclid, Descartes, and Newton—but as a system of relations of order among things. Einstein professed himself a Leibnizian and declared that the superiority of Leibnizianism is so obvious that one can only explain the triumph of Newtonianism by the absence of sufficient mathematical tools in the hands of Leibniz to develop a physical scientific theory that would successfully compete with that of Newton.[1] That Einstein was not directly influenced by the works of Leibniz is fairly obvious. The question is, was Einstein's development somehow indebted to Leibniz's suggestion, or was it independent? Einstein's Leibnizianism was noticed by Reichenbach, who took it for granted, however, that it was an independent creation.[2] I shall try to show that some of Leibniz's ideas were partly responsible for the development of differential geometry in mathematics and of field theory in physics.

This approach will solve another problem. Was Einstein merely lucky to find an elaborate mathematical tool waiting for him to use? Physicists have often concluded from his success that mathematics regularly, albeit unintentionally, forges tools for physics. Neither the methodology nor the history of physics will bear this out, and Einstein's success does seem unusual even in a class of lucky accidents of similar nature. What I shall try to show is that physics and mathematics in the nineteenth century struggled with problems of common Leibnizian heritage, so that it was not entirely a matter of luck that they converged to the point where Einstein could use the one to solve problems in the other. The convergence is not complete, however, or else Einstein's work would not have been so very original. The parallelism between physics and mathematics has been illustrated by Max Jammer in his *Concepts of*

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[1] Einstein's introduction to Max Jammer, Concepts of Space (1954).

[2] H Reichenbach, "Die Bewegungslehre Bei Newton, Leibniz, und Huyghens," *Kant Studien*, 29 (1924), 417 18; trans. and ed. by Maria Reichenbach, *Modern Philosophy of Science* (1959), 46-7.

Space (p. 156). He compares Riemann's metric with Faraday's field and invokes the name of Leibniz. Yet all he says by way of connection is that we see here Leibniz's principles of continuity and of action in the vicinity. Now, if we do not wish to attribute the principle of continuity to Archimedes, then it has to go to Galileo; and if we do not wish to attribute the principle of action by contact to Democritus or Plato, then it has to go to Galileo or Descartes. Jammer does not, then, succeed in presenting the Leibnizian link between Faraday and Riemann.[33]

Descartes' program was to reduce physics to geometry (and geometry to algebra). When Leibniz found Cartesian physics unsatisfactory, he reversed the program. For Democritus both space and matter were independent entities. Plato and his followers viewed matter as the property of space and viewed space alone as autonomous or substantial. Leibniz suggested that only matter, and not space, is substantial—in some sense of substantial. Here he took his lead from Spinoza, who viewed time as merely an ordering relation between events, and perhaps also from Aristotle's theory of space as a collection of places. Space and time, said Leibniz, are the relations of order, viz., of coexistence and succession, among phenomena and qualities. In order to avoid question-begging, it is quite obvious, things must be unextended and events must take no time at all to occur; time, then, will be the order of succession of instantaneous events, and space the order of readiness to interact through the proximity of unextended qualities.

The relation between Leibniz's ideas here and his contribution to the development of the calculus is the topic of a separate paper, as is also his critique of the Cartesian school and even his application of it in part to Newtonianism.[4] Yet one item from the critique of Cartesianism is essential to the development of the Leibnizian theory of space. Leibniz found unsatisfactory Descartes' view of matter as pure extension; matter, says Leibniz, is both extension and force; and by force he meant both passive momentum and active kinetic energy. And so, when Leibniz decided that extension was not essential to matter, he decided that force alone is; extension, then, is the order of relations among points endowed with force.

[3] Nor is this easy. In the last note to the introduction to his Electric Waves, Hertz says: "The expression 'electric force' . . . is only another name for a state of polarization of space"; yet he shows no intention of applying this to geometry.
[4] This alludes to the two other papers, in the first session of the Symposium, by Dr. Carolyn Iltis of the University of Wisconsin and Dr. Uta Merzbach, Curator of Mathematical Instruments at the Smithsonian Institute.

This interpretation of Leibniz's ideas owes much to recent commentators on Leibniz, from Russell onwards. How much of it is read into Leibniz is hard to say, but the kernel of the relative view of space is undeniably in Leibniz's writings. Let us assume now that this Leibnizian kernel is the kernel of Einstein's theory of space. (We shall examine this assumption at the end of this paper.) The question before us, then, is whether these kernels are historically linked. Did Leibniz have any impact on the development of physics?

In the early eighteenth century Leibniz was a formidable opponent, the grand old man of the opposition. The mid-century saw a radical change; Voltaire savagely ridiculed him, and even Euler poked gentle fun at him. D'Alembert tried to say a kind word about him in his Preliminary Discourse, but had precious little to say. The nineteenth century relegated him to Naturphilosophie, and he was then almost unknown in scientific society. In 1902 Russell declared war on the relativist theory of space, starting with the remark that all philosophers of that period accepted it dogmatically. It hardly needs saying that in physics the parallel situation in that period was exactly the reverse. Leibniz is not mentioned in Russell's paper against relative space, though a translation of Leibniz into English and a book on Leibniz—by Russell—had appeared a short while before. The revival of interest in Leibniz, exemplified by the works of Russell, Couturat, Dewey, and Cassirer, marks a new development, beyond the scope of the problems of the present paper. If any connection between the Einsteinian revolution and Leibniz is to be found, it will not be found in the early twentieth century, nor in the nineteenth century when Leibnizian philosophers barely confronted Newtonian scientists, as they did in the late eighteenth century. The rapidly dwindling popularity of Leibniz in the more scientific circles of the time makes our search rather easy. If any link at all, between Leibniz and the nineteenth century scientifically respectable circles, is to be found, it seems fairly safe to consider only two possible candidates: Kant and Boscovich. I shall speak of Kant's relation to the development of nineteenth-century mathematics, and the Kant-Boscovich model and its impact on nineteenth-century physics—with special reference to Leibniz, of course.

A Starting Point: Leibniz the Critic

The most important and least easily dismissed part of a thinker's contribution is his criticism of current views. Such criticism may or may not be the beginning of his own alternative theory. But if it is valid, the maxims of rational discourse require that it should bring about some change or another. I must, then, begin with Leibniz's critique of Newton, and see what change if any it brought about.

In England, the best-known work of Leibniz was, perhaps, his correspondence with Clarke—which terminated only with Leibniz's death. In it he rambles as usual—stressing his theology, harping on the public's mechanistic bias in favor of action by contact, and attacking the idea of empty space, chiefly on theological grounds. Yet some of his criticism is too powerful to be ignored as conservative or idiosyncratic or theological. If space is homogeneous and isotropic, he says, then we land in the usual difficulties associated with infinity and absoluteness of frame of reference. Moreover, the location of any piece of matter in space is arbitrary, since space is homogeneous, except in relation to other matter. But if we locate matter in relation to other matter, then we need no additional frame of reference; hence we need no space as such for the location. The same may be said, more strongly, of two Newtonian atoms that are identical except for their location, and even more so of two parts of empty space: they can be anchored nowhere in space as such, and they are only distinguishable by reference to each other. If spatial order is relational essentially and independent of autonomous space, then surely the latter can be dismissed as performing no function at all.

These criticisms are very powerful. Were they utterly misunderstood? Were they totally ignored? Historians of science would answer, if at all, in the affirmative and documents do seem to support this view. Yet there is a tradition of publicly denouncing critics of accepted scientific doctrines while their criticism is probed behind closed doors. Publicly, Berkeley's critique of Newton's calculus was despised and dismissed out of hand. That he was nonetheless taken very seriously is a known fact. This tradition is still alive today. When a covariant version of quantum theory is accepted, but not before then, the desirability of such a version will be admitted officially. Meanwhile even those who spend much time and effort in search for it, often openly deny its desirability. [5]

The result is that we cannot find direct, decisive evidence to determine whether the various appearances of a criticism are interrelated by a common source,

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[5] For example P. A. M. Dirac, *Rev. Mod. Phys*. (1948). For a more detailed discussion see my *Towards An Historiography of Science* (1963; reprint, Wesleyan University Press, 1967)

by a common inner logic, or by some sort of accident. That the Leibnizian critique did recur is a fact; what if any was the link between its various recurrences?

Kant in a New Perspective

Much scorn has been poured on Kant's head on account of his in- ability to foretell that Gauss and Einstein were going to break away from his aprioristic adherence to Euclid. Everybody before Kant, including Newton, held similar views, but this only makes the need for a scapegoat all the more intense. And the scapegoat is Kant. The need for scapegoats is based on the view that scientists should be able to avoid error. Nowadays a more liberal view of science has emerged, according to which intellectual progress, especially scientific progress, is the outcome of severe criticisms of bold ideas and their replacement by other bold ideas, and so on indefinitely. This view has been stated most succinctly by Sir Karl Popper and applied by him and his disciples to various fields of science and its history; it has even been applied to the field of mathematics (by Lakatos).

One of the most important philosophico-historical works on the subject of space in the pre-Einsteinian era is Russell's Foundations of Geometry (1897), which is a most remarkable and lamentably neglected work. It is neglected, incidentally, because in it Russell supports the idea of basing metric geometry on projective geometry, an idea which lost much of its attraction with the development of non-metric spaces, topology in general, and the set-theoretical foundations of mathematics in particular, to which, of course, Russell's logical contribution is better known. This shows that too many of us still value a work only if we agree with its content. Certainly Russell in that volume acquiesces in that attitude, though his tone is one of moderation. He quotes the contemptuous criticisms leveled by Felix Klein and Sophus Lie against Helmholtz's venture into geometry and tries to absolve Helmholtz on the ground that Helmholtz did make one lasting contribution when he proved Riemann's generalized Pythagorean Theorem for infinitesimals (i.e. the dependence of the metric tensor on the coordinates alone). Similarly, Russell mentions that the work of Gauss and his followers was "aimed as much at discrediting Kant as at advancing Mathematics." And, again, Russell accepts the discredit to the extent that he accepts the criticism. But he does salvage from Kant's philosophy what can be, or even should be, salvaged in the light of such later developments as Klein's and Lie's. These people were not interested in philosophy, Russell says, but their work is philosophically very interesting.

To translate all this into modern parlance is enlightening. Though Helmholtz's contribution was indeed rejected by his followers, his concern, his problems, and his orientations, were respected; and that is why philosophically Klein could be uninterested yet highly interesting. Whether Kant's direct influence, e.g., on Riemann, is taken seriously or not, is philosophically less important than the fact that even his most ardent opponents, such as Gauss, took up problems raised by Kant. Gauss's work is philosophically very interesting precisely because it is a reaction to Kant's views on mathematical and physical concepts and laws. Finally, as to Gauss's wish to discredit Kant, it is indeed to Kant's—or to anyone's, for that matter—highest credit that the attempts to discredit him led to developing new ideas. Let me go into detail.

Kant's Concept of Space in Russell's Improved Version

For a long time Kant vacillated between Leibnizian relative space and Newtonian absolute space. He ultimately settled for Newton, but expressed his sympathy with Leibniz even then. In his discussion of the mathematical antinomies in the Critique Of Pure Reason, he says he would be a Leibnizian had he thought that science was concerned with things in themselves rather than that science was a form of intuition for the organization of experience.

However Newtonian Kant wished to be, he could not be Newtonian in one fundamental respect: he could not see space as a substance any more than he could see any other object of scientific inquiry as a substance or a thing in itself. Space was Newtonian in the sense that it must be empty, indeed was a priori empty, in order to be filled with things, or rather our conception of things. But space as a mode of intuition, as a mental receptacle, differs from Newton's real receptacle, and willy nilly comes closer to Leibniz's ideas of space as a set of relations.

We see here the power of Leibniz's ideas. Take Leibnizian space and Newtonian space; take a conceptual image of either, and you see that the images almost coincide; this is so because the main conceptual role of space is that of ordering. Leibniz's idea, then, is more economical in Ockham's sense. It is not at all easy to apply Ockham's razor, since Ockham speaks vaguely of not multiplying things unnecessarily, but just what is necessary is left open. It looks as if Berkeley shares with Leibniz the idea of denying the existence of autonomous space. But this is quite misleading. It is easy to deny the existence of all substances. The question was how to account for physical phenomena like motion. Here Berkeley's idea of space is psychological and thus irrelevant, Newton's concept of space is very useful, and Leibniz's is an undeveloped idea. What Leibniz discovered was the function of space as a set of ordering relations—an undeveloped idea since it did not in itself lead to the construction of a new geometry. I shall now try to show that Kant in fact developed Leibniz's idea even though he preferred to regard himself as a Newtonian, and that through Kant, Leibniz's idea bore fruit.

One might use Russell's later clarification of this: one might say that Kant's form of space was not a set of actual relations among things but a conceptual tool for describing them, and thus provided a set or a system of possible relations among things, as opposed to the sub-space of any given spatial order, such as a system of actual relations between things, which occupies only one of many sets of possible ordering relations.

That in such a form of space the elements are points is obvious; but the atoms of space need not be physical, so that the nature of the physical atom can remain open. That in such space emptiness may, but need not, be permitted is obvious too. If things are in a space of possible relations and occupy one set of infinitely many sets of possible relations, what happens to the other sets which are unoccupied? The unoccupied sets may have nothing to do with the occupied set, with the things which occupy it. Alternatively, the unoccupied sets may constitute a primary property of these things. These two alternatives would render empty space possible and impossible respectively. That is to say, the more we view things as substantial, the more Kant's space looks empty. The more we view things as dispositional, the more Kant's space looks like a plenum (of dispositions or possibilities). Indeed, to solve certain difficulties inherent in the Kant-Russell view, we shall have to do just that. The difficulties are the ones adumbrated by Leibniz, which were again raised by Russell, as I shall soon show, and solved by Einstein.

To repeat, in Russell's objectified version, Kant's space is a space of a possible order of relations, and as such it is an improvement on Leibniz. It is empty, and is thus vulnerable to some Leibnizian objections. Kant's space is filled by

Einstein with matter. Both Russell and Einstein are linked to Leibniz via Kant, and to Kant via the tradition of nineteenth-century geometry.

Nineteenth-Century Geometry

Nineteenth-century geometry developed with an inner logic of its own. Gauss rebelled against Kant's claims; he even tried (in vain) to work out a crucial experiment between Euclid and Bolyai. The story of non-Euclidean geometry is often told with the stress on the axiom of parallels. This stress is justified to the extent that for some historical reasons this axiom was viewed—no longer today—as the most vulnerable part of Euclid's axiomatic system. But even here, the idea that a vulnerable part was battered again and again until it gave way seems rather naive: why did it give way just then and not before or after? The truth seems to be related to dissatisfaction with the Euclidean infinity of space, and this was reflected in Kant's antinomies. True, some of Leibniz's objections were invalidated by Riemann in the mid-nineteenth century when he constructed a spherical finite space, homogeneous and isotropic (thus proving that infinity was not the outcome of these properties; and so it turns out that on this rather central issue Leibniz was in logical error). Yet on this very point Riemann's interest in spherical geometry can be linked to Leibniz via Kant: the parallel axiom was dismissed, and then parallel lines altogether, while homogeneity and isotropy were preserved. But to come back to the stress on the axiom of parallels. First, giving it up as a reaction to Kant meant reacting against Kant's attempt to reconcile the two competing approaches, of Newton and Leibniz, to geometry. Second, important as the defiance of Euclid's axioms was, the great progress made in geometry was not derived from non-Euclidean axiomatic systems, hyperbolic, spherical, or other; the great progress came from the differential metric geometry of Gauss and Riemann. The chief problems this development either encountered *en route* or took as basic, were typically Kantian: assuming nothing but the possibility of motion of rigid bodies in space and the possibility of the relations of distance in space, what constraints do these assumptions impose on our geometry? This is a transcendental argument in geometry. If such argument is not indebted to Kant, then we have to revise our concepts of intellectual influence. If, as I think, it is indebted to Kant, then we must reject the view that Kant's influence was marginal. As Russell illustrates in his *Foundations of Geometry*, this transcendental approach is very central to nineteenth-century geometrical thinking.

It is very interesting to see the similarity between Kant and Leibniz as it emerges from nineteenth-century geometry. The development of geometry did much to clarify philosophical issues and nail down positions. Russell's philosophical summary of nineteenth-century geometrical efforts is partly Kantian, but more Leibnizian than Kantian. In it he does not mention Leibniz at all—and this three years before his *Critical Exposition of The Philosophy of Leibniz* (1900). It looks as if he had not read Leibniz until then. It is very strange that in such a historical-philosophical book as Russell's *Foundations of Geometry*, Leibniz is not mentioned, though the central philosophical problems it solves are of typical Leibnizian stock. The three central problems of geometry, says Russell, are first, what makes various parts of space distinguishable; second, to what are points in space related; and third, why is it that spatial figures are relations yet divisibility applies only to figures and not to relations. The first question comes as if straight from Leibniz's third letter to Clarke. The difficulties occur, even though Russell's space is a system of relations, because it is a system of possible relations, in itself empty. Russell puts into space some abstract matter in order to overcome this kind of problem. But he sees this solution as Kantian: he does not insist that space inherently cannot exist without matter inside it; he says that we cannot envisage empty space. Here he failed to render Kantianism as objective as he had intended, and thus failed to start the line of applying nineteenth-century geometry to physics. Einstein did that single-handed.

Russell's Kantianism of 1897 is very much in the tradition in geometry developed by Clifford (1845-1879) and Poincaré.(1854-1912); so is his lack of ability or desire to apply the new geometry to concrete problems of physics. There were no problems of physics stemming from the acceptance of Euclidean space; Gauss tried to force one on the world, but failed. Geometry was an exercise in possible worlds, provided certain general geometrical facts, such as motion and spatial relations of distance, were permitted. The stress on the possibility of relations is Kantian, in contradistinction to a stress on actual relations, which is Leibnizian, as well as to a stress on physical properties of space as such, which is the traditional Euclidean-Newtonian view.

Prelude to Field Theory

Relational space demands point atoms, since extended atoms need first a space in which to be embedded. But autonomous space does not require extended or point atoms. Boscovich (1711-1787) peopled Newton's autonomous[6] space with Leibnizian point-atoms. His problem was that of elastic collisions. Infinitely hard bodies which collide exert infinite force on each other, of course. To avoid this calamity they must be elastic. Lavoisier, years later, put his infinitely hard atoms into a perfectly elastic and continuous medium, "caloric," to avoid the same calamity (I do not know how successfully). Boscovich had no use for any medium, and he had not invented a perfectly elastic medium. To make his atoms elastic he endowed them with a repulsive force which increases rapidly with the increase or risk of collision, i.e., with the increase of proximity of the atoms about to collide. This gave each atom a certain shield which resembled impenetrability. If so, reasoned Boscovich, then there is no need for Newton's atoms to have bulk: the extension of matter may be explained as the result of repulsive forces, and so a collection of atoms would appear bulky even if they are point atoms in the void. This, in essence, is Boscovich's speculation.

Kant. in his pre-critical period, preceded Boscovich in making a similar proposal, for similar though less explicit reasons.[7] Unlike Leibniz, Boscovich fails to explain space as a property of matter; but following Leibniz he does explain bulk or extension in space as a property of matter. If we have space, why not follow Descartes and explain matter as occupying space? The answer is that with the introduction of Newtonian forces Boscovich found this procedure defective. But if bulk is explained as a property of atoms endowed with force, why not explain space as the totality of bulk? The answer even today, is, no one knows how to formulate such an explanation. Meanwhile space itself has become in one sense still more Newtonian than Cartesian: for Descartes and Leibniz space was full; for Newton it was empty except for the atom; for Boscovich it was almost empty, in the strictest sense of "almost."

In his critical period Kant produced a more Leibnizian variant of this theory. For Boscovich, a body is denser and more rigid or solid when more mass points are compressed into its volume. Kant seems to object to Boscovich here. Density of repulsive force, or elasticity, is to him quite different from density of attractive force, which is Newtonian mass distribution, as exemplified, he says, by water and quicksilver, each of which may become denser or rarer by compression or dilation.

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Like Boscovich, Kant wishes to explain bulk by repulsive force and assumes the repulsive force to be a short-range elastic force; unlike Boscovich, but like Leibniz, Kant views the atom as space filled with repulsive force—whose size, he added, is determined by the conflict between attraction or repulsion, or rather not the conflict but the resultant balancing of this conflict.

An atom may possess the same volume when its attraction increases, on the condition that its repulsion too increases. The attraction and repulsion thus operate locally simultaneously in the whole interior of the atom, whereas the attraction also acts on remote bodies. Remote bodies, in return, may cause change within the atom, dilate or compress it. If an atom is dilated, it is less dense in the mathematical sense: it fills space like Swiss cheese, only in a continuous fashion (like the set of all rational fractions as compared with the set of real numbers). Hence, says Kant, whereas the density of matter with respect to attraction, i.e. Newtonian mass density, is an intrinsic characteristic of atoms, varying in a fixed manner between water and mercury, the density of matter with respect to repulsion has no maxima or minima; ideally an atom can be compressed to a point or spread over the whole of space. This is the embryo elastic space (as opposed to space filled with elastic matter, since elasticity and gravity are for Kant what makes matter material).

Kant's most important disciple was Ørsted (1775-1851). Ørsted's problem was electrochemistry, and his starting point was the Kant-Boscovich model. He could not explain with the help of that model how chemical affinity becomes electric force, since in that model forces depend on configuration only. He postulated that forces change their character depending on the physical set-up or the physical *Gestalt* in which they operate. He acknowledged the influence of Schelling here, that is of Schelling's organicist view of nature, which, incidentally, also owes much to Leibniz, but along less reputable scientific lines.

Not only did Ørsted propose his theory of conversion of forces, which Faraday (1791-1867) developed into the theory of conservation of forces (forces can convert into other forces but not vary, much less be destroyed). When Ørsted reported his discovery of electromagnetism in 1819, he said that the electric "conflict" (the word may come from Kant, see above) which constitutes the electric current (whatever this may mean) leaves the conducting wire and goes through space to deflect the magnetic needle. Faraday denies, in his paper of 1821, on the electric motor, the existence of magnetic attraction and repulsion as elementary. He declares them compound forces. The primary forces of all magnets, he says, are all circular, and rectilinear forces—attraction and repulsion—are resultants of couples of rotational forces along tangential circles in opposite directions.

One interesting aspect of this is that Faraday's theory comes to do away with action at a distance—a pet aversion of his which he tried to eliminate at the first occasion. Second, his forces, like Oersted's are not bound to centers of force, and move freely in empty space like gods. Faraday knew nothing of Leibniz or of Kant, presumably.[8] He never tried to reduce space to fields; had he known of Riemann's work he might have done so, but he did not. Yet he tried to reduce all matter to fields of force, including bulk, inertia, and gravity. In this he said he was indebted to Boscovich's reduction of bulk to forces. But unlike Boscovich's forces, and like Oersted's, Faraday's forces filled empty space.[9] The complementariness between Faraday and Riemann is, indeed, as striking as Jammer notes; but it is not so much plenism and continuity, as plenism of dispositions of relations in a continuity of range. But Riemann's relations are of distance and Faraday's of interaction. There is still a chasm, which was bridged over half a century later by the genius and luck of Einstein.

Field Theory

Faraday's desire to explain matter by a theory of force made De la Rive view Faraday's speculations as dangerously close to idealism, as he put it in his memorial on Faraday.[10] De la Rive thus expressed the positivistic sentiment of his generation. A generation later, sentiments went the other way. Even if our theory of matter were most satisfactory, Heaviside (1850-1925) declared, we could still wish to explain it further. The important aspect of Maxwell's views, Poynting (1852-1914) said, in his

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[8] Faraday knew Thomas Young well, and Young was familiar with Kant's doctrines; he is known to have censured Kant's style in a manner indicating that he thought the subtlety of Kant's view was not so great as to justify so cumbersome an exposition. Faraday alludes to Kant in his notes to his lectures to the City Philosophical Society, Royal Institution MS, p. 112. See also my *Faraday as a Natural Philosopher,* 1971.

[9] It is on this crucial point that I think Faraday's originality is unacknowledged, even by L. L. Whyte and L. P. Williams.

[10] "Notice sur Michael Faraday," trans. in *Phil. Mag*., 34 (1867), 410. 11 Sylvanus P. Thompson tells how surprised he was to find an idea of his in Faraday's work; cf. Jane S. Thompson, Sylvanus Thompson: His Life And Letters (London, 1920) 43-4.

celebrated paper on energy-flow, is this: towards the end of his life, Maxwell insisted on the existence of pure energy in empty space.

It is doubtful that Heaviside or Poynting had read Faraday or knew of his speculations. Faraday was viewed as an etherist both at that time and until very recently (with the exception of Émile Meyerson perhaps, and of Einstein who, in the London *Times*, February 4, 1929, described Faraday's view of fields of forces in empty space). As Einstein pointed out, the logic of the situation forced Maxwell, and later Hertz, into a more Faradayan position, and so, though Faraday was not well known, his ideas survived. Again we see the logic of a situation forcing thinkers to revive ideas which had given rise to their problem.[11]

Let us return to De la Rive's charge that Faraday's theory was idealistic. The opposite of idealism is realism, or the view that the material world exists. There are many versions or classes of versions of realism, one of which is known as materialism or mechanistic materialism. This doctrine asserts that the essence of the material world is matter, which behaves in accord with Descartes' principles, or Newton's, or Boscovich's, etc. There is no logical impossibility in asserting both that the physical world exists and that its essence is not matter, but, say, spirits of things (animism), or force, or energy. Yet viewing matter as essentially force or energy is viewing matter as potential. And this raises the question: What does this potentiality actualize into? The answer is, inevitably, into other potentialities, and so on. This looks very frustrating and objectionable, and so opposition to Faraday is even more understandable than opposition to Leibniz—as Faraday had a clearer conception of force.[12]

Aristotle's matter is both potential and actual. In his *Letters To A German Princess* (1795), Euler praises Descartes for having reduced the potential to the actual: things repel each other because otherwise they would not be what they are. But

[11] Sylvanus P. Thompson tells how surprised he was to find an idea of his in Faraday's work; cf. Jane S. Thompson, *Sylvanus Thompson: His Life And Letters* (1920), 43-4.

[12] Lenin's *Materialism and Empirio-Criticism* (1909) is often cited as a text in which realism is viewed as more fundamental than materialism, and equating mass with energy as at least preserving realism. Yet in that very discussion Lenin slides rather apologetically from materialism to a non-materialistic realism: he does not admit that equating mass with energy, realist as it is, is anti-materialist. Moreover, those who quote Lenin are rather apologetic too: they do not notice that he is here ready to move only under the pressure of science; that, moreover, he is not convinced that the pressure exists. He says, since energy is defined by mass, it is too circular to define mass by energy. This perceptive remark is overlooked by his apologetic defendants. Indeed, this objection was met by twentieth-century Faradayans, especially Einstein and Schrödinger.

then, persistence of actual essence is the one and the only potentiality Descartes does require. Faraday's theory is reversed Cartesianism, which may be defended by claiming that even the most actual actuality contains potentiality anyway. Here Popper's theory of dispositions as inherent everywhere and of propensities as objective dispositions, is valuable as a *post-hoc* clarification (similar to Russell's above).

The End of the Controversy

In general relativity, matter moves in accord with some law of inertia, but only after deforming space. What does it matter whether matter gravitates and thus deviates from its inertial path or whether instead of gravitating it deforms its inertial path? There are mathematical differences between the formulae, of second or third order of magnitude. This may be an accident of a formal mathematical nature, and in itself this difference might be overlooked.[13] Bigger experimental discrepancies are tolerated with equanimity, when the problems they involve are not really interesting: such discrepancies are merely covered by some correction factor or other. What is really significant, according to Einstein, is that gravitation and geometry become one, thus insuring that geometry is a part of physics proper. From the start Einstein was ready to explain matter. When Maxwellian fields showed themselves to possess mass density proportional to their energy density, Einstein tried to explain all mass as a property of energy, thus depriving the mass-point of its materiality, though it still possessed gravity; but gravity should be a field. Viewing space-time as a set of dispositions and field physics as a set of dispositions too, the idea of viewing the one as an aspect of the other seems possible, however remotely.

In Einstein's view of unified field theory as a generalized geometry, one might say that fields of force become a property of space, or vice-versa; force-field and space become one. It would not be clear then whether the generalized theory would be a modified Cartesianism (matter is a property of space) or modified Leibnizianism (space is a property of matter). It is less clear now, since the project seems to have failed. It seems that sooner or later such questions cease to have significance, since modification has since gone beyond earlier imagination. Yet the existence of both a Cartesian element (geometry as physics) and a Leibnizian element (matter as force) in

[13] H. P. Robertson, in *Albert Einstein, Philosopher Scientist*, in P. A. Schilpp, ed. (1949), 1, 329.

contemporary theory, as well as the absence of some powerful unifying ideas, however preliminary, may be pointed out with some interest, and perhaps concern.

To conclude, Einstein's geometrization of gravity is a part of a long struggle. Leibniz had a theory of both space and matter which was very unorthodox. Its greatest shortcoming, Euler asserted correctly, is that it could not replace Euclid's geometry, with which it conflicted. Both Boscovich and Kant tended towards Leibnizianism with regard to both space and matter—Kant more so than Boscovich. Through Kant's acceptance of Euler's criticism, and in a period of reaction to Kant, non-Euclidean geometry was born. Through Kant's theory of matter, field-theory was born. The two were united in Einstein.

Yet one should not exaggerate the continuity, which obtains not so much for influential ideas as for programs and problems. It should be stressed that non-Euclidean geometry reinforced, in a non-Leibnizean fashion, the homogeneity and isotropy of space. It is thus important to note that deviations from these dogmas were first attempted in the field of elasticity, or of applied mathematics, which came opportunely for Einstein. It is also important to note that it is not easy to decide how much Einstein's program is a variant of that of Leibniz.

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