Newtonian Studies

By Alexandre Koyré

Harvard University Press
1965

I
The Significance of the Newtonian Synthesis

It is obviously utterly impossible to give in a brief space a detailed history of the birth, growth, and decay of the Newtonian world view. It is just as impossible even to give a reasonably complete account of the work performed by Newton himself.[1] Thus, by necessity, I am obliged to restrict myself to the very essentials and to give the barest outline of the subject. Moreover, in doing so I will assume a certain amount of previous knowledge. It is, I believe, a legitimate assumption, because, as a matter of fact, we all know something about Newton, much more, doubtless, than we know about any of the other great scientists and philosophers whose common effort fills the seventeenth century – the century of genius, as Whitehead has called it.

We know, for instance, that it is to Newton's insight and experimental genius – not *skill*: others, for instance, Robert Hooke, were just as skilled, or even more so than he – that we owe the idea of decomposition of light and the first scientific theory of spectral colors;[2] that it is to his deep philosophical mind that we owe the

[1] The best general account of Newton's scientific work is still F. Rosenberger, *I. Newton und seine physikalischen Principien* (Leipzig, 1895). See, however, H. W. Turnbull, *The Mathematical Discoveries of Newton* (London: Blackie, 1945); S. I. Vavilov, *Isaac Newton* (Moscow: Akademiia Nauk, 1943), German translation (Berlin: Akademie-Verlag, 1951); and I. B. Cohen, *Franklin and Newton* (Philadelphia: The American Philosophical Society, 1956). The best biography is L. T. More's *Isaac Newton* (New York and London: Scribner, 1934).

[2] The production of spectral colors by crystals and drops of water, and the concomitant theory of the rainbow, has a long history and even prehistory behind it extending through the Middle Ages to antiquity. In the seventeenth century it had been studied chiefly by Marcus Antonius de Dominis, *De radiis visus et lucis in vitris perspectivis et iride tractatus* (Venice, 1611); by Descartes in "Dioptrique" and "Météores," essays appended to his *Discours de la méthode* (Leiden, 1637); by Marcus Marci, *Thaumanthias, liber de arcu coelesti deque colorum apparentium natura* (Prague, 1648); by F. M. Grimaldi, *Physico-mathesis de lumine, coloribus et iride* (Bologna, 1665); and especially by Robert Boyle, *Experiments and Considerations Upon Colours* (London, 1664), and Robert Hooke, *Micrographia: or some Physiological Descriptions of Minute Bodies made by Magnifying Glasses* (London, 1665). To Newton belongs not the discovery of the phenomenon, but (1) the application of exact measurements to its study and (2) its

formulation – though not the discovery – of the fundamental laws of motion[1] and of action, together with the clear understanding of the method and meaning of scientific inquiry; that it was his invention of the calculus that enabled him to demonstrate the identity of terrestrial and celestial gravitation and to find out the fundamental law of attraction that binds – or at least until recently bound – together the smallest and the largest bodies – stars and atoms – of the infinite Universe. We know too, of course, that it is not to him, but to his great rival Leibniz,[2] that we owe *de facto* the actual spread and development of the infinitesimal calculus, without which the gradual extension and perfection of the Newtonian *systema mundi* would be impossible.

Besides, all of us, or if not all still most of us, have been born and bred – or better and more exactly, not *born* (as this is impossible) but only *bred* – in the Newtonian or, at least, a semi-Newtonian world, and we have all, or nearly all, accepted the idea of the Newtonian world machine as the expression of the true picture of the universe and the embodiment of scientific truth – this because for more than two hundred years such has been the common creed, the *communis opinio*, of modern science and of enlightened mankind.

Thus it seems to me that I have the right to assume that when we are speaking about Newton and Newtonianism we know more or less what we are speaking of. More or less! Somehow this very expression used in connection with Newton strikes me as improper, because it is possible that the deepest meaning and aim of Newtonianism, or rather, of the whole scientific revolution of the seven-

---

explanation as a decomposition (and recomposition) of white light into its colored components by the prism, in contradistinction to the pre-Newtonian conception that explained the appearance of the spectral colors by a process of qualitative change suffered by white light in its passage through a prism. On the history of that question see Vasco Ronchi, *Storia della luce* (Bologna: Zanichelli, 1939; 2nd ed., 1952), and Roberto Savelli, "Grimaldi e la rifrazione," *Cesalpina*, 1951.

[1] The laws of motion owe their discovery to Galileo and Descartes. See my *Études galiléennes* (Paris: Hermann, 1939); also R. Dugas, *Histoire de la mécanique* (Paris: Éditions Dunod, 1950), and *La Mécanique au XVII^e siècle* (Paris: Éditions Dunod, 1954), and A. R. Hall, *The Scientific Revolution* (London: Longmans, Green, 1954).

[2] Nobody doubts today the complete independence of Leibniz's invention of the differential calculus; nobody has ever doubted the superiority of the Leibnizian symbolism. See H. G. Zeuthen, *Die Geschichte der Mathematik im XVI. and XVII. Jahrhundert* (Leipzig: Teubner, 1903); C. B. Boyer, *The Concepts of the Calculus* (New York: Columbia University Press, 1939; 2nd ed., New York: Hafner, 1949). Therefore it is very interesting to note that Professor Hadamard believes it to be just as inferior to the Newtonian one as the conception of the "differential" is to that of the "fluxion." See Jacques S. Hadamard, "Newton and the Infinitesimal Calculus," in the Royal Society of London, *Newton Tercentenary Celebration* (Cambridge, England: University Press, 1947), pp. 35–42.

.eenth century, of which Newton is the heir and the highest expression, is just to abolish the world of the "more or less," the world of qualities and sense perception, the world of appreciation of our daily life, and to replace it by the (Archimedean) universe of precision, of exact measures, of strict determination.

Let us dwell for a moment upon this revolution, one of the deepest, if not the deepest, mutations and transformations accomplished – or suffered – by the human mind since the invention of the cosmos by the Greeks, two thousand years before.[1] This revolution has been described and explained – much more explained than described – in quite a number of ways. Some people stress the role of experience and experiment in the new science, the fight against bookish learning, the new belief of modern man in himself, in his ability to discover truth by his own powers, by exercising his senses and his intelligence, so forcefully expressed by Bacon and by Descartes, in contradistinction to the formerly prevailing belief in the supreme and overwhelming value of tradition and consecrated authority.

Some others stress the practical attitude of modern man, who turns away from the *vita contemplativa*, in which the medieval and antique mind allegedly saw the very acme of human life, to the *vita activa;* who therefore is no longer able to content himself with pure speculation and theory; and who wants a knowledge that can be put to use: a *scientia activa, operativa*, as Bacon called it, or, as Descartes has said, a science that would make man master and possessor of nature.[2]

The new science, we are told sometimes, is the science of the craftsman and the engineer, of the working, enterprising, and calculating tradesman, in fact, the science of the rising bourgeois classes of modern society.[3]

There is certainly some truth in these descriptions and explana-

---

[1] See my "Galileo and the Scientific Revolution of the Seventeenth Century," *Philosophical Review 52* (1943), 333–348.

[2] Philosophers are often inclined to misjudge the situation of contemporary philosophical positions and – when dealing with the past – to forget that, as often as not and even more often than not, philosophical (and religious) teachings are not so much *expressing* as *opposing* the prevailing trends of their time.

[3] The psychosociological explanations of the rise of modern science present us usually with a mixture of two by no means equivalent theories: (1) modern science is the offshoot of the technical development of the sixteenth and seventeenth centuries; it was made by technicians, civil and especially military engineers (Leonardo, Stevinus), by the *proti* of the Arsenal of Venice, and so on; and (2) modern science is made by scientists who, because of the increasing importance of technics and the growing significance of the bourgeoisie in the sixteenth and seventeenth centuries, started thinking about problems of industry that they had persistently neglected since Archimedes time. Both these theories seem to me to miss (1) the role of purely theoretical interest in mathematics which led to – and was maintained by – the rediscovery of Greek science,

tions: it is clear that the growth of modern science presupposes that of the cities, it is obvious that the development of firearms, especially of artillery, drew attention to problems of ballistics; that navigation, especially that to America and India, furthered the building of clocks, and so forth – yet I must confess that I am not satisfied with them. I do not see what the *scientia activa* has ever had to do with the development of the calculus, nor the rise of the bourgeoisie with that of the Copernican, or the Keplerian, astronomy. And as for experience and experiment – two things which we must not only distinguish but even oppose to each other – I am convinced that the rise and growth of experimental science is not the source but, on the contrary, the result of the new *theoretical*, that is, the new *metaphysical* approach to nature that forms the content of the scientific revolution of the seventeenth century, a content which we have to understand before we can attempt an explanation (whatever this may be) of its historical occurrence.

I shall therefore characterize this revolution by two closely connected and even complementary features: (*a*) the destruction of the cosmos, and therefore the disappearence from science – at least in principle, if not always in fact – of all considerations based on this concept,[1] and (*b*) the geometrization of space, that is, the substitution

and (2) the overwhelming importance of the study, and the autonomous evolution, of astronomy, promoted much less by practical needs, such as the determination of longitude at sea, than by theoretical interest in the structure of the universe. Besides, they forget that mathematicians and astronomers (not to speak of experimental physicists) need money as much as (or even more than) theologians and jurists and are therefore likely to stress the practical value of their work in order to "sell" their science to wealthy and ignorant patrons. This kind of propaganda is by no means a feature of the twentieth century: it had already begun in the sixteenth. It is chiefly to his skill and value as propagandist (*buccinator*) that Bacon owed his popularity among the seventeenth- and eighteenth-century scientists. The psychosociological (Marxist and semi-Marxist) theory is to be found at its best in F. Borkenau, *Der Uebergang vom feudalen zum bürgerlichen Weltbild* (Paris: Alcan, 1934); B. Hessen, "The Social and Economic Roots of Newton's *Principia*," in *Science at the Cross-roads: Papers Presented to the International Congress of the History of Science and Technology Held in London, 1931, by the delegates of the U.S.S.R.* (London: Kniga, 1931); and E. Zilsel, "The Sociological Roots of Science," *American Journal of Sociology 47* (1942), 544–562. For criticism see G. N. Clark, *Science and Social Welfare in the Age of Newton* (London: Oxford University Press, 2nd ed., 1949); H. Grossmann, 'Die gesellschaftlichen Grundlagen der mechanistischen Philosophie und die Manufaktur," *Zeitschrift für Sozialforschung*, 1935, pp. 161 sq. See equally P. M. Schuhl, *Machinisme et philosophie* (Paris: Presses Universitaires de France, 1938; 2nd ed., 1947), and my papers "Les Philosophes et la machine," *Critique 23* (1948), 324–333 and *27*: 610–629; and "Du monde de l'à peu près à l'univers de la précision," *Critique 28* (1948), 806–823, reprinted in *Études d'histoire de la pensée philosophique* (Paris: Armond Colin, 1961).

[1] As we shall see, Newtonian science, or at least the Newtonian world view, asserted the purposeful character of the world (solar system). It *did not* explain its features by deducing them from a purpose. Kepler still used this pattern of explanation.

of the homogeneous and abstract – however now considered as real – dimension space of the Euclidean geometry for the concrete and differentiated place-continuum of pre-Galilean physics and astromony.

As a matter of fact, this characterization is very nearly equivalent to the mathematization (geometrization) of nature and therefore the mathematization (geometrization) of science.

The disappearance – or destruction – of the cosmos means that the world of science, the real world, is no more seen, or conceived, as a finite and hierarchically ordered, therefore qualitatively and ontologically differentiated, whole, but as an open, indefinite, and even infinite universe, united not by its immanent structure but only by the identity of its fundamental contents and laws;[1] a universe in which, in contradistinction to the traditional conception with its separation and opposition of the two worlds of becoming and being, that is, of the heavens and the earth, all its components appear as placed on the same ontological level; a universe in which the *physica coelestis* and *physica terrestris* are identified and unified, in which astronomy and physics become interdependent and united because of their common subjection to geometry.[2]

This, in turn, implies the disappearance – or the violent expulsion – from scientific thought of all considerations based on value, perfection, harmony, meaning, and aim, because these concepts, from now on *merely subjective*, cannot have a place in the new ontology. Or, to put it in different words: all formal and final causes as modes of explanation disappear from – or are rejected by – the new science and are replaced by efficient and even material ones.[3] Only these

[1] Geometrization of space implies necessarily its infinitization: we cannot assign limits to Euclidean space. Accordingly, the destruction of the cosmos can be characterized – as by Miss M. Nicolson – as "the breaking of the circle," or – as by myself – as "the bursting of the sphere."

[2] See my *Études galiléennes* and "Galileo and Plato," *Journal of the History of Ideas 4* (1943), 400–428, reprinted in Philip Wiener and Aaron Noland, eds., *Roots of Scientific Thought* (New York: Basic Books, 1957).

[3] It has often been said that modern science is characterized by the renunciation of the search for causes and restriction to that of laws. Yet, as has been shown by P. Duhem, *ΣΩΖΕΙΝ ΤΑ ΦΑΙΝΟΜΕΝΑ, Essai sur la notion de la théorie physique de Platon à Galilée* (Paris: Hermann, 1908), *La Théorie physique: Son object, sa structure* (Paris: Chevalier and Rivière, 1906), this "positivistic" attitude is by no means modern but was widely represented in Greek and also medieval astronomy and philosophy, which, as often as not, considered the circles, eccentrics, and epicycles of Ptolemy as pure mathematical devices and not as physical realities. The chief advocate of that view in the Middle Ages was Averroes; as for Ptolemy himself, he seems to adopt it in his *Almagestum* (*Mathematical Syntax*), though not in his *Hypotheses of the Planets*. On the other hand, as was conclusively shown by E. Meyerson, *Identité et realité* (Paris: Vrin, 5th ed., 1951), trans. Kate Loewenberg as *Identity and Reality*

latter have right of way and are admitted to existence in the new universe of hypostatized geometry and it is only in this abstract-real (Archimedean) world, where abstract bodies move in an abstract space, that the laws of being and of motion of the new – the classical – science are valid and true.

It is easy now to understand why classical science – as has been said so often – has substituted a world of quantity for that of quality: just because, as Aristotle already knew quite well, there are no qualities in the world of numbers, or in that of geometrical figures. There is no place for them in the realm of mathematical ontology.

And even more. It is easy now to understand why classical science – as has been seen so seldom – has substituted a world of being for the world of becoming and change: just because, as Aristotle has said too, there is no change and no becoming in numbers and in figures.[1] But, in doing so, it was obliged to reframe and to reformulate or rediscover its fundamental concepts, such as those of matter, motion, and so on.

If we take into account the tremendous scope and bearing of this so deep and so radical revolution, we shall have to admit that, on the whole, it has been surprisingly quick.

It was in 1543 – one hundred years before the birth of Newton – that Copernicus wrested the earth from its foundations and hurled it into the skies.[2] It was in the beginning of the century (1609 and 1619) that Kepler formulated his laws of celestial motions and thus destroyed the orbs and spheres that encompassed the world and held it together;[3] and did it at the same time that Galileo, creating the first scientific instruments and showing to mankind things that no human

(New York: Dover, 1962), and *De l'explication dans les sciences* (Paris: Payot, 1921), this renunciation has always been temporary, and scientific thought has always attempted to penetrate behind the laws and to find out the "mécanisme de production" of the phenomena. I could add that on one hand it was just the search for causal laws of the celestial motions which led Kepler to his "New Astronomy" conceived as *Celestial Physics*, and on the other hand, that the absence of any theory of gravity led Galileo to the erroneous conception of gravitation as constant force.

[1] Thus Newton's *Opticks* denies the existence of any qualitative change in the light passing through a prism: the prism acts only as a sieve; it disentangles a mixture and sorts out the different rays which compose the white light, already present as such, in the mixture in which it consists. According to Newton, the prism experiment, like every good experiment, reveals something which is already there; it does not produce anything new.

[2] *De revolutionibus orbium coelestium* (Nuremberg, 1543).

[3] The first two in the *Astronomia nova ΑΙΤΙΟΛΟΓΗΤΟΣ sive physica coelestis tradita commentariis de motibus stellae martis* (1609); the third one in the *Harmonices mundi* (Lincii, 1619).

eye had ever seen before,[1] opened to scientific investigation the two connected worlds of the infinitely great and the infinitely small.

Moreover, it was by his "subjecting motion to number" that Galileo cleared the way for the formulation of the new concepts of matter and motion I have just mentioned, which formed the basis of the new science and cosmology;[2] concepts with the aid of which – identifying matter and space – Descartes, in 1637,[3] tried, and failed, to reconstruct the world; concepts that – redistinguishing between matter and space – Newton so brilliantly, and so successfully, used in his own reconstruction.

The new concept of motion which so victoriously asserts itself in the classical science is quite a simple one, so simple that, although very easy to use – once one is accustomed to it, as we all are – it is very difficult to grasp and fully to understand. Even for us, I cannot analyze it here,[4] yet I would like to point out that, as Descartes quite clearly tells us, it substitutes a purely mathematical notion for a physical one and that, in opposition to the pre-Galilean and pre-Cartesian conception, which understood motion as a species of becoming, as a kind of process of change that affected the bodies subjected to it, in contradistinction to rest, which did not, the new – or classical – conception interprets motion as a kind of being, that is, not as a process, but as a *status*, a *status* that is just as permanent and indestructible as rest[5] and that no more than this latter affects the bodies that are in motion. Being thus placed on the same ontological level, being deprived of their qualitative distinction, motion and rest become indistinguishable.[6] Motion and rest are still – and even

[1] *Sidereus nuncius* (Venice, 1610).

[2] *Dialogo . . . sopra i due massimi sistemi del mondo* (Florence, 1632) and *Discorsi e dimostrazioni intorno à due nuove scienze* (Leiden, 1638).

[3] *Discours de la méthode pour bien conduire sa raison et chercher la verité dans es sciences* (Leiden, 1637) and *Principia philosophiae* (Amsterdam, 1644); but already in 1629 and 1630 in his unpublished "Monde ou traité de la lumière."

[4] See my *Études galiléennes*.

[5] Motion, therefore, persists *sua sponte* – just like rest – not needing for its persistence either an external or an internal motor, or cause. Accordingly, it persists changeless – as change implies a cause – that is, with the same speed, and in the same direction; it is to this kind of motion – rectilinear and uniform – that Newton applied the term "inertial"; see Chapter III, "Newton and Descartes." The term "inertia" originated with Kepler, who gave it the meaning of "resistance to change." Accordingly, motion for Kepler being a change, *inertia* is resistance to motion; for Newton, for whom motion is no longer change, *inertia* is the force of resistance to (positive or negative) acceleration and change of direction.

[6] The equivalence of rectilinear motion and rest is asserted by Descartes *expressis verbis*. In the Newtonian physics *relative* motion and rest are equivalent; *absolute* motion and rest, of course, are not. Unfortunately, they remain indistinguishable, at least for us, if not for God.

more than ever – opposed to each other, but their opposition becomes a pure correlation. Motion and rest no longer exist in the bodies themselves; bodies are only in rest or in motion in respect to each other, or to the space in which they exist, rest, and move; motion and rest are relations, though, at the same time, they are considered as *states*. It is this conception (of the inner difficulties of which Newton was doubtless quite aware) that carries – and perhaps undermines – the magnificent structure of classical science and it is about this motion that in his famous first law or axiom Newton tells us that *corpus omne perseverare in statu suo quiescendi vel movendi uniformiter in directum nisi quatenus a viribus impressis cogitur statum illum mutare.*[1]

The motion dealt with in this law is not the motion of the bodies of our experience; we do not encounter it in our daily lives. It is the motion of geometrical (Archimedean) bodies in abstract space. That is the reason why it has nothing to do with change. The "motion" of geometrical bodies in geometrical space changes nothing at all; the "places" in such a space are equivalent and even identical. It is a changeless change, if I may say so, a strange and paradoxical blending together of the same and the other that Plato tried – and failed – to effect in his *Parmenides*.

The transformation of the concept of motion by substituting for the empirical concept the hypostatized mathematical one is inevitable if we have to subject motion to number in order to deal with it mathematically, to build up a mathematical physics. But this is not enough. Conversely, mathematics itself has to be transformed (and to have achieved this transformation is the undying merit of Newton). Mathematical entities have to be, in some sense, brought nearer to physics, subjected to motion, and viewed not in their "being" but in their "becoming" or in their "flux."[2]

The curves and figures of geometry have to be seen, and understood, not as built up of other geometrical elements, not as cut out in space by the intersection of geometrical bodies and planes, nor

[1] "Every body perseveres in its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed upon it" (Isaac Newton, *Philosophiae naturalis principia mathematica*, axiomata sive leges motus, Lex I). According to this law, whereas *motion* is a state, *acceleration* is a change. Circular motion, being an accelerated one because it implies a continuous change of direction, is, therefore, easily recognizable and distinguishable from rest. E. Mach in his famous criticism of Newton seems to have overlooked this simple fact; see *The Science of Mechanics*, trans. T. J. McCormack (La Salle, Illinois: Open Court, 1942), pp. 276–285.

[2] See Hadamard, "Newton and the Infinitesimal Calculus," and Boyer, *The Concepts of the Calculus*.

even as presenting a spatial image of the structural relations expressed in themselves by algebraic formulas, but as engendered or described by the motion of points and lines in space. It is a timeless motion, of course, that we are here dealing with, or, even stranger, a motion in a timeless time – a notion as paradoxical as that of changeless change. Yet it is only by making changeless change proceed in timeless time that we can deal – effectively as well as intellectually – with such realities as speed, acceleration, or direction of a moving body in any point of its trajectory, or, *vice versa*, at any moment of the motion describing that trajectory.

It is a thrilling story, the story of the successful and unsuccessful efforts of the human mind to formulate these new and strange ideas, to build up, or, as Spinoza so pregnantly has said, to *forge*, the new tools and patterns of thinking and of understanding. It fills the fifty years that separate the *Discours de la méthode* from the *Philosophiae naturalis principia mathematica*. A series of great thinkers – to mention only Cavalieri and Fermat, Pascal and Wallis, Barrow and Huygens – had made their contributions to the final success, and without them the *Principia* would not have been written; the task would have been too arduous, even for Newton, *qui genus humanum ingenio superavit*.[1]

Thus, modifying somewhat the celebrated statement of Newton, made in his famous letter to Robert Hooke, we could, with truth, say that if Newton saw as far as he did, and so much farther than anybody had seen before him, it was because he was a giant standing on the shoulders of other giants.[2]

The physicomathematical current I have just been sketching is certainly the most original and most important trend of seventeenth-century scientific thought. Yet, parallel to it there runs another one, less mathematical, less deductive, more empirical and experimental. Being less pretentious (or more diffident), it does not attempt the sweeping generalizations of the mathematicians. It views them with misgiving and even with hostility and it restricts itself to the discovery of new facts and to the building up of partial theories explaining them.

This current is inspired not by the Platonic idea of the mathe-

[1] Zeuthen, *Die Geschichte der Mathematik im XVI. und XVII. Jahrhundert*; L. Brunschvicg, *Les Étapes de la philosophie mathématique* (Paris: Alcan, 1912).

[2] This famous phrase is not Newton's invention, but originates in the Middle Ages with Bernard of Chartres and was used also in the sixteenth and seventeenth centuries; see Chapter V, p. 227, n. 3.

matical structure and determination of being, but by the Lucretian, Epicurean, Democritean conception of its atomic composition (strange as it may seem, most modern ideas lead back to some old Greek fancy). Gassendi, Roberval, Boyle (the best representative of their group), Hooke – they all oppose the more timid, more cautious, and more secure *corpuscular philosophy* to the panmathematism of Galileo and Descartes.[1]

Thus when Galileo tells us that the book of nature – that book in which the medieval mind perceived the *vestigia* and the *imagines Dei* and read the glory of God expressed in sensible symbols of beauty and splendor revealing the hidden meaning and aim of the creation – was, in truth, written in geometrical characters, in circles, triangles, and squares, and only told us the intellectually marvelous story of rational connection and order, Boyle protests: the book of nature, said he, was certainly "a well-contrived romance" of which every part, "written in the stenography of God's omniscient hand," stood in relation to every other; but it was written not in geometrical but in *corpuscular* characters.

Not mathematical structure but corpuscular texture formed for him the inner reality of being. In the explanation of the universe we have to start with – or stop at – matter, not homogeneous Cartesian matter, but matter already formed by God into various, diversely determined corpuscles. These are the letters which motion forms into the words of the divine romance.

Looking at things from this perspective we see quite clearly that Newton presents us with a synthesis of both trends, of both views. For him, just as for Boyle, the book of nature is written in corpuscular characters and words. But, just as for Galileo and Descartes, it is a purely mathematical syntax that binds them together and gives its meaning to the text of the book.

Thus, in contradistinction to the world of Descartes, the world of Newton is conceived as composed not of two (extension and motion) but of three elements: (1) *matter*, that is, an infinite number of mutually separated and isolated, hard and unchangeable – but not identical – particles; (2) *motion*, that strange and paradoxical relation-state that does not affect the particles in their being, but only transports them hither and thither in the infinite, homogeneous void; and (3) *space*, that is, this very infinite and homogeneous void in which, unopposed, the corpuscles (and the bodies built of them) perform their motions.[1]

[1] See K. Lasswitz, *Geschichte der Atomistik* (Leipzig, 1890), vol. II; R. Lenoble, *Mersenne et la naissance du mécanisme* (Paris: Vrin, 1943); Marie Boas, "The Establishment of the Mechanical Philosophy," *Osiris 10* (1952), 412–541; and E. J. Dijksterhuis, *Die Mechanisierung des Weltbildes* (Berlin: Springer, 1956), trans. C. Dikshoorn as *The Mechanization of the World Picture* (Oxford: Clarendon Press, 1961).

There is, of course, a fourth component in that Newtonian world, namely, attraction which binds and holds it together.[2] Yet this is not an *element* of its construction; it is either a hyperphysical power – God's action – or a mathematical stricture that lays down the rule of syntax in God's book of nature.[3]

The introduction of the void – with its correlative, attraction – into the world view of Newton, in spite of the tremendous physical and metaphysical difficulties involved by this conception (action at a distance; existence of the nothing), was a stroke of genius and a step of decisive importance. It is this step that enabled Newton to oppose and unite at the same time – and to do it *really*, and not *seemingly*, like Descartes – the discontinuity of matter and the continuity of space. The corpuscular structure of matter, emphatically asserted, formed a firm basis for the application of mathematical dynamics to nature.[4] It yielded the *fundamenta* for the relations expressed by space. The cautious corpuscular philosophy did not really know what it was doing. But, as a matter of fact, it had been only showing the way to the Newtonian synthesis of mathematics and experiment.

[1] On Newton's conception of space, see Léon Bloch, *La Philosophie de Newton* (Paris: Alcan, 1908); E. A. Burtt, *The Metaphysical Foundations of Modern Physical Science* (London: Kegan Paul, 1925; 2nd ed., 1932); Hélène Metzger, *Attraction universelle et religion naturelle chez quelques commentateurs anglais de Newton* (Paris: Hermann, 1938); also Max Jammer, *Concepts of Space* (Cambridge, Mass.: Harvard University Press, 1954); Markus Fierz, "Ueber den Ursprung und die Bedeutung der Lehre Isaac Newtons vom absoluten Raum," *Gesnerus 11* (1954), 62–120; and my *From the Closed World to the Infinite Universe* (Baltimore: Johns Hopkins Press, 1957). See also A. J. Snow, *Matter and Gravity in Newton's Physical Philosophy* (New York: Oxford University Press, 1926), and Stephen E. Toulmin, "Criticism in the History of Science: Newton on Absolute Space, Time and Motion," *The Philosophical Review* (1959). Space for Newton (as for Henry More or Thomas Bradwardine) is the eternal realm of God's presence and action – not only his *sensorium* but also, if one may say so, his *actorium*.

[2] To be quite correct, I should mention also the repulsive forces that hold the corpuscles apart and prevent them from gathering together in a cluster. However, these repulsive forces are short-range forces, and, though very important in physics, they play no role in the building of the universe so long as they are not used for the formulation of a theory of aether whose action on the bodies "explains" gravitation; see Chapter III, Apps. A and B.

[3] As a matter of fact, it is both: a hyperphysical power acting according to a strict mathematical law.

[4] The physics of central forces necessarily involves an atomic structure of matter, even if the matter is reduced to mere points, as by Boscovich.

The void... action through the void... action at a distance (attraction) – it was against these features and implications of the Newtonian world view that the opposition of the great Continental contemporaries of Newton – Huygens, Leibniz, Bernoulli – well trained in the Cartesian rejection of unclear and unintelligible ideas, was directed.[1]

In his famous, brilliant *Lettres anglaises*, or, to give them their official title, *Lettres philosophiques*[2] – readable even today – Voltaire very wittily sums up the situation: a Frenchman who arrives in London finds himself in a completely changed world. He left the world *full;* he finds it *empty*. In Paris the universe is composed of vortices of subtle matter; in London there is nothing of that kind. In Paris everything is explained by pressure which nobody understands; in London by attraction which nobody understands either.[3]

Voltaire is perfectly right: the Newtonian world is chiefly composed of void.[4] It is an infinite void, and only a very small part of it – an infinitesimal part – is filled up, or occupied, by matter, by bodies which, indifferent and unattached, move freely and perfectly unhampered in – and through – that boundless and bottomless abyss. And yet it is a world and not a chaotic congeries of isolated and

[1] The criticism of the conception of attraction was made by Descartes in his attack on Roberval, who asserted universal attraction in his *Aristarchi Sami De mundi systemate partibus et motibus eiusdem libellus cum notis. Addictae sunt Æ. P. de Roberval notae in eundem libellum* (Paris, 1644), reissued by Mersenne in his *Novarum observationum physico-mathematicarum* (Paris, 1644), vol. III. Descartes points out (see his letter to Mersenne of 20 April 1646, *Oeuvres*, ed. C. Adam and P. Tannery (Paris, 1897–1913), IV, 401) that, in order to be able to attract body B, body A should know where to find it. Attraction, in other words (as W. Gilbert and also Roberval recognized without considering it an objection), involves animism. (See Chapter III, p. 59, n. 2.)

[2] The *Lettres philosophiques* were published first in English, under the title *Letters Concerning the English Nation* (London, 1733); then in French under the title *Lettres philosophiques par M. de Voltaire* (Amsterdam [in fact Rouen, by Jore], 1734) and *Lettres écrites de Londres sur les anglais par M. de Voltaire* (Basel [in fact London], 1734). Numerous other editions, more or less modified by Voltaire, followed. See the introduction of G. Lanson to his critical edition of these letters: *Lettres philosophiques*, 2 vols. (Paris: Cornely, 1909; 3rd ed., 1924). On Voltaire and Newton see Bloch *La Philosophie de Newton*; Pierre Brunet, *L'Introduction des théories de Newton en France* (Paris: Blanchard, 1931), vol. I; and R. Dugas, *Histoire de la mécanique au XVII siècle* (Paris: Dunod Éditeur, 1954).

It is well known that Voltaire had been converted to Newtonianism by Maupertuis who, as Huygens did for Locke, assured him that the Newtonian philosophy of attraction was true. Maupertuis even agreed to read through the letters (XIV and XV) dealing with Descartes and Newton. On Maupertuis see Pierre Brunet, *Maupertuis* (Paris: Blanchard, 1929).

[3] See letter XIV, Lanson edition, II, 1.

[4] Not only are the heavenly spaces empty and void, but even the so-called "solid bodies" are full of void. The particles that compose them are by no means closely packed together, but are separated from one another by void space. The Newtonians, from Bentley on took an enormous pride and pleasure in pointing out that "matter" proper occupies a practically infinitesimal part of space.

mutually alien particles. This, because all of these are bound together by a very simple mathematical law of connection and integration – the law of attraction – according to which *every one of them is related to and united with every other.*[1] Thus each one takes its part and plays its role in the building of the *systema mundi.*

The universal application of the law of attraction restores the physical unity of the Newtonian universe and, at the same time, gives it its intellectual unity. Identical relations hold together identical contents. In other words, it is the same set of laws which governs all the motions in the infinite universe: that of an apple which falls to the ground[2] and that of the planets which move round the sun. Moreover, the very same laws explain not only the identical pattern (discovered by Kepler) of the celestial motions but even their individual differences, not only the regularities, but also the irregularities (inequalities). All the phenomena which for centuries baffled the sagacity of astronomers and physicists (such, for instance, as tides) appear as a result of the concatenation and combination of the same fundamental laws.

The Newtonian law of attraction according to which its force *diminishes* in proportion to the square of the distance is not only the only law of that kind that explains the facts but, besides, is the only one that can be uniformly and universally applied to large and small bodies, to apples and to the moon. It is the only one, therefore, that it was reasonable for God to have adopted as a law of creation.[3]

Yet, in spite of all this, in spite of the rational plausibility and

[1] According to Newton, only these corpuscular attractions, whatever they may be, are real. Their resultants are by no means real forces, but only "mathematical" ones. Thus, it is not the earth that attracts the moon, but each and every particle of the earth attracts each and every particle of the moon. The resultant global attraction has no other than mathematical existence.

[2] The famous story according to which Newton's thinking on gravitation had been aroused by the sight of an apple falling to the ground, which has been treated as legend by generations of historians, appears to be perfectly true, as has been convincingly demonstrated by J. Pelseneer in "La Pomme de Newton," *Ciel et terre 53* (1937), 190–193; see also *Lychnos* (1938), 366–371. See also I. B. Cohen, "Authenticity of Scientific Anecdotes," *Nature 157* (1946), 196–197, and D. McKie and G. R. de Beer, "Newton's Apple," *Notes and Records of the Royal Society 9* (1951–52), 46–54, 333–335.

[3] The inverse-square law of the diminishing of attraction with distance is the only one which makes possible a direct comparison between the earth's attraction of an apple and the earth's attraction of the moon, because it is the only one according to which the earth, or, generally, a spherical body, attracts all external bodies, irrespective of their distance from it, as if all its mass were concentrated in its center. It is true that it shares this mathematical property with another law, namely the one according to which the force of attraction increases proportionally to the distance. But as in this case all celestial bodies would accomplish their circuits in the same time, it is obviously not the law of our world.

mathematical simplicity of the Newtonian law (the inverse-square law is simply the law of extension of spherical surfaces identical with that of the propagation of light), there was in it something that baffled the mind. Bodies attract each other, act upon each other (or, at least, behave as if they did). But how do they manage to perform this action, to overcome the chasm of the void that so radically separates and isolates them from each other? We must confess that nobody, not even Newton, could (or can) explain, or understand, this *how*.

Newton himself, as we well know, never admitted attraction as a "physical" force. Time and again he said, and repeated, that it was only a "mathematical force," that it was perfectly impossible – not only for matter but even for God – to act at a distance, that is, to exert action where the agent was not present; that the attractive force, therefore – and this gives us a singular insight into the limits of the so-called Newtonian empiricism – was not to be considered as one of the essential and fundamental properties of bodies (or matter), one of these properties such as extension, mobility, impenetrability, and mass, which could neither be diminished nor increased;[1] that it was a property to be explained; that he could not do it,[2] and that, as he did not want to give a fanciful explanation when lacking a good theory, and as science (mathematical philosophy of nature) could perfectly well proceed without one, he preferred to give none (this is one meaning of his celebrated *Hypotheses non fingo*), and leave the question open.[3] Yet, strange, or natural, as it may seem, nobody – with the single exception of Colin Maclaurin – followed him in that point. The very first generation of his pupils (Cotes, Keill, Pemberton) accepted the force of attraction as a real, physical, and even primary property of matter and it was their doctrine which swept over Europe and which was so strongly and persistently opposed by Newton's Continental contemporaries.

[1] A property which can be neither increased nor diminished belongs to the essence of the thing.

[2] As a matter of fact he tried – three times – to do it, that is, to explain attraction by aetherical pressure. See Philip E. B. Jourdain, "Newton's Hypotheses of Ether and Gravitation," *The Monist* 25 (1915).

[3] The famous *Hypotheses non fingo* of the General Scholium of his second edition of the *Principia* does not mean a condemnation of all hypotheses in science but only of those that cannot be proved or disproved by mathematically treated experiment, specifically, of global qualitative explanations such as were attempted by Descartes. This pejorative meaning of the term coexists in Newton with a nonpejorative one (in the first edition of the *Principia* the axioms or laws of motion are called *hypotheses*) and is certainly inherited by him from Barrow and Wallis, or even from Galileo.

Newton did not admit action at a distance. Yet, as Maupertuis and Voltaire very reasonably pointed out, from the point of view of purely empirical knowledge (which seemed to be the point of view of Newton), the ontological distinction between the attraction and the other properties of bodies could not be justified. We do not, of course, understand attraction. But do we understand the other properties? Not understanding is not a reason to deny a fact.[1] Now attraction is a fact. Thus we have to admit it just as we are admitting other facts or properties of bodies. Who knows, besides, what unknown properties we may discover as pertaining to them? Who knows with what sort of properties God has endowed matter?

The opposition to Newtonianism – understood as *physics* – was in the beginning deep and strong. But gradually it crumbled away.[2] The system worked and proved its worth. And as for attraction, progressively it lost its strangeness. As Mach has very finely expressed it, "the uncommon incomprehensibility became a common incomprehensibility." Once used to it, people – with very few exceptions – did not speculate about it any more. Thus fifty years after the publication, in 1687, of the *Philosophiae naturalis principia mathematica* – a title just as daring and just as consciously challenging as the *Physica coelestis* of Kepler eighty years earlier or the *Evolution créatrice* of Bergson two hundred years later – the leading physicists and mathematicians of Europe – Maupertuis, Clairaut, D'Alembert, Euler, Lagrange, and Laplace – diligently began the work of perfecting the structure of the Newtonian world, of developing the tools and methods of mathematical and experimental investigation (Desaguliers, s'Gravesande, and Musschenbroek),[3] and of leading it from success to success, till, by the end of the eighteenth century, in the *Mécanique analytique* of Lagrange and the *Mécanique céleste* of Laplace, the Newtonian science seemed to reach its final and definitive perfection – such a perfection that

[1] For Malebranche as well as for Locke, all action of a body upon another – communication of motion – was understandable.

[2] See Brunet, *L'Introduction des théories de Newton en France*, vol. I.

[3] J. T. Desaguliers, *Physicomechanical Lectures* (London, 1717), in French translation (Paris, 1717); *A System of Experimental Philosophy* (London, 1719); *A Course of Experimental Philosophy* (London, 1725; 2nd ed. in 2 vols., London, 1744–1745); W. J. s'Gravesande, *Physices elementa mathematica experimentis confirmata, sive introductio ad philosophiam Newtonianam*, 2 vols. (Leiden, 1720–1721); *Philosophiae Newtonianae institutiones* (Leiden, 1728); *Éléments de physique ou introduction à la philosophie de Newton* (Paris, 1747); Petrus Musschenbroek, *Epitome elementorum physicomathematicorum* (Leiden, 1726); *Elementa physices* (Leiden, 1734). See Pierre Brunet, *Les Physiciens hollandais et la méthode expérimentale en France au XVIII siècle* Paris: Blanchard, 1926).

Laplace could proudly assert that his *System of the World* left no astronomical problem unsolved.

So much for the mathematicians and scientists. As for the others, for those who could not understand the difficult intricacies of geometrical and infinitesimal reasoning and who, like Locke (reassured by Huygens), took them for granted, there came forth a series of books – and very good ones – such as Pemberton's *View of Sir Isaac Newton's Philosophy* (London, 1728; French translation, Paris, 1755), Voltaire's *Lettres philosophiques* (1734) and *Éléments de la philosophie de Newton* (Amsterdam, 1738), Algarotti's *Il Newtonianismo per le dame* (Naples [Milan], 1737; 2nd ed., 1739; French translation, Paris, 1738), Colin Maclaurin's *Account of Sir Isaac Newton's Philosophical Discoveries* (London, 1746; French translation, Paris, 1749),[1] Euler's *Lettres à une princesse d'Allemagne* (St. Petersburg, 1768–1772), and finally Laplace's *Système du monde* (1796), which in a clear and accessible language preached to the *honnête homme*, and even to the *honnête femme*, the Newtonian gospel of mathematicophysical and experimental science.

No wonder that (in a curious mingling with Locke's philosophy) Newtonianism became the scientific creed of the eighteenth century,[2] and that already for his younger contemporaries, but especially for posterity, Newton appeared as a superhuman being[3] who, once and for ever, solved the riddle of the universe.

Thus it was by no means in a spirit of flattery but in that of deep and honest conviction that Edmund Halley wrote, *nec fas est propius Mortali attingere Divos*.[4] Did not, a hundred years later, Laplace, somewhat regretfully, assign to the *Principia* the pre-eminence above all other productions of the human mind? Indeed, as Lagrange somewhat wistfully put it, there being only one universe to be explained, nobody could repeat the act of Newton, the luckiest of mortals.

Small wonder that, at the end of the eighteenth century, the century that witnessed the unfettered progress of Newtonian science, Pope could exclaim:

[1] All these books, when not written in French, were immediately translated into it and thus made accessible to all educated people throughout Europe.

[2] For Voltaire, as well as for Condorcet, Locke and Newton represent the summits of science and philosophy.

[3] It is well known that the Marquis de L'Hôpital asked – quite seriously – if Newton ate and slept like other mortals.

[4] "Nearer the gods no mortal may approach"; "Isaac Newton, an Ode," trans. Leon J. Richardson in *Sir Isaac Newton's Mathematical Principles of Natural Philosophy*, trans. Andrew Motte, ed. Florian Cajori (Berkeley: University of California Press, 1947), p. xv.

> Nature and nature's laws lay hid in night:
> God said, Let Newton be! and all was light.

Pope could not know indeed that

> 'T was not for long: for Devil, howling, "Ho,
> Let Einstein be!" restored the *status quo*.

But let us now come back to Newton. It has often been said that the unique greatness of Newton's mind and work consists in the combination of a supreme experimental with a supreme mathematical genius. It has often been said, too, that the distinctive feature of the Newtonian science consists precisely in the linking together of mathematics and experiment, in the mathematical treatment of the phenomena, that is, of the experimental or (as in astronomy, where we cannot perform experiments) observational data. Yet, though doubtless correct, this description does not seem to me to be a complete one: thus there is certainly much more in the mind of Newton than mathematics and experiment; there is, for instance – besides religion and mysticism – a deep intuition for the limits of the purely mechanical interpretation of nature.[1] And as for Newtonian science, built, as I have already mentioned, on the firm basis of corpuscular philosophy, it follows, or, better, develops and brings to its utmost perfection, the very particular logical pattern (by no means identical with mathematical treatment in general) of atomic analysis of global events and actions, that is, the pattern of reducing the given data to the sum total of the atomic, elementary components (into which they are in the first place dissolved).[2]

The overwhelming success of Newtonian physics made it practically inevitable that its particular features became thought of as essential for the building of science – of any kind of science – as such, and that all the new sciences that emerged in the eighteenth century – sciences of man and of society – tried to conform to the Newtonian pattern of empirico-deductive knowledge, and to abide by the rules laid down by Newton in his famous *Regulae philosophandi*, so often quoted and so often misunderstood.[3] The results of

[1] It seems to me quite certain that Newton arrived at the conclusion that a purely mechanical explanation of attraction was perfectly impossible because, in order to do so, he had to postulate another – less awkward, yet still nonmechanical – power, namely, that of repulsion.

[2] Thus (see p. 15, n. 1) the global effect of a body acting upon another body is the sum total of atomic actions.

[3] On the *Regulae philosophandi*, see Chapter VI.

this infatuation with Newtonian logic, that is, the results of the uncritical endeavor mechanically to apply Newtonian (or rather *pseudo* Newtonian) methods to fields quite different from that of their original application, have been by no means very happy, as we shall presently see. Yet, before turning our attention to these, in a certain sense illegitimate, offshoots of Newtonianism, we have to dwell for a moment upon the more general and more diffuse consequences of the universal adoption of the Newtonian synthesis, of which the most important seems to have been the tremendous reinforcement of the old dogmatic belief in the so-called "simplicity" of nature, and the reintroducing through science into this very nature of very important and very far-reaching elements of not only *factual* but even *structural* irrationality.

In other words, not only did Newton's physics use *de facto* such obscure ideas as power and attraction (ideas suggesting scholasticism and magic, protested the Continentals), not only did he give up the very idea of a rational deduction of the actual composition and formation of the choir of heaven and furniture of earth, but even its fundamental dynamic law (the inverse-square law), though plausible and reasonable, was by no means necessary, and, as Newton had carefully shown, could be quite different.[1] Thus, the law of attraction itself was nothing more than a mere fact.

And yet the harmonious insertion of all these facts into the rational frame of spatiomathematical order, the marvelous *compages* of the world, seemed clearly to exclude the subrationality of chance, but rather to imply the suprarationality of motive; it seemed perfectly clear that it had to be explained not by the necessity of cause, but by the freedom of choice.

The intricate and subtle machinery of the world seemed obviously to require a purposeful action, as Newton did not fail to assert. Or, to put it in Voltaire's words: the clockwork implies a clockmaker (*l'horloge implique l'horloger*).

Thus the Newtonian science, though as *mathematical philosophy of nature* it expressedly renounced the search for causes (both physical and metaphysical), appears in history as based on a dynamic conception of physical causality and as linked together with theistic or deistic metaphysics. This metaphysical system does not, of course, present itself as a constitutive or integrating part of the Newtonian science; it does not penetrate into its formal structure. Yet it is by no means an accident that not only for Newton himself, but also for all the Newtonians – with the exception only of Laplace – this science implied a reasonable belief in God.[1]

[1] Newton, *Mathematical Principles of Natural Philosophy*, Book I, Theorem IV, Corr. 3–7.

Once more the book of nature seemed to reveal God, an engineering God this time, who not only had made the world clock, but who continuously had to supervise and tend it in order to mend its mechanism when needed (a rather bad clockmaker, this Newtonian God, objected Leibniz), thus manifesting his active presence and interest in his creation. Alas, the very development of the Newtonian science which gradually disclosed the consummate skill of the Divine Artifex and the infinite perfections of his work left less and less place for divine intervention. The world clock more and more appeared as needing neither rewinding nor repair. Once put in motion it ran for ever. The work of creation once executed, the God of Newton – like the Cartesian God after the first (and last) *chiquenaude* given to matter – could rest. Like the God of Descartes and of Leibniz – so bitterly opposed by the Newtonians – he had nothing more to do in the world.

Yet it was only at the end of the eighteenth century with Laplace's *Mécanique céleste* that the Newtonian God reached the exalted position of a *Dieu fainéant* which practically banished him from the world ("I do not need that hypothesis," answered Laplace when Napoleon inquired about the place of God in his system), whereas for the first generation of Newtonians, as well as for Newton himself, God had been, quite on the contrary, an eminently active and present being, who not only supplied the dynamic power of the world machine but positively "ran" the universe according to his own, freely established, laws.[2]

It was just this conception of God's presence and action in the world which forms the intellectual basis of the eighteenth century's world feeling and explains its particular emotional structure: its optimism, its divinization of nature, and so forth. Nature and nature's laws were known and felt to be the embodiment of God's will and reason. Could they, therefore, be anything but good? To follow

[1] See Metzger, *Attraction universelle*, and John H. Randall, *The Making of the Modern Mind* (Boston: Houghton Mifflin, 2nd ed., 1940).

[2] In a world made up of absolutely hard particles there is necessarily a constant loss of energy; the Newtonian God, therefore, had not only to supply the initial amount but constantly to replace the loss. Later, of course, he became a mere tinker and repairman.

nature and to accept as highest norm the law of nature, was just the same as to conform oneself to the will, and the law, of God.[1]

Now if order and harmony so obviously prevailed in the world of nature, why was it that, as obviously, they were lacking in the world of man? The answer seemed clear: disorder and disharmony were man-made, produced by man's stupid and ignorant attempt to tamper with the laws of nature or even to suppress them and to replace them by man-made rules. The remedy seemed clear too: let us go back to nature, to our own nature, and live and act according to its laws.

But what is human nature? How are we to determine it? Not, of course, by borrowing a definition from Greek or Scholastic philosophers. Not even from modern ones such as Descartes or Hobbes. We have to proceed according to pattern, and to apply the rules which Newton has given us. That is, we have to find out, by observation, experience, and even experiment, the fundamental and permanent faculties, the properties of man's being and character that can be neither increased nor diminished; we have to find out the patterns of action or laws of behavior which relate to each other and link human atoms together. From these laws we have to deduce everything else.

A magnificent program! Alas, its application did not yield the expected result. To define "man" proved to be a much more difficult task than to define "matter," and human nature continued to be determined in a great number of different, and even conflicting, ways. Yet so strong was the belief in "nature," so overwhelming the prestige of the Newtonian (or pseudo-Newtonian) pattern of order arising automatically from interaction of isolated and self-contained atoms, that nobody dared to doubt that order and harmony would in some way be produced by human atoms acting according to their nature, whatever this might be – instinct for play and pleasure (Diderot) or pursuit of selfish gain (A. Smith). Thus return to nature could mean free passion as well as free competition. Needless to say, it was the last interpretation that prevailed.

The enthusiastic imitation (or pseudo-imitation) of the Newtonian (or pseudo-Newtonian) pattern of atomic analysis and recon-

[1] The eighteenth-century optimism had its philosophical source not only in the Newtonian world view but just as well in the rival world conception of Leibniz. Mor importantly, it was based simply on the feeling of a social, economic, and scientifi progress. Life was rather pleasant in the eighteenth century and became increasingly sc at least in the first half of it.

struction that up to our times proved to be so successful in physics,[1] in chemistry,[2] and even in biology, led elsewhere to rather bad results. Thus the unholy alliance of Newton and Locke produced an atomic psychology, which explained (or explained away) mind as a mosaic of "sensations" and "ideas" linked together by laws of association (attraction); we have had, too, atomic sociology, which reduced society to a cluster of human atoms, complete and self-contained each in itself and only mutually attracting and repelling each other.

Newton, of course, is by no means responsible for these, and other, *monstra* engendered by the overextension – or aping – of his method. Nor is he responsible for the more general, and not less disastrous, consequence of the widespread adoption of the atomic pattern of analysis of global events and actions according to which these latter appeared to be not *real*, but only *mathematical* results and summings up of the underlying elementary factors. This type of analysis led to the nominalistic misconception of the relation between a *totum* and its parts, a misconception which, as a matter of fact, amounted to a complete negation of *tota* (a *totum* reduced to a mere sum of its parts is not a *totum*) and which nineteenth- and twentieth-century thought has had such difficulty in overcoming. No man can ever be made responsible for the misuse of his work or the misinterpretation of his thought, even if such a misuse or misinterpretation appears to be – or to have been – historically inevitable.

Yet there is something for which Newton – or better to say not Newton alone, but modern science in general – can still be made responsible: it is the splitting of our world in two. I have been saying that modern science broke down the barriers that separated the heavens and the earth, and that it united and unified the universe. And that is true. But, as I have said, too, it did this by substituting for our world of quality and sense perception, the world in which we live, and love, and die, another world – the world of quantity, of reified geometry, a world in which, though there is place for everything, there is no place for man. Thus the world of science – the real world – became estranged and utterly divorced from the world of life, which science has been unable to explain – not even to explain away by calling it "subjective."

[1] Contemporary physics has been obliged to transcend the atomic pattern of explanation: the whole is no longer identical to the sum of its parts, particles cannot be isolated from their surroundings, and so forth.

[2] On Newton's influence on chemistry, see Hélène Metzger, *Newton, Stahl, Boerhaave et la doctrine chimique* (Paris: Alcan, 1930).

True, these worlds are every day – and even more and more – connected by the *praxis*. Yet for *theory* they are divided by an abyss.

Two worlds: this means two truths. Or no truth at all.

This is the tragedy of modern mind which "solved the riddle of the universe," but only to replace it by another riddle: the riddle of itself.[1]

[1] See Alfred North Whitehead, *Science and the Modern World* (New York: Macmillan, 1925); Burtt, *The Metaphysical Foundations of Modern Physical Science*.